New Economic Windows

Vladimir N. Pokrovskii

Econodynamics

The Theory of Social Production

Third Edition

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Preface to the Third Edition

The third edition of the monograph is based on the text of the second edition and keeps its main structure, though some corrections and additions, that specially are not discussed, are made in the text. Besides, the three new Chaps. 8, 12 and 13 are added. In Chap. 8, the ability of the theory to describe a real situation is illustrated, using, as an example, the historical (1960–2016) statistical data for the Russian national economy. Chapter 12 contains the application of the theory, developed in the monograph, to the reconstruction of global production activity on the Earth from the ancient times. And, finally, Chap. 13 contains discussion of the principles of organization of social production; a special attention is given to the rules of distribution of social product, which, eventually, determine social relations and structure of the society. The contents of the Chap. 3 and Appendix A are essentially changed.

The timeliness and, perhaps, even an indispensability of the publication of a new edition is justified by greater interest to the problems of economy and sociology from representatives of natural sciences (to whom I belong). The monograph proposes a new view on the economic growth theory from the point of view of a physicist. I have tried also to comprehend and consistently to state the conventional economic principles and theories, hoping, that the proposed monograph could serve as a reference book to the researchers of social problems. The experience of physicists has appeared and could appear in the future useful for investigation of economic problems.

The author will be grateful for all responses and comments.

Moscow, Russia
October 2017

Vladimir N. Pokrovskii

Preface to the Second Edition

While studying and teaching *Methods of Mathematical Modelling of Economic Processes*, I have been confused about some discrepancies between various parts of the economic theory. There was an impression that the economic theory exists in independent fragments. Especially upsetting for me, a person who began the study economic theory with *Das Kapital*, was the fact that Marx' theory seems to have no concern in mainstream economics.

I realised later that I was not the sole person to feel a deep dissatisfaction with the situation with the economic theory and its ability to describe reality. To say nothing of the numerous papers, there are many books devoted to a critique of mainstream economics (Nelson and Winter, 1982; Kornai, 1975; Beaudreau, 1998; Keen, 2001). There is a special online *Real-World Economics Review* (http://www.paecon.net/) opposing the mainstream theories. The people—who are engaged in ecology—are traditionally confronting the conventional economic thinking and are looking for physical terms to explain the phenomena of production (Costanza, 1980; Odum, 1996). Some physicists are trying to find new approaches to the analysis of economic situations (Mantegna and Stanley, 1999).

This book contains no critique of any theories. It is devoted to understanding the principles of production and contains a consecutive exposition of the technological theory of social production, which can also be understood as the theory of production of *value*. In the foundation of the theory, the achievements of classical political economy are laid. The labour theory of value is completed, after Marx's hints in *Das Kapital*, with *the law of substitution*. The latter states that, when interpreting value, one has to ensure that the workers' efforts in production of things are substituted with the work of production equipment. A new important concept of *substitutive work, as a value-creating production factor*, was introduced and used to formulate the appropriate theory. The adequacy of the theory has been tested by using the historical data for the U.S. economy.

The book is written by a physicist for the scientifically literate reader, who wishes to understand the principles of the functioning of a national economy. The book contains a discussion of conventional models (Leontief's input–output model, the classical Walras market theory and others) and can be considered as a textbook

for students of various specialties who have the necessary preparation in physics and mathematics and a desire to study economic problems. I think the monograph could be interesting for energy specialists, who are engaged in planning and analysing the production and consumption of energy carriers, and for economists, who want to know how energy and technology are affecting economic growth.

The appropriate formulation of the theory has a long history. This monograph was launched, in fact, as a revision and enlargement of my book *Physical Principles in the Theory of Economic Growth*, issued by Ashgate Publishing in 1999. However, it appears that the proper description of the theory has required the text to be completely rewritten and new material to be added, so that I have the opportunity to present a new book with a new title. I have used this edition to clarify the concepts and methods of the theory as far as it was possible for me at the moment.

I am grateful to many people—who support and encourage me in my work. I especially would like to separate a few persons, with whom I had the opportunity to discuss many relevant topics: Robert Ayres, Bernard Beaudreau, Sergio Ulgiati, Andre Maisseu, Michail Gelvanovskii, Grigorii Zuev and Irina Kiselyeva. Some issues became clearer for me after a discussion on the *generalized labour theory of value* with members of the *Socintegrum forum* (http://socintegrum.ru/); I am thankful especially to Valerii Kalyuzhnyi and Grigorii Pushnoi. Finally, I would like to express special thanks to my editors Maria Bellantone and Mieke van der Fluit at *Springer*.

Moscow, Russia Vladimir N. Pokrovskii
May 2011

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Contents

Notations and Conventions

A	Input-output matrix with components a_i^j;
$A = \frac{Y}{L}$	Labour productivity;
B	Capital-output matrix with components b_i^j;
E	Primary energy used in production;
E_P	Primary substitutive work used in production;
I	Gross investment in production system;
I_j	Gross investment of product j;
I^i	Gross investment in sector i;
I_j^i	Gross investment of product j in sector i;
K	Value of production equipment in production system;
K_j	Value of production equipment of kind j in production system;
K^i	Value of production equipment in sector i;
K_j^i	Value of production equipment of kind j in sector i;
L	Workers' efforts in production system;
L^i	Workers' efforts in sector i;
M	Amount of circulating (paper and credit) money;
M_0	Amount of circulating paper money;
N	Number of population;
p	Price of substitutive work as a production factor;
p_j	Price of product j;
P	Substitutive work
P^j	Substitutive work in sector labeled j;
Q_j	Quantity of product j in natural units;
R_j	Value of stock of fundamental product j;
S	Entropy;
t	Time;
$U(\cdot)$	Utility function, welfare function;
$u(\cdot)$	Subjective utility function;
W	Value of national wealth;

W_j	Value of national wealth of the kind j;
w	Price of workers' efforts, wage;
X_j	Gross output of product j;
Y	Final output, gross domestic product;
Y_j	Final output of product j;
Z^i	Production of value in sector i;
α	Technological index;
α^i	Technological index in sector i;
$\beta = \frac{\Delta Y}{\Delta L}$	Marginal productivity of workers' efforts at $P = const$;
β_i	Marginal productivity of workers' efforts in sector i;
$\gamma = \frac{\Delta Y}{\Delta P}$	Marginal productivity of substitutive work at $L = const$;
γ_i	Marginal productivity of substitutive work in sector i;
$\delta = \frac{1}{K}\frac{dK}{dt}$	Rate of real growth of capital stock;
$\tilde{\delta}$	Rate of potential growth of capital stock;
ε	Substitutive work requirement;
$\overline{\varepsilon} = \varepsilon\ \frac{K}{P}$	Non-dimensional technological variable;
ε^i	Substitutive work requirement in sector i;
$\overline{\varepsilon}^i = \varepsilon^i\ \frac{K^i}{P^i}$	Non-dimensional technological variable for sector i;
η	Rate of real (effective) growth of substitutive work;
$\tilde{\eta}$	Rate of potential growth of substitutive work;
λ	Labour requirement;
$\overline{\lambda} = \lambda\ \frac{K}{L}$	Non-dimensional technological variable;
λ^i	Labour requirement in sector i;
$\overline{\lambda}^i = \lambda^i\ \frac{K^i}{L^i}$	Non-dimensional technological variable for sector i;
μ	Rate of capital depreciation;
ν	Rate of real (effective) growth of labour;
$\tilde{\nu}$	Rate of potential growth of labour;
$\xi = \frac{\Delta Y}{\Delta K}$	Marginal productivity of capital;
$\xi^i = \frac{\Delta Z}{\Delta K^i}$	Sector marginal productivity;
Ξ	Marginal productivities tensor with components $\xi^i_j = \frac{\Delta Y_j}{\Delta K^i}$;
ρ	Price index;
τ	Time of technological rearrangement

Latin suffixes take values $1, 2, \ldots, n$ and numerate products and sectors. As a rule, the upper suffix numerates sectors, the lower suffix numerates products. The rule about summation with respect to twice repeated suffixes is sometimes used.

The chapter number and the number of a formula in the chapter are shown in references to formulae.

Abstract

The monograph represents one of the main problems—why do economies grow?—from a physicist's point of view. Econodynamics itself is regarded as a science with its own concepts and principles—a science which investigates processes of appearing, movement and disappearing of value, being hardly interested in its material carrier. To reconsider the theory of economic growth, the author analyses the concepts of value and utility and their relationship to the thermodynamic concepts. The approach allows the author to include characteristics of technology into description of development and to formulate phenomenological (macroeconomic, no price fluctuations are discussed) theory of production as a set of evolutionary equations in one-sector and multi-sector approximations. The monograph presents the topics in a compact and consistent form that makes it a suitable introductory text for the students of various specialties, who are studying economic problems. The professional researchers could find the monograph to be useful, if they would be ready to get rid of some of neo-classical prejudices.

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Chapter 1
Introduction: The Value-Creating Factors

Abstract It is enough to look at the contents of economic courses, to become easily convinced, that the common thing for all of them is 'a substance' of value. It is convenient to use the name – economic dynamics (econodynamics) – for the discipline. It investigates the processes of emergence, motion and disappearing of value, just as hydrodynamics investigates processes of motion of liquids, electrodynamics – those of changing electric and magnetic fields, thermodynamics – processes connected with the motion and conversion of heat.... In this chapter, the concept of value is reviewed and the role of basic production equipment, as a set of sophisticated devices, which allow human beings to attract energy from natural sources for the production of useful things, is discussed.

1.1 A National Economy at a Glance

The enormous growth of the human population through the centuries is connected with special features of the population. In contrast to any other biological population inhabiting the earth, humans have invented the highly sophisticated artificial means of supporting their own existence while developing a great level of cooperation of members of their society. Since Paleolithic times, clothing, shelter and fuel have become necessities of life almost as fundamental as the food itself. The initial motive power of production is the demand of people, their desire to consume and, consequently, to produce things. As an economic system, a society produces everything that is necessary for a survival: means for the maintenance of human existence, and tools to provide such support. Since Paleolithic times the organization of human society has also been progressing. Modern society presents itself as a huge hierarchal organization, including the government, firms, banks, colleges, libraries and so on. It is a very complex organization, and every one of the members of the society, in some way, is included in the system.

A huge amount of artificial things are accumulated by societies: buildings, transport ways, bridges, production equipment, energy supply systems, sanitation systems

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and so on. Aside from the tangible things, a society accumulated a great amount of intangible objects: knowledge of the laws of nature, principles of organization of society, items of the literature and arts and so on. Both the tangible and intangible constituents of *the wealth of the society* are equally important for maintaining the existence of human communities. To create and maintain national wealth, that is, things that are useful for human beings, *a social production system* was invented and maintained by humans, and this is just what distinguishes human populations from other biological populations. The society, as an economic system, produces everything that is needed for the survival of the community: both the means for supporting the human existence and the means for generating such support.

To design a theory of social production–distribution, it is necessary to keep in mind some heuristic model, which could be imagined due to the remarkable achievements of the classical political economy and neoclassical economics [1]. Some main constituents of the production–distribution system are presented in Fig. 1.1. The central position in the model is the production block, which consists of many production units: the enterprises, factories, firms, research institutes and other organizations that create everything what the man needs. From a material point of view, the production system takes minerals and ores from the environment, transforms natural substances into finished and semi-finished things, the latter istransformed into other things and so on, until all this is finally consumed, and the substances are returned into the environment as waste. This is the material side of production. Human beings always consume the products, so the products always have to be created.

The interaction between various units of the production system and the population is realized by means of the money exchange, so it is possible to present the production system and population as being immersed in a money environment, as shown schematically in Fig. 1.2. The money medium is created by the government, the central bank and many commercial banks. The central bank issues the banknotes and coins – the primary money – that is distributed over commercial banks. The mechanism of issuing assumes that all paper money is circulating among economic subjects: practically no paper money is contained in the commercial banks. The central bank also provides the commercial banks with credits, and the commercial banks can provide their customers with credit money. The records on the accounts of customers are non-paper money, which are created by the commercial banks. The central bank and commercial banks introduce an uncertain amount of the circulating money in coins, banknotes and deposits in the system consisting of the government and the many customers of the commercial banks.

The member of the society exchanges his services for an intermediate product – *money*, and then exchanges the money for products he wants. Therefore, simultaneously with the motion of products, one discovers the motion of money, which has to be considered as a separate, special artifact. The money is circulating in the economy, providing the exchange of products. Modern money is nothing more than a certificate that its owner has a right to get a certain set of products. Modern money is paper money and records on the accounts in the central and commercial banks and, thus, is inherently useless. The value of modern money derives only from the fact that it can be exchanged for the product.

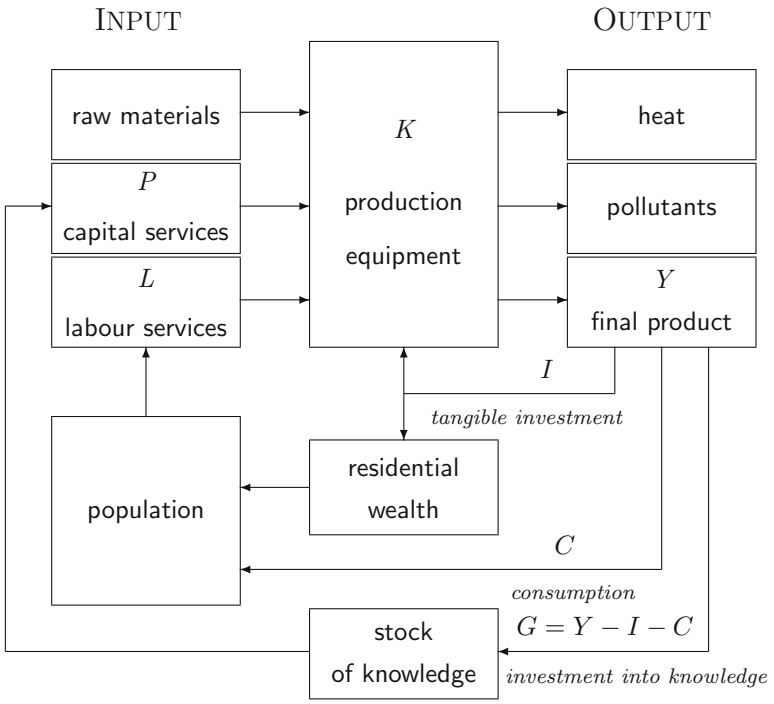

Fig. 1.1 Fluxes in the production-consumption system. To produce a thing or a service, apart from production equipment K, one needs raw materials (ores, water, air, energy carriers and so on), worker efforts L and some factor which can be conventionally called capital services P. The last factor is closely connected with production equipment – capital stock K, but different from it. Though capital services P can be considered formally as an independent production factor, it is hardly possible to find for it any other interpretation that is different from the amount of work of production equipment, which is done with the help of external energy sources instead of the workers' efforts. The output of the production process is a multitude of things and services, which are measured by their total value Y. A part C of final product Y is directly consumed by human beings, and a part I goes to the enhancement of the production system through an increase in the stock of production equipment, so that the production system itself is a subject of evolution. The production processes are accompanied by the emergence of heat and pollutant fluxes, but this is another side of the problem to which we shall not pay much attention to the monograph.

The real production and *the money system* are intervened with each other, thus one can think that an appropriate description can be achieved when these phenomena are studied together. But one ought to consider the real production as a basis of the whole system and it is possible to begin studying of the national economy with the production system, considering the money system as a neutral intermediator. The architecture of the production system appears complex, but in the simple approach the production system can be considered as a set of the interacting pure sectors; in the

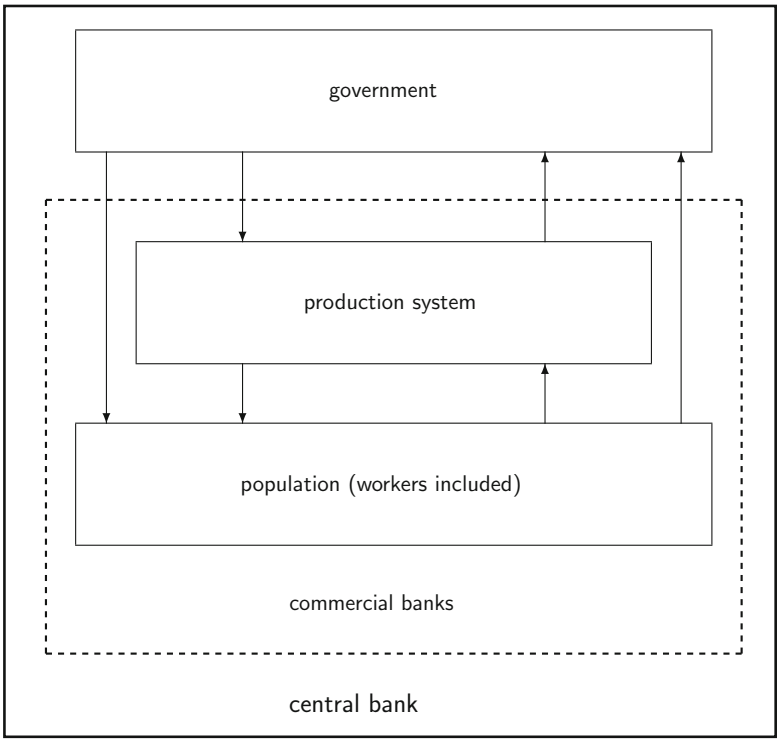

Fig. 1.2 The architecture of a national economy. The central bank and commercial banks create a money medium for the activity of economic agents. The production system creates all products and generates the fluxes of products to workers and between production units. The fluxes of money, depicted in the picture, are moving in opposite direction. Households are buying products, and money is returning to the producers. The government receives its part of the produced value in the form of taxes, which, in different amounts, are returning to the economic agents. Each flux of money is a result of negotiation and agreement between corresponding agents.

most elementary case, the production system can be considered as the only sector. This heuristic model of the society allows us to develop the theory of the production system in a simple, so-called macroeconomic approach. The investigation of the laws of production is one of the central issues of econodynamics.

1.2 The Concept of Value

The notion of the *product* appears to be one of the fundamental concepts of economic theory. It can be defined as something that is produced to be consumed. It does not matter whether the moment of consumption coincides with the moment of production as, for example, in the case of transport services, or does not coincide. In the latter case, the product exists for some time in its material or non-material form. Also, it

is insignificant, whether the product is intended to satisfy the needs of the producer or is prepared for sale.[1]

According to the statements of the researchers,[2] the product can be considered as the unity of *use-value* and *production-value*, which allows products to participate in the processes of exchange. In the exchange, the products oppose each other, and the use-value of one product stands against the use-value of another. Products with various use-values can be compared due to the fact that the production-values of all products differ only in quantity, not in quality. Thus, the property that allows the

[1] Let us pay attention to the distinction of the concepts *a product* and *a commodity*. The latter is defined as something that is made for sale that is for an exchange at which value is disposed. From here some people wrongly conclude that the thing made for the producer's consumption does not possess value. This statement has been rejected by Marx ([2], Chap. 1, Sect. 4): "Since Robinson Crusoe's experiences are a favourite theme with political economists, let us take a look at him on his island. Moderate though he be, yet some few wants he has to satisfy, and must, therefore do a little useful work of various sorts, such as making tools and furniture, taming goats, fishing and hunting. Of his prayers and the like we take no account, since they are a source of pleasure to him, and he looks upon them as so much recreation. In spite of the variety of his work, he knows that his labour, whatever its form, is but the activity of one and the same Robinson, and consequently, that it consists of nothing but different modes of human labour. Necessity itself compels him to apportion his time accurately between his different kinds of work. Whether one kind occupies a greater space in his general activity than another, depends on the difficulties, greater or less as the case may be, to be overcome in attaining the useful effect aimed at. This our friend Robinson soon learns by experience, and having rescued a watch, ledger, and pen and ink from the wreck, commences, like a true-born Briton, to keep a set of books. His stock-book contains a list of the objects of utility that belong to him, of the operations necessary for their production; and lastly, of the labour time that definite quantities of those objects have, on an average, cost him. All the relations between Robinson and the objects that form this wealth of his own creation, are here so simple and clear as to be intelligible without exertion, even to Mr. Sedley Taylor. And yet, those relations contain all that is essential to the determination of value".

[2] Still Aristotle, analysing the exchange of various things, wrote '... all things that are exchanged must be somehow comparable' ([3], Book 5, Sect. 5). Marx ([2], p. 14) wrote: '... when commodities are exchanged, their exchange value manifests itself as something totally independent of their use value. But if we abstract from their use value, there remains their value as defined above. Therefore, the common substance that manifests itself in the exchange value of commodities, whenever they are exchanged, is their value'. The brief history and the analysis of concept of value are exposed, for example, by A.N. Usoff in a work 'What is value' (http://www.usoff.narod.ru/Us4.htm, in Russian). Having begun with concepts of use-value and production-value, Usoff has shown, how it is necessary to introduce the concept of value, free from the pre-prepared interpretations. Everyone, who was studying in a higher educational institution in the USSR until 1990, knows the statement that 'value is the expenses of labour'. However, there is no indispensability to reduce the concept of value to expenses of labour in advance. Factorial theories of value, that is the reduction of value to labour, capital and other universal factors of production, are considered in the following section.

products to be compared and exchanged is their *exchange value* or just *value*.[3] Value is an attribute of a product, just as mass is an attribute of matter.

One believes that, irrespective of this or that factorial interpretation of value, the products are exchanged on average according to their values. This is an axiom, which gives a relative measure of value, and allows one to ascribe a certain quantity of value to the products and to estimate the value of a set of products. Value is measured in conventional money units, which are set, when the recognised means of circulation (money) are introduced into the economic system (see Chap. 3). Due to the overall exchange with the help of the money, all commodities can be evaluated, and this is considered as an estimation of their *value* in arbitrary money units (dollars, pound sterlings, euros *et cetera*). One can estimate, for example, a multitude of services and things produced by a nation for a year. This quantity is called the Gross Domestic Product (GDP).

The mechanism of exchange has been scrutinized. Some scholars emphasized the demand side of the phenomenon and argued, that there is no value without utility, so that value ought to be considered as a market estimate of the utility of a thing. Other scholars argued that there are some things (water and air, for example), which have utility without market value, and thus, to understand the meaning of value, one has to refer to the supply side and take into account the production costs of things. It was accepted later (the contributions of Walras [5] and Marshall [6] used to be especially stressed) that both the cost of production (supply) and utility (demand) were interdependent and mutually determinant of value of things. It had appeared to be fruitless to argue whether demand or supply determines value, as, in Marshall's words, 'we might as reasonably dispute whether it is the upper or under blade of a pair of scissors that cuts a piece of paper, as whether value is governed by utility or costs of production'.

The motion and transformations of products in an economy can be described as fluxes of value, which appears at the first touching substances of nature with the hand of a human being, moves together with material substance of a product, leaving its material form, transfers into other substances, and disappears at final consumption. The study of these processes is a subject of an empirical science that can be called *economic dynamics (econodynamics)*, which can be defined as a science which investigates the processes of emerging, moving and disappearing of value, being hardly interested in its material carriers. The concept of value in econodynamics is as important as the concepts of energy and entropy in physics. Now we have

[3]Marx distinguished concepts *exchange value* and *value*, the last was identified by him as expenses of labour. It is possible to find the statement in the forth volume of 'Capital' (The Theories of Political Economy, Chap. 8, Sect. 5), that '... commodities do not exchange according to their values, but at average prices, which differ from their values... ', named in other places as 'prices of production'. Marx's observation should be interpreted in such a way, that '... commodities do not exchange according to *expenses of labour*, but to the differing from the expenses of labour quantities, which are usually interpreted as their *value*...'. The quantity *value* and *expenses of labour* are different and can be estimated separately, which has been stated already long ago [4]. Further everywhere, the term value is understood as *exchange value.* .

fragments of this science only, and one of the fragments – the theory of production – is described in this monograph.

The concept of value allows to unify the description and to speak both about the production of things, and about production of value. Thus it is possible to say, that the production system creates things, but the value of things is determined by functioning of all system of production–distribution. Note, that there is some strangeness with the modern use of concept of value. In their daily work economists estimate streams of value between people, enterprises and countries, but in theoretical constructions, economists try to avoid this concept; the concept of utility is used instead. The political economy of the nineteenth century has turned into the *economics* of our days, which is defined as '... the study of how societies use scarce resources to produce valuable commodities and distribute them among different groups' ([7], p. 5). But economic sciences cannot exist without the concept of value. Consideration of streams of value (in any monetary units) in a national economy makes possible the general descriptive schemes of production and distribution.

1.3 Factor Theories of Value

Over the centuries researchers have tried to understand how things get value, or, in other words, to find a certain universal source of wealth, to reduce production of value Y in monetary units with quantities of some universal creating value factors, which have the special name *of production factors*. A formulated in this way *law of production of value* plays a fundamental role in economic theories and, consequently, ought to be considered as *the basic economic law*.

1.3.1 Classic Labour Theory of Value

Benjamin Franklin, known for his works on electricity, was one of the first to formulate the statement that a measure of value is work spent by laborers [8]. This idea was especially developed in works by Adam Smith [9], David Ricardo and Karl Marx [2] and appears to be central in the political economy of the beginning of the nineteenth century. In classic political economy, labour was considered as the only factor creating value. According to Smith, 'value of any commodity...to the person who processes it and who means not to use or consume it himself, but to exchange it for other commodities, is equal to the quantity of labour which enables him to purchase or command'. According to Marx, 'all commodities are only definite masses of congealed labour time'. *The labour theory of value* states that value of the created product is equivalent to socially necessary expenses of labour needed for its production. According to this theory, output of production system Y is defined as function of expenditure of labour L

$$Y = Y(L).$$

When considering the dynamics, the output is usually measured by monetary units of constant purchasing capacity (see greater details in Sect. 2.2.3), which excludes inflationary phenomena, when the quantity Y creeps upwards owing to the depreciation of the monetary unit. The quantity represents a 'physical' content of the results of production. Considering the quantity Y proportional to the quantity of labour, that was spent during the production of this goods and present, according to Marx, true labour value, one can formally write

$$Y = A\,L. \tag{1.1}$$

On the simple assumption, one can easily find from this relation that output changes, when the used technology of production has been modified, according to the law

$$Y = A_0 e^{\psi t}\,L,$$

where A_0 – value of labor productivity in initial point in time, ψ – the reduction rate of consumption of work at the introduction of technological improvements.

As a rule, the growth rate of output exceeds the growth rate of expenditure of labor. Growth of labour productivity Y/L is connected with an increase of productive force of labour, which, according to Marx (Capital, Volume 1, Part 1, Sect. 1), '... is determined by various circumstances, amongst others, by the average amount of skill of the workmen, the state of science, and the degree of its practical application, the social organization of production, the extent and capabilities of the means of production, and by physical conditions'. However, many efforts and time have been required to understand 'various circumstances' and to introduce variables, which would allow to formalize their influence on labor productivity Y/L. While the reduction of value to one factor – expenditures of labour L – did not explain all phenomena of economic growth, other production factors, in line with expenditures of labour L, such as land and capital, have been introduced into the law of production of value [10].

1.3.2 Role of Production Equipment

The important element of production is equipment, about which we think as of assembly of different machines, buildings, roads, harbours, pipelines and similar objects, including animals and their pastures. Installation and operation of the production equipment leads to variation of output[4] at the constant expenditures of labour L, and to an increase of labor productivity Y/L; it would be strange to not consider

[4]Considering production in approximation of several branches, Marx in the third volume of 'Capital' has noticed, that profit distribution on branches conforms to distribution of expenses of work in branches then only, when the ratio of the constant capital to variable one, that is, in Marx's terms, an organic structure of the capital, or, in other words, the ratio of value of the production equipment to expenses for employment of labour in branches, is constant; otherwise conformity it is not observed.

this effect. And indeed, it has been introduced into the theory of value [10] as an additional variable – a monetary assessment of the production equipment (the basic production capital) K, as an essential production factor. On this assumption, output Y is recorded as a function of two variables

$$Y = Y(K, L). \tag{1.2}$$

In relation (1.2) capital K and labour L are regarded as perfect substitutes for one another, that is, a given output can be achieved by any combination of the two factors, though, of course, there is a most efficient combination, depending on the prices of production factors.

It has been suggested (see, for example, [11]) many particular forms of function (1.2), but one of them, proposed by Cobb and Douglas [12], has appeared the most common

$$Y = Y_0 \frac{L}{L_0} \left(\frac{L_0}{L} \frac{K}{K_0} \right)^{\alpha}, \quad 0 < \alpha < 1. \tag{1.3}$$

Function (1.3) has the advantage of not depending on the initial values of production factors and is often used for interpretation of phenomena of economic development. The index α ought to be considered as a characteristic of the production system itself.

The other tradition [13–16], in accordance with empirical facts, considers the output as a linear function of capital (or generalised capital)

$$Y = AK. \tag{1.4}$$

The 'capital' productivity A, due to empirical evidence, does not depend on production factors. It is easy to see that the laws (1.3) and (1.4) are compatible only at the value $\alpha = 1$, which leads to the exception of the expenditure of labour in the law of production of value.

Another paradox, described Solow [17], exists: the theory based on the neoclassic production function (1.2) in any form does not include technological changes. Nevertheless, there has been a clear belief that, in recent centuries, technological progress was ultimately the source of economic growth in developed countries and it should be incorporated into the theory of economic growth.

To avoid the specified difficulties, it was suggested [17] to modify concepts of labour L and capital K. The arguments of function (1.2) must be considered, not as capital and expenditures of labour, but as services of the capital $K' = A_{\mathrm{K}}(t)K$ and labour $L' = A_{\mathrm{L}}(t)L$, which are connected with measured quantities of capital stock K and labour L, but are somewhat different from them, so that

$$Y = Y(K', L'). \tag{1.5}$$

It specified an indispensability of taking into account a role of the production equipment in the theory of production of value.

An extra time dependence of function (1.2) (the so-called exogenous technological progress) has been introduced, and this time dependence can be found empirically [18].

Multipliers $A_K(t)$ and $A_L(t)$ can be chosen variously, and the production function can be written in a variety of ways [17]. In one of the elementary (but often used) cases, for example, production function is recorded in the form

$$Y = Y_0 A(t) \frac{L}{L_0} \left(\frac{L_0}{L} \frac{K}{K_0} \right)^{\alpha}, \quad 0 < \alpha < 1, \tag{1.6}$$

where the only time-dependent multiplier $A(t)$ appears to describe the influence of technical progress.

The concepts of labour and capital services appeared to be necessary and very useful to explain the observed growth of output [19]. However, the problem of endogenous inclusions of technical progress in the theory remains unsolved, or, taking advantage of Solow's words [20], there remains a question: *'whether one has anything useful to say about the progress, in a form that can be made part of an aggregative growth model.'*

In past decades, there have been some attempts to improve the neoclassical theory by including in the production function new variables, such as technology, or human capital or stock of knowledge H [21–25], or consumed energy E [26–28]. It was assumed that output Y can be written as a function of three, or more, variables

$$Y = Y(K, L, H, E, ...).$$

There was a belief that the only thing one needs to solve the problem is to find a sufficient number of appropriate variables. However, the econometric investigations of over 90 different variables, proposed as potential growth determinants, did not give a definite result [29]. A review of the latest development of the neoclassical approach can be found in a book by Aghion and Howitt [30].

The neoclassical tradition attaches much importance to the production equipment, considering its passive presence, as to some set of objects with a monetary assessment K, in the theory, ignoring its active role. The production equipment is set to carry out the certain actions, to facilitate the certain work, and some characteristic of activity of the existing capital stock must be introduced. Apparently, capital as an assembly of equipment, is not 'productive' in physical sense, it is dead [31]. Indeed, it is not so important, how many equipment we have, as what advantage from the installed equipment we have.

1.3.3 The Law of Substitution

The task of the production system is to change forms of matter, that is, to transform, for example, ores of different chemical elements into an aircraft, which can fly. To

produce a good or a service, some specific work[5] must be done. Modern technologies assume that this work can be done by a human being himself and/or by some external sources, one can say by energy sources, simultaneously. To grind corn into flour, for example, one can use a hand mill, a water mill, a wind mill or a steam mill. In these cases, as in many others, production equipment is some means of attracting external sources of energy (water, wind, coal, oil, etc.) to the production of things; the workers' efforts are substituted by the work of falling water, or wind or heat. No matter who or what does the work, all of the work must be done to obtain the final result which should be compared with the consumed energy and the workers' efforts.

It is possible that the first person to write about the functional role of machinery in production was Galileo Galilei. He realised that all machines transmitted and applied force as special cases of the lever and fulcrum principle. A prominent historian of science and technology Donald Cardwell [32] wrote that Galileo in his notes *On Motion* and *On Mechanics* recognised that 'the function of a machine is to deploy and use the powers that nature makes available in the best possible way for man's purposes... the criterion is the amount of work done – however that is evaluated – and not a subjective assessment of the effort put into accomplishing it' (pp. 38–39). The advantage of machines is to harness cheap sources of energy because 'the fall of a river costs little or nothing'.

The relevance of machinery to economic performance was clearly recognised by Marx [2], who described the functional role of machinery in production processes in Chapter XV *Machinery and Modern Industry* of *Das Kapital* as follows:

> On a closer examination of the working machine proper, we find in it, as a general rule, though often, no doubt, under very altered forms, the apparatus and tools used by the handicraftsmen or manufacturing workman: with this difference that instead of being human implements, they are the implements of a mechanism, or mechanical implements (pp. 181–182). The machine proper is, therefore, a mechanism that, after being set in motion performs with its tools the same operations that were formerly done by the workman with similar tools. Whether the motive power is derived from man or from some other machine, makes no difference in this respect (p. 182). The implements of labour, in the form of machinery, necessitate the substitution of natural forces for human force, and the conscious application of science instead of rule of thumb (p. 188). After making allowance, both in the case of the machine and of the tool, for their average daily cost, that is, for the value they transmit to the product by their average daily wear and tear, and for their consumption of auxiliary substances, such as oil, coal and so on, they each do their work gratuitously, just like the forces furnished by nature without the help of man (p. 189).

These examples illustrate, that both physicists and political economists recognised the important role of machinery in production processes as having to do with the *substitution of workers' efforts by the work of machines moved by external sources of energy*, while the extent of this substitution depends on the technology per se. It is important to keep in mind that while capital is a necessary factor input, work can only be replaced by work, or put differently, work cannot be replaced by capital.

[5] One can understand work as a process of conversion of energy in technological processes from one form to another, for example, from mechanical into thermal form.

1.3.4 Generalised Labour Theory of Value

Every economist would agree that labour is the most important factor of production, but the situation appears to be more complicated. The production-value, generally speaking, does not reduce the expenses of labour; something else should be added into the theory. One can guess that the 'something' that is needed in the theory is the Marx's phenomenon of 'the substitution of natural forces for human force'. Indeed, after understanding this phenomenon, Marx could suggest that it affects the mechanism of production of value. To understand how gratuitous work influences the value of the products, he could analyse the performance of two similar enterprises. He could suggest that the first of the enterprises use a technology which requires some amounts of labour L and substitution work P, and, to produce the same quantity of the same product, the second enterprise uses a technology with the quantities $L - \Delta L$ and $P + \Delta P$ for production factors. So far as the products are considered to be identical, the exchange values of the products of either enterprise on the market are equal, despite the difference in labour consumption. Therefore, Marx could continue to argue, value cannot be determined by labour only, but the properly accounted work of natural forces ought to be considered.[6] To produce the same quantity of value, the decrease in workers' efforts ought to be compensated by an increase in work of external sources, so that one can write the relation

$$-\beta\,\Delta L + \gamma\,\Delta P = 0,$$

where productivities β and γ of the corresponding production factors are introduced. Thus, equally with human efforts, the work of natural forces appears to be an important production factor. It is easy to see, that the quantity β/γ determines the amount of gratuitous work of external sources which is needed to substitute for the unit of human work to get an equal effect in production of value. As the work of external forces, replacing efforts of the person, is impossible without the production equipment, this phenomenon has been apprehended and described as substitution of labour by capital. However, to describe substitution correctly, *it is necessary to introduce and consider a new production factor – true substitution work of the production equipment* P.

In the general case, the work performed by labour L and substitutive work P has to correspond to a set of products, which has the exchange value Y, and one can write, assuming that the production system itself remains unchanged, the relation between differentials of the quantities

$$\mathrm{d}Y = \beta\,\mathrm{d}L + \gamma\,\mathrm{d}P. \tag{1.7}$$

[6] In fact, Marx had encountered such a problem (see footnote 4 on p. 9), but stated opposite; he frequently repeats, that only work is a source of value, but, as argues, for example, Yatskevich [33, Chap. 6] this statement is true, if the concept 'work' is understood as 'social abstract work' defined by both actual efforts of working people and all set of machine technologies and methods of work. Taking into account the effect of substitution, a measure of abstract work is the quantity $L + P$.