Research Article

Endogenous Technical Progress in the Theory of Economic Growth

Vladimir N. Pokrovskii

Moscow State University of Economics, Statistics and Informatics, Moscow 119501, Russia

Correspondence should be addressed to Vladimir N. Pokrovskii; vpok@comtv.ru

Received 8 February 2014; Accepted 19 March 2014; Published 26 March 2014

Academic Editors: T. Kuosmanen and M. Tsionas

It is shown that substitutive work, which can be defined as work of production equipment (capital stock) replacing the efforts of workers in production processes, can be considered as a measure of technical progress. The methods of estimation of substitutive work are discussed. The theoretical results are illustrated on the data for the US. economy.

1. Introduction

The theory of economic growth tries to connect the magnitude of gross domestic product (GDP), which is a measure of current achievements of an economy as a whole—a money measure of a multitude of things and services—created by society for unit of time [1], with some universal, basic factors, called production factors. In other words, one can say that the aim of the theory is to separate original sources of wealth.

The most important production factor is labour, which, in our days, is considered as the sum of the efforts of all workers, participating in the production of things and services. The labour theory of value, due to Adam Smith, Karl Marx, and David Ricardo, considered labour as the only production factor, but it has appeared that, to account for the effect of the enlargement of output with introduction of production equipment, about which we think as a collection of animals, machines, buildings, roads, harbours, pipelines, and so on, something else ought to be added into the theory. In the beginning of the last century, it was a fundamental problem of economic theory, which has required a generalisation of labour theory of value. A hypothesis was declared: the amount of capital stock itself is a source of enlargement, so that output Y can be considered as a function of two variables: labour L and capital K:

$$Y = Y(K, L). \tag{1}$$

This simple approach appears to be a foundation of the conventional neoclassical interpretation of economic development [2, 3]. Capital stock K is measured in money units, whereas labour L is measured as a number of workers or a number of working hours per year. Having an energy estimate of efforts, which are spent by a worker for a unit of time, it is possible and convenient to count labour L in energy units per year. The fundamental property of the approach (1) is that the two production factors: labour L and capital K, can substitute for each other without limit during the development of production system.

To the middle of the last century it was recognised that the theory in the simple classic form, independent of the specific form of the function (1), leaves no place for technical progress, which, nevertheless, was believed to be the ultimate source of economic growth in developed countries in recent centuries. In other words, the hypothesis about productive force of capital does not correspond to the reality. To incorporate the technical progress into the theory and save the neoclassical approach, it was suggested by different investigators [4] to modify the variables K and L in function (1) to allow for time-dependent changes in the quality or effectiveness of production factors:

$$Y = Y\left(K', L'\right). \tag{2}$$

The new variables $K' = A_K(t)K$ and $L' = A_L(t)L$ are called capital and labour services, which are connected with the measurable quantities of capital stock K and labour L, but are somewhat different from them. The time-dependent multipliers $A_K(t)$ and $A_L(t)$ reduce capital stock K and labour L to two arguments of a suitable dimensionality: it is convenient to think that K' and L' are measured in energy units.

The specific form of the function (2) may be presented in different ways [4] due to different choice of multipliers. In one of the simple cases, for example, the production function can be written in the conventional Cobb-Douglas form

$$Y = Y_0 A(t) \frac{L}{L_0} \left(\frac{L_0}{L} \frac{K}{K_0} \right)^{\alpha}, \quad 0 < \alpha < 1, \tag{3}$$

where the only time-dependent multiplier $A(t)$ has appeared to describe overall technical progress, so called exogenous technical progress.

The concepts of labour and capital services appeared to be necessary and very useful to explain the observed growth of output, but time-dependent multiplier $A(t)$ itself remains to be uncertain. It is a mere fitting device that remains unexplained, despite various reinterpretations and modifications of the production function [2, 3]. In this way, a complete description of economic growth is achieved, but we do not know what technical progress is actually, and the problem of endogenous technical progress remains.

In this paper, based on the generalised labour theory of value [5], it will be shown that a new production factor—substitutive work can be introduced, as a characteristic of capital stock, and considered as a driver of technical progress. An expression for multiplier $A(t)$ in (3) will be given in terms of production factors. I hope that the short and concise exposition of the theory in the first sections of the paper could be helpful.

2. The Concept of Substitutive Work

The complexity of the concept of neoclassical capital was analysed by Robinson [6], who noted that capital can be characterised not only by the money estimate of production equipment: the collection of industry buildings, roads, production tools, instruments, rather sophisticated machines, animals, and so on, but also by other quantities. Apparently, as a collection of equipment, capital is not "productive" in the physical sense; it is dead [7]. The production equipment is needed to do some actions, to perform some work, and one needs in another characteristic of the existing capital stock to describe the activity. The neoclassical variable "capital" unites two functions of production equipment: both static and dynamic. One can think that it would be more appropriate if we would ascribe a separate independent variable to each of the two distinct roles of the variable "capital" in (1) to separate the functional roles of capital in production: its quantity and its activity.

These statements can be reformulated as a special generalisation of the labour theory of value, which ought to be completed with the law of substitution: the workers' efforts are substituted with work of equipment in production processes. Indeed, it is not so important how much of equipment we have, as how much work can be done by the equipment. To quantify the phenomenon, we have to introduce a variable P, work of production equipment (including animals), which produces, in all relations, the same effect as the workers' efforts. So, the production of value Y can be considered as a function of the two production factors:

$$Y = Y(L, P). \tag{4}$$

The quantity P substitutes for workers' efforts in production, and this allows to dub it as *substitutive work*, which is genuine work of production equipment, which fulfils the same operations as working people, but with help of external sources of energy. Human work is substituted by useful work (in the thermodynamic sense) of the production equipment. Simultaneously, production of value can be related to the magnitude of capital stock K, so that we can write

$$Y = Y(K). \tag{5}$$

One can note that the above speculations are nothing more than reinterpretation of neoclassical theory. The only change we have made is a separation of the two distinct roles of the variable "capital" in (1): instead of the only neoclassical variable "capital," we have to introduce two variables to describe the functional roles of capital in production: its quantity and its activity. The total capital stock K is monetary value of all cumulative investment (after depreciation), while capital service P is a substitute of human labour. Substitutive work P can be identified with capital service $K' = A_K(t)K$ in (2). Such interpretation of neoclassical theory corresponds to understanding of the concept of capital by Robinson [6].

3. Three-Factor Production Function

Due to the previous speculations, production of value Y can be considered as a function of the three production factors:

$$Y = Y(K, L, P). \tag{6}$$

We consider aggregate capital stock K to be the various means of attracting both labour L and capital service P to the production, so that K ought to be considered as a complement to both L and P, which are substitutes to each other. These properties of the production factors allow us to specify the production function for output Y. In a simple, one-sector approximation, an expression for production of value is presented by two alternative relations [5, 8]:

$$Y = \begin{cases} \xi K, & \xi > 0 \\ Y_0 \dfrac{L}{L_0} \left(\dfrac{L_0}{L} \dfrac{P}{P_0} \right)^{\alpha}, & 0 < \alpha < 1. \end{cases} \tag{7}$$

The quantity ξ represents marginal productivity of aggregate capital K. The time-dependent quantities α and ξ are interconnected internal characteristics of the production system itself.

The production function ought to be completed with equations for production factors. The total capital stock K is determined as a monetary value of all cumulative investment (after depreciation). The two other production factors, L and P in (6) and (7), are determined by investment I and technological characteristics of capital stock, $\overline{\lambda}$ and $\overline{\varepsilon}$:

$$\frac{dK}{dt} = I - \mu K, \qquad \frac{dL}{dt} = \left(\overline{\lambda}\,\frac{I}{K} - \mu\right) L,$$
$$\frac{dP}{dt} = \left(\overline{\varepsilon}\,\frac{I}{K} - \mu\right) P, \tag{8}$$

where μ is a coefficient of depreciation.

It can be easily found that the growth rates of production factors are connected by the relation

$$\frac{1}{K}\frac{dK}{dt} = \frac{1}{L}\frac{dL}{dt} + \alpha\left(\frac{1}{P}\frac{dP}{dt} - \frac{1}{L}\frac{dL}{dt}\right), \quad \alpha = \frac{1-\overline{\lambda}}{\overline{\varepsilon}-\overline{\lambda}}. \tag{9}$$

It can be demonstrated that the index α in (7) is the same quantity as α in (9).

4. Substitutive Work as a Measure of Technical Progress

The comparison of the two generalisations of labour theory of value, presented by (3) and (7), allows us to give interpretation of the neoclassical technical progress. One can note that capital service $K' = A_K(t)K$ in (2) presents the active role of production equipment and can be considered as an independent variable, that is, a direct substitute for labour, and one can identify capital service with substitutive work, $K' = P$. Labour services $L' = L$ are regarded just as estimation of workers' effort (in energy units) to have a standard reference. The comparison of (3) with the second line of (7) allows us to connect the neoclassical technical progress with the (time-dependent) ratio of production factors P/K:

$$A(t) = \left(\frac{K_0}{K}\frac{P}{P_0}\right)^{\alpha}, \quad 0 < \alpha < 1. \tag{10}$$

For simplicity, we assume here that the indexes in (3) and (6) are equal. In the considered simple case, the exogenous technical progress in neoclassical sense appears to be a function of the ratio of substitutive work to stock of capital P/K. In other cases, the situation can be more complex, but the ratio P/K itself can considered as a measure of technological progress, independent of the interpretations made in the neoclassical theory. The nondimensional ratio of substitutive work to labour efforts P/L can also be a convenient characteristic of technical progress.

5. A Method of Calculation of Substitutive Work

The definition of index of technical progress as the ratio of production factors P/K or P/L could be useful, if one has methods to measure the quantity P. This is a problem which has been considered elsewhere [9, 10]. The direct estimations of substitutive work P, as work of production equipment, are possible and, for sure, will be in use in the future, though at the moment direct methods of estimations do not determine good numbers. Luckily, there is a method of calculating the quantity (simultaneously with calculating the technological index α) in the case, when empirical time series for output Y, capital K, and labour L are known [5].

At given values of K and L, the growth rate of substitutive work, due to (9), can be presented as function of α:

$$\frac{1}{P}\frac{dP}{dt} = \frac{1}{\alpha}\left(\frac{1}{K}\frac{dK}{dt} - (1-\alpha)\frac{1}{L}\frac{dL}{dt}\right). \tag{11}$$

The technological index α can be exposed, due to the second line of (7), as

$$\alpha = \frac{\ln(L_0Y/LY_0)}{\ln(L_0P/LP_0)}. \tag{12}$$

One can introduce a symbol for logarithm of substitutive work

$$Z = \ln\frac{P}{P_0} \tag{13}$$

and see that, when the technological index α is excluded from (11) and (12), this quantity obeys the differential equation

$$\frac{dZ}{dt} = \left[\ln\left(\frac{L_0Y}{LY_0}\right)\right]^{-1}\left(\ln\frac{L_0}{L} + Z\right) \times \left(\frac{1}{K}\frac{dK}{dt} - \frac{1}{L}\frac{dL}{dt}\right) + \frac{1}{L}\frac{dL}{dt}. \tag{14}$$

This equation can be solved numerically to obtain the substitutive work corresponding to the given values of Y, K, and L. The value of P_0 ought to be estimated empirically. Simultaneously, values of the technological index α, according to (12), can be found.

6. Estimates for the US Economy

The method of description of economic growth, discussed in this paper, has been developed and tested through analysis of empirical data for the US economy [8–10]. It was shown that the proposed theory, in contrast to the neoclassical generalisation of labour theory of value, allows us to explain the main fact of industrial development; that is, output expansion has outpaced population growth, due to the technical progress. Here we are presenting some results to illustrate the situation.

To test the theory, the empirical time series of output Y, capital stock K, and labour L were used. The compatibility of data, a collection of which can be found in [9], or in [5], was investigated. The results for important quantities, values of the substitutive work P and technological index α, are demonstrated in Figures 1 and 2. In the first of the figures, one can see the calculated values of substitutive work (the lower solid line in Figure 1) in comparison with total consumption of energy carries E (the upper solid line in Figure 1). The running of production equipment is obviously impossible without attraction of great amounts of energy to the production. However, one can see that the magnitude and

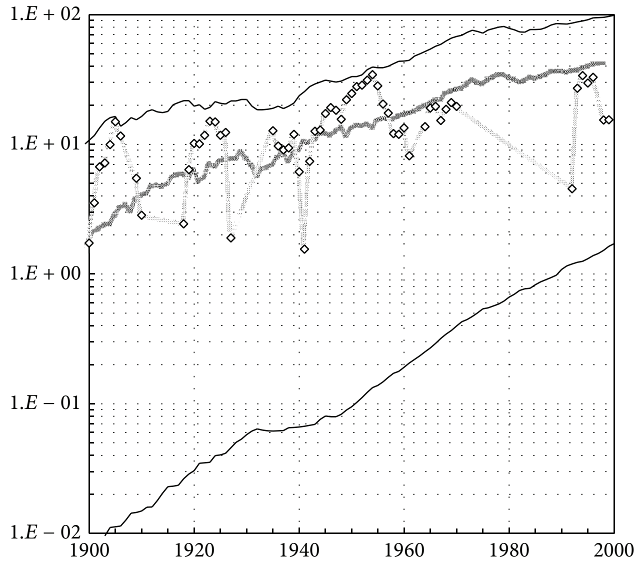

Figure 1: Total energy and substitutive work in the US economy. The solid lines represent consumption of energy careers (primary energy, top curve) and productive consumption of energy (substitutive work, bottom curve). The dashed line depicts primary energy needed for work of production equipment, estimated directly on the basis of empirical data. Primary substitutive energy is also calculated (and depicted by symbol ◇) as a part of primary energy, which is anticorrelated with labour. All quantities are estimated in quads per year (1 quad = 10^{15} Btu ≈ 10^{18} joules). According to Figure 1 of [10].

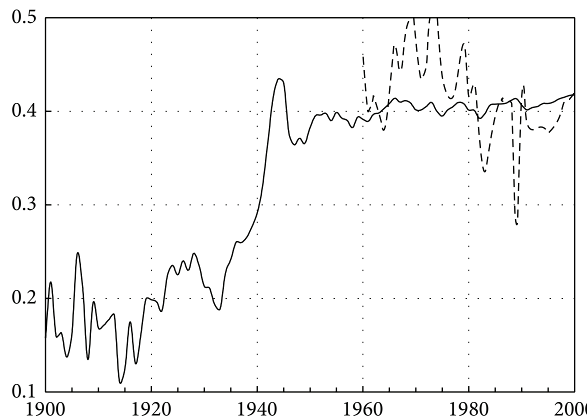

Figure 2: Technological index. Solid line represents values of the technological index α found according to (12)–(15). The dashed line represents values calculated as the fraction of expenses, necessary for maintenance of the production equipment. According to Figure 2 of [9].

the growth rate of substitutive work are, generally speaking, different from the growth rate of total consumption of energy carries. The difference is connected, first, with the fact that only part of the total energy is directed to do work with the help of production equipment; this part—primary substitutive work was estimated by two different methods and shown in Figure 1 by points and rhombi. Then, the amount

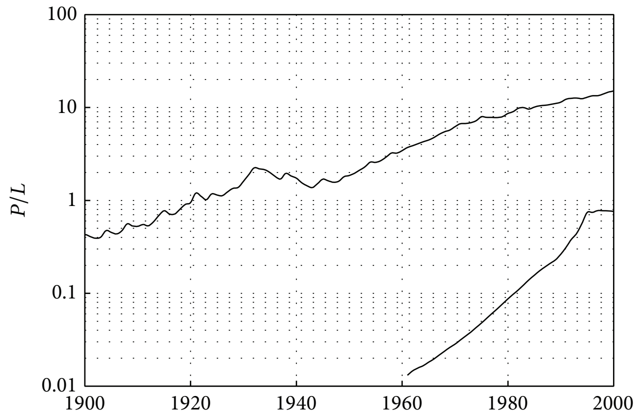

Figure 3: The ratio of substitutive work to workers' efforts. The ratio of substitutive work to energy estimates of workers' efforts for the US economy (the upper curve) and for the Russian economy (the lower shorter curve). According to Figure 1 of [8].

of substitutive work depends on the efficiency of conversion, the growth rate of which is increasing with time due to the technical innovation.

A number of authors in the past and recent times have emphasized the importance of energy in economic activity. There were some hopes that introduction of characteristics of usage of energy into the theory of economic growth could help to solve the problem of technical progress, and some attempts were made to introduce total consumption of energy E as a production factor in line with neoclassical factors L and K, so that production function could be written in the form

$$Y = Y(K, L, E). \tag{15}$$

However, it has appeared that relation (15) does not reflect the proper role of capital and energy in production, and attempts to expand the neoclassical theory of economic growth by introducing "consumed" energy as a production factor led to unresolved contradictions and were unsuccessful [11].

Simultaneously, with substitutive work, values of the technological index α are estimated and shown in Figure 2. The value of the technological index α can be also calculated by another method; the technological index represents the fraction of expenses, necessary for maintenance of the production equipment, in the full expenses for the production factors [9].

It is important that, in contrast to the exogenous neoclassical technical progress, values of substitutive work P, which is responsible for "endogenous" technical progress, can be estimated with different methods. One can use the ratio P/K or P/L as a measure of technical progress: for this aim, it is convenient to use the nondimensional quantity P/L, values of which are shown in Figure 3 for two countries. The quantity shows the level of development: at the end of the last century, every worker in the US was accompanied by more than ten automatic people, whereas in Russia it was only one, who accompanied the worker.

7. The Concluding Remarks

Production equipment is an essential part of modern production processes, but capital stock, as collection of machines, is not productive; productivity is provided with work that is fulfilled with capital stock [7]. Thus, to construct a proper and consistent description of economic growth, one has to leave the neoclassical interpretation, return to the labour theory of value, and expand it in the different direction. The theory has to be completed with the substitution law: the new and very important production factor appears to be *substitutive work*. This approach allows us to change the *"exogenous"* technical progress of the neoclassical approach into *"endogenous"* one, that is, to demonstrate that substitutive work is the underlying driver of technical progress. The two production factors: labour and substitutive work, appear to be the only original sources of wealth and drivers of economic growth.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

References

[1] P. Studenski, *The Income of Nations. Theory, Measurement and Analysis: Past and Present*, New York University Press, Washington, DC, USA, 1961.

[2] P. Aghion and P. W. Howitt, *Endogenous Growth Theory*, The MIT Press, Cambridge, Mass, USA, 1998.

[3] P. Aghion and P. W. Howitt, *The Economics of Growth*, MIT Press, Cambridge, Mass, USA, 2009.

[4] R. Solow, "Technical change and the aggregate production function," *Review of Economic Studies*, vol. 39, pp. 312–330, 1957.

[5] V. N. Pokrovskii, *Econodynamics. The Theory of Social Production*, Springer, London, UK, 2011, http://www.springer.com/physics/complexity/book/978-94-007-2095-4.

[6] J. Robinson, "The production function and the theory of capital," *The Review of Economic Studies*, vol. 21, no. 2, pp. 81–106, 1953-1954.

[7] B. C. Beaudreau, *Energy and Organization: Growth and Distribution Re-Examined*, Greenwood Press, Westport, Conn, USA, 1998.

[8] B. C. Beaudreau and V. N. Pokrovskii, "On the energy content of a money unit," *Physica A: Statistical Mechanics and its Applications*, vol. 389, no. 13, pp. 2597–2606, 2010.

[9] V. N. Pokrovskii, "Energy in the theory of production," *Energy*, vol. 28, no. 8, pp. 769–788, 2003.

[10] V. N. Pokrovskii, "Productive energy in the US economy," *Energy*, vol. 32, no. 5, pp. 816–822, 2007.

[11] R. U. Ayres, J. C. J. M. van den Bergh, D. Lindenberger, and B. Warr, "The underestimated contribution of energy to economic growth," *Structural Change and Economic Dynamics*, vol. 27, pp. 79–88, 2013.