National Income and General Productivity in Terms of Energy

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In this study, exploring the field of energy value theory, the national economy is treated as a whole in a twofold sense: all units of the system—individuals, enterprises, households, governmental agencies—are considered, while the relations among them, arising from the social division of labor, are disregarded. In other words, the analysis deals with macroeconomic aggregates, but does not touch on the «circular flow» in the economy—the social circulation of goods and money. Speaking more generally, a «universe» is looked upon as a «body». This is the way in which the energy supply and the energy expenditure of living organisms are ascertained in physiology of nutrition.

Although the flow of energy can be regarded from the economic point of view as continuous, and the energy equations are valid for any accounting period used in economics, the energy value theory examines long run problems only. It has nothing to do with the everyday economic expectations and decisions, which must be shaped in terms of money, or with the exchange of goods against production-factor services, or goods against goods between the units of the economy. Therefore, it does not enter the domain of those branches of economics which deal with exchange values, i. e., with magnitudes in terms of money.

The energy approach in economics is «orthodox». It is in agreement with the prevailing doctrines of contemporary economics and contemporary physics. It leans on them and makes wide use of their conceptual tools. Only four new concepts need to be mentioned: «energy cost» (or «energy expenditure»), «energy value», «primary energy» (from the economic point of view) and «net-maintenance ratio». They are defined in the next section.

I

Let us call the energy from primary sources simply primary energy. From the economic point of view, primary energy is to be understood as the heat transferred from Nature to the economy by Man. In accordance with this definition the harnessed motive power of running water and wind can be re-
presented by its coal equivalent, that is to say, by the coal from which the same quantity of electricity or mechanical work could be produced. The most important «bearers» of primary energy are fuels—coal, mineral oil, natural gas, fuel wood, peat, etc., the currents of water and air, and the harvest of food and feed plants.

Let us further define as net energy-cost of an economic good (service, inanimate material good, or animal) the work or work equivalent of useful heat used to produce the good itself and its material; and as supplementary energy-cost the energy—heat or heat content of matter—lost in its production in the sense of engineering. Net energy-cost and supplementary energy-cost taken together give the gross energy-cost of production. It should be noted that the work used to produce work and useful heat does not belong to net energy-cost; it is a separate net-maintenance item. (See below, equation (5).)

Now, from the theory of thermodynamics, we know that

\[ \text{Energy Available for Work} = \text{Energy Transferred} - \text{Energy Lost} \quad (1) \]

Empirically the above equation holds for the production of useful energy in general, i.e., it is valid for work as well as for useful heat. «Energy transferred» is in this case what we have defined as «primary energy».

Hence we may write, for a «closed» or «isolated» economy,

\[ \text{Useful Energy Produced} = \text{Primary Energy Output} - \text{Energy Losses} \quad (2) \]

For a growing economy the useful energy can be divided into «useful energy used for maintenance of the economy»—briefly, «net maintenance»—and «energy used for end-consumption and growth».

Thus we have

\[ \text{Useful Energy} = \text{Primary Energy} - \text{Useful Energy for End-Consumption} - \text{Energy Losses for Maintenance} \quad (3) \]

or

\[ \text{National Income} = \text{Primary Energy Output} - \text{Net Maintenance and Losses} \quad (4) \]

Formulas (3) and (4) are identical expressions of what may be called the fundamental equation of energy for an economy.

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1 According to the First Law of Thermodynamics energy cannot be created or destroyed. According to the Second Law of Thermodynamics every transformation of energy into work is accompanied by losses of energy in the form of heat. If it were not for the First Law, no energy balance could be established. If it were not for the Second Law, all energy transferred would be available for work.

2 This is because Net Maintenance = (Gross) Maintenance — Energy Losses in Production for Maintenance, and Energy Losses = Losses in Production for Maintenance + Losses in Production for Income.

For theoretical interpretation and statistical-engineering computations a more detailed formula should be given, namely

\[
\text{Work Performed and Use} \text{ful Heat Used in Production of Direct Services} + \text{Work Performed and Useful Heat Used in Production of Additional Capital; Useful Energy Stored as Additional Energy Stocks} = \text{Work Performed for Increase of Population; Useful Energy Stored as Additional Human Body Substance}
\]

\[
= \text{Heat Content of Primary Energy Output} - \text{Work Performed and Useful Heat Used in Production of Additional Real Capital and Production of Additional Human Population} - \text{Work Performed and Useful Energy Stored in Reproduction of Real Capital and Production of Additional Human Population}
\]

\[
\text{Heat Content of Energy} - \text{Work Performed and Useful Heat Used in Production of Additional Real Capital and Production of Additional Human Population}
\]

For physical homogeneity, the work performed is to be expressed in heat, i.e., by its heat equivalent.

The services are classified as «direct» or «indirect» according to whether they are rendered directly to the final consumers—the individuals—or to the producing units. The direct services embrace: the «personal services», i.e., the services related to mind culture, body culture, and entertainment of the individual, and the household services. Except for medical services, which belong to maintenance of the population, and preparing of food, which belongs to energy benefication, the direct services are constituents of national income. The indirect services embrace transportation, trade, banking, insurance, and social—i.e., governmental—services. In equation (5) transportation of goods, trade, and banking are included in reproduction of capital and production of additional capital. Governmental services satisfy collective wants and constitute a purely maintenance item. Insurance is by definition maintenance.

Energy losses embrace the energy dissipated in the sense of thermodynamics and the heat of combustion of matter lost in physical and physiological processes. They also include the hypothetical losses arising out of the accounting conversion of heat and chemical energy into work.

As can be seen from equation (5), the energy value of things in the energy turn-over of the economy is differently composed according to their physical nature and «function». The energy value of national-income and net-maintenance items may have one or two elements: net energy-cost only or net energy-cost and energy content (unconvertible material goods have net energy-cost but no energy content; convertible inanimate material goods and living body substance have both net energy-cost and energy content; for services and heat, net

\[\text{In the article «The Concept of Energy in Economics», previously cited, I had adopted the division of the social services into direct and indirect—accepted by all official statistical agencies of the Western world. However, the idea of maintenance supplied new and decisive arguments to treat all social services as «overhead cost» of the national economy, i.e., as «user cost» of the producing units. Personal services produced by governmental agencies, e.g., public education, belong to national income.}\]
energy-cost is identical with energy content). The energy value of primary-energy and energy-loss items has one element only: energy content. The energy value of energy losses is identical with the supplementary energy-cost of the components of national income and net maintenance.

It has been mentioned that equations (2) to (5) refer to a «closed» economy. In an «open» economy imports and exports of energy and matter must be considered. Imports of primary energy must appear as a new positive item on the right side of the equations; exports of primary energy on the left. Imports of unconvertible inanimate material goods and animals have to be deducted from, and exports added to, the respective items in the composition of national income.

The inference which can be gained for economic theory from the foregoing analysis is important. Equation (5) shows that the development of the population is most intimately connected with the development of national income; the increase of population is a part of national income. It shows further that national income is predominantly motion. In a «stationary» economy the «social product» consists only of motion.

II

The energy approach provides a clear concept of productivity of the national economy and enables us to measure it in a very simple way. Since primary energy is used in order to obtain national income,

\[ \text{General Economic Productivity} = \frac{\text{National Income}}{\text{Primary Energy}} \quad (6) \]

and

\[ \text{National Income} = \text{Primary Energy} \cdot \text{General Economic Productivity} \quad (7) \]

The ratio of total useful energy to primary energy expresses the efficiency of transformation of energy in the sense of thermodynamics, that is

\[ \text{General Physical Productivity} = \frac{\text{Total Useful Energy}}{\text{Primary Energy}} \quad (8) \]

From equation (3) it follows that national income can be expressed as a difference, as total useful energy less useful energy for maintenance. Hence

\[ \frac{\text{Useful Energy for Consumption and Growth}}{\text{Primary Energy}} = \frac{\text{Total Useful Energy}}{\text{Primary Energy}} - \frac{\text{Useful Energy for Maintenance}}{\text{Primary Energy}} \quad (9) \]

or

\[ \text{General Economic Productivity} = \text{General Physical Productivity} - \text{Net Maintenance Ratio} \quad (10) \]

In accordance with equations (7) and (10) we arrive at the relation

\[ \text{National Income} = \text{Primary Energy} \cdot (\text{General Physical Productivity} - \text{Net Maintenance Ratio}) \quad (11) \]

which leads to far-reaching economic conclusions. It shows that we may increase national income by increasing the total supply of energy (i. e., primary energy),
by improving the efficiency of energy transformation (i. e., physical productivity),
by diminishing the net-maintenance ratio \(^1\), or—of course—by any combination
of these three policies.

In order to see the importance of the concept «general economic productivity
of the national economy in terms of energy», the conceptual problem of pro­
ductivity must be examined in its many aspects. For this purpose it is necessary
to distinguish between the following categories or «kinds of productivity»:
Physical Productivity of a Resource in terms of Matter, or Energy, or Energy
and Matter;
Physical Productivity of a System in terms of Matter, or Energy, or Energy
and Matter;
Economic Productivity of a Resource in terms of Matter, Money, or Money
and Matter;
Economic Productivity of a System in terms of Money or Energy.

In the above classification the term «system» stands for «material system
using resources for production».

*Physical productivity* is thought of ordinarily as a property of a system, and
very seldom as a property of a resource. Characteristic of the physical applica­
tion of the concept «productivity» is the fact that the «subject» of productivity
is considered for itself, i. e., not in relation to other systems or resources.

The *physical productivity of a material system* consists in its efficiency in
transforming energy or matter. It is the capacity of the system to produce a
certain product from a given resource in an unspecified time or in a given time
from an unspecified resource (the other external effects of the production process
being always ignored). The first case is the case of transformation of energy.
Here the simple relation «one resource → one product» holds, and the ratio

\[
\frac{\text{Total Quantity of Product}}{\text{Total Quantity of Resource}}
\]

which expresses the productivity of the system, can be interpreted either as a
«quota» (e. g., useful energy in work as percentage of total energy transferred)
or as an «average product» with reference to resource input (e. g., electricity
in kilowatt hours per ton of coal). The second case is the case of transformation
of matter. The concept of productivity then is tied not to the amount of material
transformed, but to the speed with which the transformation takes place. The
product-resource ratio is an «average product» with reference to resource equip­
ment (e. g., yarn in meters per spindle per hour).

One can speak of *physical productivity of a resource* in the sense of «natural
productivity» or «fertility», which is something absolute, i. e., it does not depend
on the efficiency of the transforming system. This is the content of energy or

\(^1\) The term «net-maintenance ratio» was suggested by P. Stanley King.
of a chemical element in a chemical compound, or the content of a chemical compound in a combination of chemical compounds (e.g., heat of combustion of fuels, nitrogen content of soils, metal content of ores, etc.—per unit of mass).

From the viewpoint of physics, the resource to be transformed is not included in the system and the increase or decrease of its quantity does not affect the system. Since the process of transformation also leaves its composition unaltered (except for wear and tear), the physical productivity of an inorganic system is limited only by the general physical laws. However, when the concept of productivity is applied to living beings, the Law of the Diminishing Increment in Product (ordinarily known as the Law of Diminishing Returns) enters the field. This is due to the fact that the «system», because of its metabolism, changes necessarily with the performance of its functions (the organism grows, ages, and dies). Thus biological productivity is to be considered as a special case of physical productivity of a system. It is the efficiency of living beings to transform food or feed into life maintenance, work, body tissues, and milk, or—physically speaking—to transform chemical energy into useful heat, motion, and chemical energy.

In contrast to physical productivity, *economic productivity* is more often referred to as productivity of a resource than as productivity of a system. But there is another, more important, difference. While physical productivity is not affected by relations of its «subject»—system or resource—to other systems or resources, economic productivity is influenced by the interdependence of economic variables: economic productivity is productivity of resource combinations and interrelated systems. A third difference must also be mentioned: there are physical systems which play the role of resources in economic systems, e.g., equipment units like workers, animals, acres of land, prime movers, electro-generators, machines, furnaces, etc.

*Economic productivity of a resource* is its contribution to a product produced through the cooperation of many resources. Its absolute amount cannot be measured. However, a *change* in the «average product» of a single resource, while all other resources remain unaltered, can be interpreted as a *change* in its productivity. The concept of marginal product, which embodies the condition «ceteris paribus», conveys the same idea.

The economic productivity of an equipment or input unit has a different importance in different resource combinations. The importance is determined by the money value of the resource input relative to the *cost* of production, that is to say, by single cost relative to total cost.

This brings us to the problem of the *economic productivity of a system*, i.e., of a producing unit. For brevity, let us concentrate on the «system of systems»—the national economy.

Within the framework of the national economy the general physical productivity can be defined either as the ratio of two total values, namely

\[ \frac{\text{Total Useful Energy}}{\text{Total Input of Primary Energy}}. \]
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or as an average efficiency, that is to say, as the arithmetic mean of all efficiencies realized in the individual cases of energy transformation, weighted by the primary energy inputs relative to the total input of primary energy. (Here the term «total input» is used instead of «total output» to allow for imports; see page 94.)

Can we similarly treat the general economic productivity, using the exchange (money) value approach?

For a ratio of two total values we have indeed the numerator—the net national product (national income) in terms of money. But what will be the denominator? We cannot add together population and national wealth. Nor can we take the selling value of total output (all gross returns), because the ratio which will be obtained, namely

\[
\text{Total Quota of Net Product} = \frac{\text{Net National Product in money terms}}{\text{Selling Value of Total Output}}, \tag{12}
\]

depends on the vertical integration of production \(^1\).

More consistent, though difficult to apply, appears to be an average-ratio solution. A general index of input coefficients for all resources and all producing units or «industries» (groups of producing units) would show the change in the general economic productivity in money terms, provided that the output quantities have remained the same. Constructed according to the Laspeyres’ formula, for example, the index will be, for the year 1 (base, year 0)

\[
I^{(a)}_{1/0} = \frac{\sum_{i=1}^{mn} \pi_0 q a_1}{\sum_{i=1}^{mn} \pi_0 q a_0} = \frac{\sum_{i=1}^{mn} \pi_0 q a_0}{\sum_{i=1}^{mn} \pi_0 q a_0} \cdot a_1 \tag{13}
\]

where the symbols indicate:
\(\pi\) price of input
\(q\) quantity of output
\(a\) input coefficient, i. e., quantity of input / quantity of output (the reciprocal of «average product») for one resource in one producing unit or industry
\(m\) number of producing units or industries
\(n\) number of resources (kinds of inputs) in each producing unit or industry.

The condition that the output quantities are constant is set up in addition to the assumption that the prices of inputs remain the same while the input coefficients change. It is indispensable. If not fulfilled, no weights for the input

\(^1\) The ratio Net National Product in money terms/Man-Hours Worked, which at present predominates in the empirical analysis of productivity, does not measure either general physical productivity or general economic productivity. Its variations merely express changes in the overall economic productivity of labor, under the condition that the inputs of capital have remained the same.
coefficients can be objectively established—and formula (13) turns into an index of input quantities (q),

$$\mathbf{I}_{1/0}^{(q)} = \frac{\sum_{i=1}^{mn} \tau_0 \varrho_1}{\sum_{i=1}^{mn} \tau_0 \varrho_0} = \sum_{i=1}^{mn} \frac{\tau_0 \varrho_0}{\sum_{i=1}^{mn} \tau_0 \varrho_0} \varrho_0$$  \hspace{1cm} (14)

In both formulas (13) and (14) the first term represents a ratio of a hypothetical and an actual value of total cost. However, the index of input quantities (formula 14) cannot be interpreted as an index of economic productivity, because it reflects not only changes in input coefficients but also changes in output quantities (since \( q = a q \)). Even when all formal conditions are fulfilled, a general index of input coefficients is difficult to interpret, if the input coefficients for labor and those for other resources are moving in opposite directions. To avoid false conclusions, the general index of input coefficients should be split into an index for labor input coefficients and an index for non-labor input coefficients.

Against the background of the logical difficulties and unrealistic assumptions which the exchange value approach raises, the advantages of the energy approach in the exploration of general economic productivity are obvious. The productivity of a national economy is reckoned as its efficiency to transform energy into welfare and life (utility and population) by organized application of physical productivity. The method which the energy approach provides for its measurement is conceptually simple and yields unhypothetical results.

Like biological productivity, economic productivity obeys the Law of the Diminishing Increment in Product (the Law of Diminishing Returns). While the First and Second Laws of Thermodynamics are empirical laws, this law can be rationally derived from the physical (chemical) laws governing the structure of matter; only its parametrical constants have to be found by experiment. It has economic significance, because—economically considered—the resources combined for production belong to the system. A change in any input means a change in the system. Of course, as long as all inputs are increased proportionally, the law is not effective.

III

Economic goods have—in addition to the dimensions mass and time (for flow variables)—three «value dimensions»: exchange value, energy value, and use value. Exchange value per unit of mass or energy is price. Energy value consists of net energy-cost and—in the case of convertible goods—energy content. The use value of consumers’ goods, that is to say of the goods which satisfy human wants directly, consists in their capacity to yield utility or satisfaction, i.e., in the capacity to produce in us pleasure of higher or lower order («appertaining to man’s higher or lower nature» 1).

The relations between exchange value, energy value, and utility follow from the nature of human production and human consumption.

Viewed as a whole, human production is a growing process with no beginning or end: all its phases are simultaneously given. But if we observe what happens to the quantities of energy and matter that enter the process, another picture presents itself. Human production appears then as a stream of energy and matter which begins in physically primary production (crop production in agriculture, mining, production of hydroelectricity, etc.) and ends in human consumption. Human consumption consists of consumption of food and consumption of direct services (end-consumption). At the same time it represents two phases of human production: the production of human work and body substance and the production of direct services (i.e., end-production, which coincides with end-consumption). The production of human work, i.e., the consumption of food, does not belong to end-production, because its products are supplied to all phases of human production, including end-production. The direct services—work performed and useful heat used in personal transportation, radio broadcasting, television, studying, teaching, sports, household services, etc.—satisfy human wants directly and, therefore, yield utility. Like direct services, food also yields utility; as previously mentioned, it also is energy.

From phase to phase of transformation and transfer the stream of energy and matter becomes ever smaller. If we compare the output of direct services with the output of primary energy, we find that the «end-products» represent only a small fraction of the quantity of primary energy which enters the production process.

Thus economic activity can be described as an endeavor to get maximum utility from a given quantity of energy or to get a certain quantity of utility with a minimum quantity of energy. In the long run this can be achieved by improving the efficiency of energy transformation and by diminishing the net-maintenance ratio of the economy (see page 95). In the short run the problem is solved by the mechanism of pricing based on the interplay of prices and money costs.

The great controversies in the history of economics down to Keynes—who gave us the theory of output as a whole and the idea of working with mathematical models based on aggregates—center in the three economic concepts of value. However, seen in historical perspective, the big changes in economic thought from Physiocratism to Early Classicism in the 18th century and from Early to Late Classicism in the 19th century appear to be no revolutions but

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1 So regarded, human production is a part of a cycle called the «cycle of elements» by the chemists or the «cycle of life» by the biologists. The cycle is completed—the link between human consumption and physically primary human production is established—by soil metabolism and plant metabolism. Only chemical elements of organic matter make the full round of the cycle. Inorganic matter and energy leave the cycle during one or another phase of human or natural production.

2 Compare Thomas N. Carver, The Economy of Human Energy, New York, 1924, p. 2: «The problem of living, even in the animal sense, is largely a problem of economizing energy». Carver was one of the first economists to think in terms of energy.
only improvements in the theoretical edifice of economics. The historical merit of Adam Smith was to free economics of what was foreign to it—the elements of ethics introduced by the Physiocrats—and to add what was missing—the insight into the true relations between price («value in exchange»), utility (the correlate of «value in use»), and energy cost («real value», measured in labor). The historical merit of Walras, Jevons, and Menger—beyond Walras' idea of the general interdependence of economic variables—was to introduce the concept of marginal utility into the pure economic theory (in the exploration of economic reality by mathematical model building of today, marginal utility is absent).

From the viewpoint of energy economics, most interesting is Physiocratism. As is well known, the «physique sociale» of the Physiocrats was inspired by the idea that nature, or «land», is the only source of wealth. Since the productive forces of nature are nothing else but energy, Physiocratism can be regarded as a forerunner of the modern energy value theory. The Physiocrats were aware of the fact that wealth (les richesses) has two aspects—income and capital. This again shows how near they were to the modern concept of energy. For, in the final analysis, wealth is energy and energy can be «stored» or «released».

The economists of the Early Classical Period followed the Physiocrats in identifying the original factor of production with a form of energy. However, the one school, born in an agricultural country, attached importance to primary energy (land), while the other, witnessing the rise of an industrial country, attached importance to useful energy (labor). The classical economists followed the Physiocrats also in regarding wealth as both stock and flow. Thus the physical aspect of economic activity was fully realized. Yet two hundred years ago the Law of Conservation of Energy had not been formulated for all forms of energy, and the concept of energy as a physical common denominator had not entered human thinking.

IV

The energy value theory, which studies the dependence of human production on energy, provides us with a new approach to economic problems. This new approach presupposes the existence of national energy balances, based on statistical and engineering data. National energy balances show the sources of primary energy and the uses of useful energy; furthermore they reveal

1 See François Quesnay, «Maximes générales du gouvernement économique d'un Royaume agricole» (1758), in Physiocrates, edited by Eugene Daire, Paris, 1846, Part I, p. 82.
4 What other meaning can there be in the famous words of Adam Smith: «The annual labour of every nation is the fund which originally supplies it with all the necessaries and conveniences of life which it annually consumes»? See The Wealth of Nations, Volume I, edited by E. Cannan, New York, 1904, p. 1.
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the quantitative relations in each phase of energy transformation: from primary energy into secondary energy and from secondary energy (and primary energy for direct use) into useful energy (work, useful heat, living matter). In short, from a national energy balance we can see how primary energy is reduced to national income (useful energy for consumption and growth 1).

The energy approach can be applied to measure economic growth and economic power, to examine productivity, and to foresee changes in location of industries. What now follows is a brief discussion along these lines.

Measurement of Economic Growth and Economic Power. The method which is currently used for this purpose can be described as computation of national income in terms of money of constant purchasing power or as comparison of total net values of output at «constant prices». It is well known from the theory of index numbers that the composite quantity-indices («index numbers of physical volume») rest on two assumptions: that the commodity composition of the price-quantity aggregates is the same in time or space, and that prices are constant (equal) or change (differ) proportionally. These assumptions restrict the validity of the comparisons of national income in terms of money to short periods of time and to countries of very similar economic structure.

In long term investigations of growth and in global comparisons of economic power the energy approach is to be preferred to the money approach. As a measure for both phenomena, the total output or input of primary energy, or useful energy, or work, or the energy content of national income can be taken. In deciding which of these magnitudes to take, one has to consider that the interchangeability of the units (calories, horsepower hours, kilowatt hours, tons of coal equivalent, etc.), i.e., the homogeneity of the substance, decreases, while the insight into the development of the economy increases, proceeding from primary energy to national income.

Total work output has been computed by Read for different countries for 1929 and 1939; further by Dewhurst for the United States for 1850–1944 2. Total input of useful energy has been computed in the U.S. Department of State under the direction of Guyol for all countries of the world for 1937, and, divided into work and heat, by Wagener for Germany for 1937 3. Dewhurst has recently extended his computation to almost a full energy balance of the United States.

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1 Georg Wagener has computed the energy balance of Germany for 1937. It is published in his article «Energiebilanz» in Bergbau und Energie, Vol. 3, No. 8, August 1950. This is the first computation of a national energy balance known to me.


Georg Wagener, op. cit.
for the period 1850–1950. Dewhurst and Wagener also give figures on primary energy input (from the Department of State publication such figures can be obtained by conversion).

The following two tables give an idea of measurement of economic growth and economic power in terms of energy:

### Work Output in the United States
(American Billions of Horsepower-Hours)

<table>
<thead>
<tr>
<th>Sources</th>
<th>1850</th>
<th>1900</th>
<th>1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>10.3</td>
<td>78.5</td>
<td>674.9</td>
</tr>
<tr>
<td>Animate</td>
<td>6.8</td>
<td>21.0</td>
<td>10.2</td>
</tr>
<tr>
<td>Inanimate</td>
<td>3.6</td>
<td>57.6</td>
<td>664.7</td>
</tr>
</tbody>
</table>

Index Numbers

| All     | 100  | 762  | 6552 |
| Animate | 100  | 309  | 150  |
| Inanimate | 100  | 1600 | 18464|

### Primary Energy Input in 1937
(Large calories, i.e., Kg-calories)

<table>
<thead>
<tr>
<th>Total Quantity Per Capita</th>
<th>United States</th>
<th>USSR</th>
<th>China (including Manchuria and Jehol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(American Billions)</td>
<td>5,731 526</td>
<td>1,373 166</td>
<td>389 176</td>
</tr>
<tr>
<td>(Thousands)</td>
<td>44 089</td>
<td>8 030</td>
<td>809</td>
</tr>
<tr>
<td>(Ratio)</td>
<td>55</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Data for useful energy from U.S. Department of State, op. cit., pp. 86–87, 103, converted into primary energy by multiplying by 4.3.

### Analysis of General Productivity
This point will be treated with the help of a concrete example.

During the last hundred years—from 1850 to 1950—the national income of the United States rose «in real terms» from 9.3 to 239 American billion dollars (both figures computed at 1950 prices). This 25-fold rise of the national income was accompanied by a more than 4-fold rise of the total input of labor (from 26 to 113 American billions of man-hours worked). As a result, the average net product per man-hour went up from 34 cents to 192 cents. This change is commonly interpreted as a spectacular rise in «productivity of labor» or even in «national productivity ²». However, it measures neither the general economic productivity of the national economy—since the system does not consist of labor alone, nor the overall economic productivity of labor—since inputs of fixed and circulating capital did not remain unaltered.

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¹ J. Frederic Dewhurst, America's Needs and Resources (revised edition, New York, in press). All data used in this section are taken from this source, unless otherwise indicated.

² Among the few exceptions may be mentioned: Charles E. Young, «Applications and Problems of Productivity Data», Journal of the American Statistical Association, December 1946; Dewhurst (see footnote ¹).
The following tabulation shows how much more the input of nonhuman work has increased than the input of labor and what a small portion labor represents of the total work produced in the United States:

<table>
<thead>
<tr>
<th>American Billions of Horsepower-Hours</th>
<th>1850</th>
<th>1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total work</td>
<td>10.3</td>
<td>674.9</td>
</tr>
<tr>
<td>Human work</td>
<td>1.3</td>
<td>6.4</td>
</tr>
<tr>
<td>Nonhuman work</td>
<td>9.0</td>
<td>668.5</td>
</tr>
</tbody>
</table>

Let us see what really happened, analyzing the economic change in terms of energy.

No data on the energy content of national income are yet available. But we may accept—as a very rough approximation, for the purpose of analysis—that the expenditure of useful energy for consumption and growth rose in proportion to the exchange value of national income (at «constant prices»), i.e., that in 1950 it was twenty-five times as great as in 1850. According to recent computations of Dewhurst (adjusted for maintenance of human and animal organisms), the total input of primary energy increased in the same time from 710 to 9201 million megacalories (i.e., \(10^{12}\) Kg-calories). In other words, it was thirteen times as great in 1950 as it was in 1850. The ratio \(25 : 13 = 1.9\) shows the change in the general economic productivity, since the general economic productivity is measured by the quotient national income / total input of primary energy (see equation (7), page 94). To fix the ideas, let us repeat his in the form of the equations

\[
\begin{align*}
\frac{\text{National Income 1950}}{\text{National Income 1850}} &= \frac{\text{Primary Energy 1950}}{\text{Primary Energy 1850}} \\
\frac{\text{General Economic Productivity 1950}}{\text{General Economic Productivity 1850}} &= 25 = 13 \cdot 1.9
\end{align*}
\]

Dewhurst estimates the general efficiency of transformation of primary energy into work at 8.2 per cent for 1850 and 13.8 per cent for 1950. On the assumption that the efficiency of energy transformation in the production of useful heat was the same as in the production of work (which is known to us), these percentages can be taken to measure the change in the general physical productivity: it amounts to 70 per cent (13.8 : 8.2). Thus we find that the general economic productivity and the general physical productivity increased almost equally: 1.9- and 1.7-fold or 90 and 70 per cent. (The net-maintenance ratio must have risen too; otherwise the general economic productivity would have increased more.)

Basically, the above results mean that the great increase in both national income and average net product per man-hour was due to an enormous influx of

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1 The data given in the tabulation refer to work output, but the difference between work output and work input, due to the losses which occur in inter- and intra-plant transmission of energy, is in this case not relevant.
energy from inorganic sources and to a considerable improvement of the physical productivity—the efficiency of energy transformation.

In other words, «inanimate» mechanical work was substituted for labor on a tremendous scale, and productivity of labor—even if it did increase, as expressed in greater skill and greater effort—cannot be credited with the large increase in national income.

V

Social welfare is both physically and psychologically determined. We have to deal here with its physical determination only.

Utility has been defined (see page 98) as the feeling of pleasure—of higher or lower order—which accompanies the satisfaction of a human want, the fulfillment of a human desire. In this sense (not in the sense of usefulness, in which the word is used in common discourse), utility is a product of our psychological activity. Ordinarily we consider the consumers' goods, i.e., the goods which have the capacity to satisfy human wants directly, as the only «material» involved in the «production» of utility. We do so in spite of the fact that for the «production» of utility other «resources»—namely work of the internal human organs, useful heat for maintenance of the temperature of the human body, and different substances of the human body cells—are also physically necessary. In the theory of energy value this is accepted, so to say, on «accounting grounds»: the internal work and the heat expended for basal metabolism are charged on the «maintenance account» of the national economy. Speaking of the utility which we derive from the consumers' goods, we disregard the participation of other resources, or rather we assume their «inputs» to be constant. In this case we proceed in the manner of the physiologists who speak of the nutritive value, of the «net-energy content», of foods and feeds, ignoring the role of oxygen («air») and water in the production of work, useful heat, and body tissues.

The utility derived from a consumers' good is a mathematical function of the useful energy which is supplied to the human organism by its consumption (in the case of services this is the whole quantity of useful energy used to produce the service, not only that part of it which acts as «stimulus» upon the senses). This does not mean that utility and energy stand in a constant ratio, so that we could measure the one by the other. What it means is that to a quantity of useful energy, used in end-consumption and consumption of food, a definite quantity of utility corresponds, determined by the nature of the want, its importance for the individual, and the degree of its satisfaction at the beginning of the period observed. The function which describes this relationship may be called utility function in terms of energy.

In the same sense social utility, i.e., the utility derived from all consumers' goods by all individuals, is a function of the useful energy embodied in direct services and food intakes (i.e., of their respective energy contents). If food is considered a producers' good, social utility—«social welfare»—is identical with the «utility content» of national income, i.e., with the utility derived from it, and depends only on the useful energy of the direct services.
In the language of psychology, utility is a product of «integration» and, therefore, lies in the middle of the S-I-R formula of psychological activity, meaning «Stimulation»—«Integration»—«Reaction»\(^1\). It can be approached for quantitative determination from either side—from the side of its effect («reaction») or from the side of its cause («stimulation»). Since utility cannot be measured directly, Marshall suggested that it be determined quantitatively by «its motor force or the incentive which it affords to action\(^2\)», i. e., treated as a cause. It seems more practical to treat utility as an effect and to relate it to the useful energy used in its production.

To consider utility as a cardinal magnitude (i. e., as a quantity), is in complete harmony with the concept of marginal utility, which underlies the demand functions and is a pillar of the theory of general macroeconomic equilibrium. Marginal utility is marginal product in production of utility. In this kind of production we face the problem of allocation of resources as we do in production of economic goods. We have to allocate scarce resources in a plant producing one product in many technical units of different size (ordinarily operated one after another in the manner of fields in rotation). The «plant» is the human organism, the «product» is utility, the «technical units» are the wants, the «resources» are the energies supplied from within and without, as well as the chemical substances of the human body cells. The philosophy of life and the ethics of the individuals play a decisive and independent role in the «production» of utility: they determine—jointly with the physiological factors—the importance of the wants and the «effectivity coefficients», i. e., the «technical coefficients of production».

The utility which a nation derives from direct services and food is a definite, though unknown, quantity. Its ratio to the number of the population, i. e., the «utility per capita», measures the «level of individual utility» or the «average welfare». Now, if the aggregate utility function in terms of energy were known, important conclusions could be drawn as to the future development of the level of individual utility. If the function is logarithmic in character, the level of individual utility is generally bound to rise more slowly than the energy supply. To state it more precisely: with stable general economic productivity, propensity to save, and population, the level of individual utility increases less than proportionally to the total input of primary energy. If the function has the form \(y = k \log_{10} x\), even an economy with stationary population must finally reach the position wherein a doubling of the level of individual utility (\(y\)) will require a tenfold increase in the total input of primary energy (\(x\)). In this formula \(k\) is a structural constant.

The evidence we have so far favors the belief that the utility function—for all human beings and all kinds of consumers' goods—is logarithmic in character.

\(^1\) Whether «pleasure» or «pleasantness» (i. e., utility) is itself a feeling, or only a property of feeling, is a question for psychologists to decide.

\(^2\) Marshall, op. cit., p. 16.
From the *Weber-Fechner Law*—one of the basic laws of psychology, established by Gustav Weber in 1834 and reformulated by Fechner in 1860—we know that, within the limits in which our senses and our nervous system function, the sensation (S) increases in direct proportion to the logarithm of the stimulus (E)\(^1\), i.e., that \(S = k \log E\). But sensations are only an «intermediate product»—a «material» for utility—and, furthermore, ordinarily the stimulus received by the individual represents only a part of the quantity of energy expended to produce it.

We have also the *First Principle of Gossen*—the hypothesis, established by Hermann Heinrich Gossen just a hundred years ago (1854)—which runs as follows ²: «The magnitude of a pleasure decreases steadily, if its indulgence is continued without interruption, until satiety sets in.» By «magnitude» of a pleasure Gossen meant increment per unit of time. This is evident from the arithmetic example and the formula

\[
\frac{dW'}{dE} = \frac{P - E}{\alpha}
\]

which he gives to explain his idea ³.

In the above differential equation the symbols mean:

- \(W'\): total pleasure from all indulgences realized by an individual in a period of time
- \(E\): time actually spent in all indulgences
- \(P\): time to attain satiety in all indulgences.
- \(\alpha\): a structural constant, determined by the initial intensities of pleasures for the individual and his capacity to enjoy the different pleasures over a period of time

Now if we write \(\beta\) for \(1/\alpha\), we obtain

\[
\frac{dW'}{dE} = \beta (P - E)
\]

This formula shows a striking similarity to Mitscherlich’s formula

\[
\frac{dy}{dx} = c (A - y)
\]

---

\(^1\) See Wilhelm Wundt, *Vorlesungen über die Menschen- und Tierseele*, Leipzig, 1922, pp. 43 to 76. Wundt arrives at a simpler definition of Weber’s Law, which amounts to \(S = \log E\), by taking as a unit the sensation which corresponds to the stimulus at the moment when it is expressed by the number serving as the base of the logarithm.


\(^3\) Gossen, op. cit., pp. 18–19.
which expresses the Law of the Decreasing Increment in Product (the Law of Diminishing Returns) in its application to biological productivity in general and to economic productivity of a resource (vegetative factor) in agriculture.

In Mitscherlich's formula the symbols mean:

- \( y \) actual yield
- \( x \) input of the single variable vegetative factor of growth
- \( A \) maximal yield
- \( c \) a structural constant (different for different kinds of vegetative factors and products)

Mitscherlich's formula designates marginal product in terms of the yield in agricultural production and animal husbandry (growth of plants and animals). Under the condition that consumption is uniform in time, Gossen's formula represents marginal utility in terms of the resource or in terms of time (\( P \) and \( E \) being thought of as useful energy or time).

Let us define \( \frac{dy}{dx} = e \) and \( \frac{dW'}{dE} = \omega \). Then we have—since \( A \) and \( P \) are parametrical constants—the following straight line equations:

\[ e = cA - cy \]  \hspace{1cm} (18)

and

\[ \omega = \beta P - \beta E \]  \hspace{1cm} (19)

According to formulas (16) and (17), the marginal physical product (\( e \), the increment of yield per unit of resource) is proportional to the yield increase yet possible (the difference \( A - y \)) while the marginal «psychological product» (\( \omega \), the increment of utility per unit of time or energy supply) is proportional to the time or useful energy yet required to attain satiety (the difference \( P - E \)).

As formula (18) shows, the marginal physical product decreases, while the total product increases. In the same way, according to formula (19), the marginal «psychological product» decreases, while the time of indulgence or—under the condition mentioned—the useful energy supplied in that time increases. In the moment in which the total product reaches its maximum (\( y = A \)) or the time of indulgence is equal to the time required to attain satiety (\( E = P \)), the increment of yield or utility becomes zero.

It would be a common task of psychology and economics to verify the hypothesis of Gossen.

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2 It is the first derivative of the yield function \( y = A (1 - e^{-cx}) \) in terms of \( y \). In terms of \( x \) the derivative is \( \frac{dy}{dx} = Ae^{-cx} \).