Production of exergy from labour and energy resources

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Abstract

An indivisible relation between exergy of labour as well as of the energy resources and real economics are theoretically shown. In discussions on historical changes of productive activities of human beings from agriculture to industries, the proof of the theory of labour and the existence of an upper ceiling on Gross National Product (GNP) are given. The essential role of exergy in the market economy system in terms of productivities of goods, as well as their exchange are discussed.

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1. Introduction

It is well known that the Gross National Product (GNP) and the energy consumption have an extremely close correlation. Its reason and the role of energy in productive activities in economies are theoretically considered in this paper. We will focus on the role of ‘exergy’ from food as well as from the energy resources in the economies.

Exergy is a technical term in thermodynamics defined as the maximum work derived from an energy resource with the atmosphere as the infinitive heat sink. Therefore, the work or the labour itself is the exergy. Thermodynamics tell that exergy is conserved during ideal reversible processes, but it decreases in actual irreversible processes.

Human beings as heat engines acquire surpluses of exergy, or they acquire a larger exergy by intaking food. Similarly, surplus of exergy is generated from...
each energy resource by its burning and conversion to yield a larger exergy than what is required for mining and refining. In this paper, our labour forces and the energy from resources are dealt with exactly the same. It is pointed out that the 'surplus' plays an essential role in economics and since the surpluses are produced physically from food and energy resources, it is presumed that they reflect the real economics.

A framework for the classical labour-value theory is formulated and developed, with exergy from energy resources taken into account. The historical changes of economies of human beings, from the primitive society to the industrialized one with much energy consumption are explained with this framework. The overall productivity of labour with energy included is defined to derive the GNP as well as the productive function in terms of labour and energy instead of the conventional one with labour and capital. Since only exergy (including our labour forces) can transform materials into products for exchange in the market, it is claimed that exergy should be given a more proper role in the economics.

2. Surplus of exergy acquired from foods

Food produces the surplus of exergy \( \Delta E \) ‘physically’ for human beings. The function of food exists in the fact that we can acquire more exergy from it than that we input to produce it. This function to gain a larger exergy by a certain amount of exergy input does not follow a principle of thermodynamics; but the solar energy enables this because it helps plants grow and makes up for the difference \( \Delta E \). In this paper, we discuss on the labour productivity, advent of the market economy, and the value of labour in agriculture.

2.1. From hunting and food-gathering to agriculture

In ancient times, human lives mainly depended on hunting and food gathering. Before the beginning of agriculture, about 10 000 years ago, the world population was about 4 million. But as soon as intensive agriculture started, the settled society with a class system emerged and the population swelled to above 100 million at around the first century of the Christian era.

A question might be raised: “Why did people migrate from the ‘rich’ society in woods supported by hunting and food-gathering into the agricultural one accompanied with an intensification of labour?” Ponting [1] resolved this by stating that, as the population density of human beings increased, through conquests in food-chain competition, they had no choice but to survive by starting the denser usage of land to support their population. In short, the population pressure brought out the agricultural society.

In agriculture, the labour productivity of food production, or doubling rate of labour exergy

\[
\kappa_F = \frac{E_L}{E_F}
\]

(1)
is much higher, though the workload is heavier than for hunting and food-gathering, where $E_L$, exergy gained from food and $E_F$ exergy input to food production.

For Hair Indian in Canada, $\kappa_F$ was given to be 4.6, the San tribe 9.6, and farmers who were breeding horses and cattle at Yunnan province in China 54. As to the individual food gathering, it was 17 for the Machigenga tribe, for garden works, 1.4 and 0.8 for food gathering in the forests [2]. The labour force of the San tribe took 820 h per year to yield 1.15 million calories, while 9.06 million calories were produced by farmers at Yunnan province in China from only 1129 working hours. This shows that the high productivity of labour $\kappa_F$ has been achieved at the cost of intensified labour. Focusing on the productivity of labour $\kappa_F$, we obtain:

$$\kappa_F = 1 + \Delta E/E_F; \text{ where } \Delta E = E_L - E_F$$

From this equation, we can say that the surplus of exergy $\Delta E$ is positive if $\kappa_F$ exceeds unity. It is obvious that if $\Delta E > 0$, people are able not only to gather food but also to increase the population and invest their extra labour into other productive activities. With this extra labour, they could produce tools, houses, cookware, housework equipment, and clothes, partly for the purpose of exchange. As more people started settled lives, the demands for those products increased. It was the beginning of the market economy.

2.2. The value of labour

At the very first stage of division of labour, people might exchange handicraft products such as farming tools, cookware, fabrics, porcelain, food and animals. We can consider that the price of a product was originally dictated by the working hours needed for its production. If a head of deer captured in 1-h hunting is exchanged equivalently with a head of beaver in 2-h hunting, the beaver-hunters feel it a bad bargain and think of changing to achieve more profitable targets.

A relation between food exergy $F$ produced and consumed in society per day is given by [2]

$$F = \kappa_F \alpha_F t_F r_F; \quad \alpha_F = m_F/N$$

where, $F$ = food-exergy from food needed by one person per day (food-cal/capita day), $N$ = number of family members (capita), $m_F$ = number of food producers (capita), $t_F$ = working hours of food producer for food production per day (hour/day), $r_F$ = labour exergy of food producer per hour (labour-cal/hour capita), and $\kappa_F$ = productivity of labour in food production (food-cal/labour-cal).

Eq. (3) relates the exergy of the total labour required for food production (labour cal/day) to the exergy of food (food-cal/day) demanded by the total population per day.

Now, we will add a condition:

$$F = t_F r_F$$

This means that a human being is regarded as an ideal thermodynamic engine, which generates labour a force from food without any exergy loss. This condition
makes it possible to measure the value of labour-exergy (labour-cal) and the value of food exergy (food-cal) on the same scale. Thus we do not have to distinguish between them in this paper.

3. Labour productivity in agriculture and GNP

A change of lifestyle from the migratory life of hunting and gathering to the settled one of agriculture might bring to people a drastic change in their economic lives. Settlement should enable people to possess much more goods which couldn’t be kept before for the sake of easiness of carrying when moving. As agriculture started, the surplus of labour-exergy as well as the demand for goods other than food would increase simultaneously. In response to the increased demand, in amount and variety, the surplus of labour might be appropriated into producing goods other than food. In this process, a division of labour developed to augment activities of production and exchange. These finally would make private possession, storing of articles as well as exchanging goods for money prevail among the economic life of people. Thus the money market economy system manifested itself. We will now discuss production and exchange of the industrial goods and their ‘exchange value’ measured with labour-exergy as the ‘absolute value’ for human beings.

3.1. Labour productivity of agriculture and of industry, and their relation with GNP

Consider two economic sectors: a food-producing sector (typically, agriculture) and an industrial sector producing commodities except food. We have the following equation:

\[ p_G G' = p_G \kappa_G a_G t_G r_G; \text{ where } a_G = m_G / N \]  

where, \( G' \) = quantitative industrial demand (quantity/day capita), \( p_G \) = price (i.e. exchange value) of an industrial product in terms of food value (food-cal/quantity), \( \kappa_G \) = quantitative productivity of labour (quantity/labour-cal), \( m_G \) = number of workers in the industrial sector (capita), \( t_G \) = labour hours in industrial sector per day (hour/day capita), and \( r_G \) = labour exergy of industrial worker per hour (labour-cal/hour capita). The term \( a_G t_G r_G \) shows the amount of labour-exergy input for productive works in the industrial sector.

Now, a condition that workers in both the agricultural and the industrial sectors exchange and acquire both food and industrial commodities equally is written by:

\[ p_G G' = p_G \kappa_G a_G t_G r_G; \quad a_G = m_G / N \]  

This indicates that the industrial products \( G'm_G \) out of the total \( G'N \) are consumed by the workers in the industrial sector themselves and the rest \( G'm_F \) are exchanged to acquire their food \( Fm_G \). Combining Eqs. (5) and (6), we have

\[ \kappa_G t_G r_G = \kappa_F t_F r_F \]
\[ Y = F + G = \kappa_F t_F r_F = \kappa_G t_G r_G; \]  
\[ G = G' p_G; \quad \kappa_G = p_G \kappa'_G. \]  

where the term \( p_G G' = G \) is the exchange value of industrial products measured with the absolute food value (food-cal/capita day) or an amount of food exchanged equally with the industrial products, and \( \kappa_G \) is the ‘qualitative labour productivity’ (food-cal/labour-cal), or the food exergy exchanged equivalently with the industrial products produced by a unit labour-exergy input. In the following sections, the basis of general simplifications \( r_G = r_F = r \) and \( t_G = t_F = t \) are assumed. We will then obtain

\[ \kappa_G = \kappa_F = \kappa \]  
\[ G'/F = \alpha_G / p_G \alpha_F = (\kappa'_G / \kappa_G) \alpha_G / \alpha_F \]  
\[ Y = F + G = \kappa_F L; \quad L = r t \]  
\[ G = \kappa_G \Delta L; \quad \Delta L = L - F / \kappa_F = F (1 - 1 / \kappa_F) \]  
\[ \kappa_F = 1 / \alpha_F \sim 1 / E^*; \quad E^* : \text{Engel’s coefficient} \]

where \( \Delta L \) denotes the net surplus of labour-exergy, and the total value \( G \) of products is obtained from \( \Delta L \) multiplied by the labour productivity \( \kappa_G \) [Eq. (13)]. \( 1 / \kappa_F \) is a fraction \( F / Y \) or the Engel’s coefficient and \( \alpha_G \) and \( \alpha_F \) are assumed to involve each dependent family members, thus \( \alpha_G + \alpha_F = 1 \).

From these equations, we can draw some important conclusions. First, Eq. (10) explains that those commodities produced at a cost of equal workload are exchanged equivalently, which gives a proof of the “labour value theory” built by Marx [4] and Smith [3]. Secondly, Eq. (12) indicates that food productivity multiplied by food expense, \( \kappa_F F \), gives a ceiling for the GNP which stands for all food-value of products by all labour inputs. These relations hold regardless of the number of economic agents:

\[ \kappa_G = \kappa_H = \ldots = \kappa_F \]  
\[ Y = F + G + H, \ldots = \kappa_F L. \]

After all, the main suggestion in this section is to adopt labour (=food) exergy as the universal measure of the ‘absolute value’, and \( \kappa_F L \) as the exchange value of labour or the labour value. This is the generalized idea of “labour” by Marx [4] and Smith [3], or “grain” by Ricardo [5] as the measure of value.

3.2. Labour productivity in agriculture

Unlike the quantitative productivity \( \kappa'_G \) of labour in the industrial sector, \( \kappa_F \) is influenced to a great extent by the natural environment. The objects for investing the
labour force are such indirect things as soil, water, and so on, which are not as clear as those in industry: machines and materials. The main purpose of labour is to sow a field with seed, which itself does not require a high labour force, but just to support the operation of mothering nature where right timing with the climate and weather conditions plays a crucial role. Nonetheless, it is doubtless that the surplus of labour force over that to produce food to support the population is what produces industrial products.

As the growing population causes decreasing marginal returns from land, i.e. people might have to go farther to obtain food, or they are forced to use poorer soils, \( \kappa_F \) will decrease finally to unity. At this point, people must work just for living without rest; it is impossible for them even to preserve the human species. Therefore, the very minimum condition for a species to preserve and to keep economic activities is given by \( \kappa_F > 1 \). From Eq. (14), an approximate value of \( \kappa_F \) can be estimated using data for \( \alpha_F \). In Japan, \( \kappa_F \) was estimated to be 1.6 in 1900 [6], while it was 1.7 in Choshu-han (feudal domain) in the 1840s, since Edo-era statistics tell that final consumption was 57 thousand Kan (unit of weight equivalent to 3.75 kg) of silver coins in the agricultural sector and 44 thousand Kan in the non-agricultural sector [7].

3.3. Intensified agriculture by intensification of labour: the usage of oxen and horses

The usage of oxen and horses in agriculture holds a significant meaning from exergy-economic point-of-view. When society was supported only by hunting and food gathering, there was no sense of possession and all gathered foods were distributed to people according to their needs without considering their ability to hunt. However, in the agricultural society, the division of labour as well as the sense of possession arose. Finally a farmer ‘A’, for example, might have succeeded in possessing and utilizing other labour forces, e.g. oxen and horses to improve productivity. This usage of other labour forces differs from the primitive usage of wild plants and animals in respect that it is an expansion of workload which only the farmer ‘A’ enjoys as a part of his own labour force. Outwardly, the workload of the farmer ‘A’ increases by \( k(> 1) \) times; thus, in the same working hours, farmer ‘A’ can produce more than farmer ‘B’ who does not own oxen and horses. Though the total amount of labour-exergy input by ‘A’ is a sum of workload of ‘A’ himself and of the oxen and horses, the latter is left out of consideration to result in an apparent gap between the productivities of farmers ‘A’ and ‘B’. The usage of oxen and horses is, in nature, an increase of the substantial workload input or an intensification of labour, but it additionally means an improvement of the superficial labour productivity attributed to ‘A’.

4. Usage of exergy from energy resources in productive activities

Similarly to that for food, the surplus \( \Delta E \) of exergy is generated ‘physically’ from each energy resource by its burning and converting to yield a larger exergy than that required for its mining and refining. This function of producing a surplus of exergy makes it possible to position energy resources as the inherent means of producing a
surplus of exchange value, just as food does. We will describe, in this paper, the relation between labour-exergy and resource-exergy in productive activities, GNP and the production function.

4.1. Distribution of exchange value of exergy from energy resources

Exergy can be treated as a commodity, which has an exchange value in itself. In the process of being mined, burnt and converted, energy resources produce a surplus of exchange value \( e \Delta E \) (\( e \): price of exergy from energy resources, food-cal/ resource-cal). To see how \( e \Delta E \) is distributed, we follow a unit of electricity \( Z \) kWh/kg generated from 1 kg of an energy resource. Take a society composed of people engaged in mining, refining and electric companies, where only exergy is the commodity to be produced and consumed.

First, the refinery sector buys the mined resource at a cost \( C_1 = eX + \Delta_1 \), where \( X \) is the exergy input (kWh/kg) to mine 1 kg of resource, \( \Delta_1 \) is the profit of the mining sector. Then the refinery sector put the price to its product \( C_2 = C_1 + eY + \Delta_2 \) to sell to the electric company, adding the cost of exergy input \( Y \) to refine and the profit \( \Delta_2 \). Finally, the electric company gains its profit \( \Delta_3 = eZ - C_2 \) by selling the net generated electric power \( Z \) valued at \( eZ \). Through this process, the total profit gained by society is \( \Delta = \Delta_1 + \Delta_2 + \Delta_3 = e \Delta E \); \( \Delta E = Z - X - Y > 0 \), thus all surplus exergy generated \( \Delta E \) from the energy resource is transformed into a surplus of exchange value \( e \Delta E \), which is distributed to all members of society. Notice that none of the profit is shared by the energy resource itself, unlike the case of labour.

4.2. Relation between labour exergy and the thermodynamic exergy from energy resources

Primitive systems for a master to avail himself of external exergy appeared in the notorious slavery mode of production where slaves were driven hard to supply power, or in labour-intensive industries where workers were forced to repeat monotonous tasks simply as a part of an assembly line. The systematization of labour, or the substantial labour intensification, enabled the master to achieve high productivities.

Smith [3] pointed out that the division of labour is a very important way of improving labour productivity by taking a pin factory as famous example. Such a labour-intensive method as the division of labour in industrial production uses workers just like machines, or heat engines, which run on food as the fuel. A worker, as a machine, generates power from food; this power is nothing but the ‘work’ or exergy in thermodynamics’ terminology. The division of labour brings advantages to the productivity partly because it saves useless motions of workers, which do not contribute to productive activities, and partly because it can increase the intensity of input exergy. In other words, increases in efficiency and intensity of labour increase the quantitative productivity \( \kappa_G \).

The same effect is expected to be taken from the usage of tools. When using tools, the input exergy is large and concentrated on productive activities. There are various
kinds of tools such as gears, hammers, bows and saws, but whichever tools are
applied for production, the power given to a certain working tool is just a transfor-
mation of an original exergy input. For this reason, we can conclude that labour
exergy is exactly thermo-dynamic exergy as we investigate how momentary labour
acts. On the stage of early industrialization, the division of labour as well as usage of
tools improve the labour productivity, which is considered to be the main driving
force to increase GNP.

4.3. Labour productivity in industry

In response to increasing demand for goods other than food, human beings
introduced machinery to avail themselves of exergy from energy resources.
Like the case of the improvement in agriculture with oxen and horses, only human
beings enjoy economic profits from this progress. Enhancing productivity by using
exergy from energy-resources is one of the general means of increasing productivity
by using external exergy, with substantial labour increases and/or its intensification.
Here the machinery, as the capital in industry, correspond to the tools in hand manu-
ufacturing. Through industrialization, human beings developed this mode of produc-
tion: labour exergy plus tools into a mode similar to exergy from energy resources plus
machinery or capitals to yield increases in overall labour productivity.
Noteworthy is the function of the industrial sector to digest the surplus absolute
labour value produced in the agricultural sector and to convert it into an exchange
value. In other words, manufactured commodities are to be produced, attached with
an exchange value high enough to be exchanged for food or absolute exchange value
in the market. Manufactured commodities are valuable only when they meet con-
sumers’ demands, but the total value produced in the industrial sector never exceeds
what is produced in the agricultural sector. Of course, it is possible to increase the
“quantitative productivity” by the usage of tools and machinery or by the division
of labour. However, the basic principle of the labour value theory works after all,
and the industrial goods produced in a certain period shall be exchanged with ones
produced in the same “labour hours”.

4.4. Input of exergy from both labour and natural energy resources

We have revealed that we do not have to make any distinction between exergy
from energy resources and labour exergy in productive activities, though they have
to be distinguished in the exchange market. Therefore, to express the overall pro-
ductive activities in economies, it is enough to add the contributions of exergy from
energy resources and of labour exergy in a similar manner by introducing their
productivities $\kappa$ or $\gamma$. Thus, we have

\[
p_jK'_j = K_F
\]

\[
Y = \sum_j G_j = K_F L = \kappa_F L + \gamma_F E
\]

\[
\alpha_j = G_j / Y.
\]
where, $E =$ total input exergy per capita (resource-cal/capita day), $\alpha_j =$ number ratio of labour force in $j$-sector, $K_j =$ overall quantitative productivity in $j$-sector with usage of energy resources (food-cal/total exergy input), $\kappa_{aF} =$ average productivity of labour in productive works (food-cal/labour-cal), and $\gamma_{aF} =$ average productivity of exergy-from resources in productive works (food-cal/resource-cal).

Here, for the sake of simplicity, the price of a natural resource is assumed to be as small as zero. The general discussions is given by the author [8]. As a result, we can presume that the gross national product $Y = K_L L$ is increased by a factor $\lambda$ with usage of energy from resources compared with that without energy resources:

$$\lambda = \frac{K_F}{\kappa_F} = \frac{\kappa_{aF}}{\kappa_F} + \frac{\gamma_{aF} E}{\kappa_F L}$$

(20)

$$E = E_T \eta \theta$$

(21)

where, $E_T =$ total consumption of primary energy (energy-cal/capita day), $\eta =$ thermal efficiency (–), and $\theta =$ ratio of total energy consumption into the industrial sector (–).

The formulations presented here are based on a simplification that the entire population of society is engaged in one of the productive sectors; deductions are made appropriately with using averaged values. As the basal metabolism of human beings is about 100 W per capita, and its enduring thermal efficiency is about 18%, we will adopt a value $L \sim 20$ W per capita here for an average “strength” of the labour force.

As for exergy from natural energy resources, it is necessary to consider the efficiency of conversion from thermal energy to average exergy input. Since, in Japan, primary-energy consumption per capita in 1980 was 4.7 kW/capita and about 55% was allotted to the industrial sector [9], we can estimate $E = 4.7 \times 0.55 \times \eta \sim 780$ W to yield $E/L \sim 40$, where $\eta \sim 0.3$ was assumed. Therefore, the increase in the gross net production due to energy usage is estimated to be

$$\lambda \sim \frac{\kappa_{aF}}{\kappa_F} + 40 \frac{\gamma_{aF}}{\kappa_F}.$$  

(22)

To proceed with our discussions more in detail, we might need to find the net exergy embodied in commodities through productive activities. This net exergy must be the work, in the strict sense of thermodynamics, which is exerted on materials to cause structural changes or motions, or to convert mechanical energies into electricity. However, since it is next to impossible to follow these very accurate flows of exergy, we adopt the total exergy input in the industrial sector, as we did for labour-exergy. The deviations from the exact exergy input into the objects are thus included in the productivity of exergy.

4.5. Relation between GNP, energy elasticities and the production function

As an estimation of $\kappa_{aF}$, we will make use of the productivity of labour in agriculture. Also, we assume $\kappa_{aF} \sim \kappa_F \sim 1.6$, with a supposition that the productivity of labour at the present time of mass energy consumption is equal to that before it appeared, say in 1900.

As for $\gamma_{aF}$, we also will use the productivity in agriculture. Utagawa [10] estimated that the ratio of the output to the input energy in paddy-rice cultivation was 0.38 in
1970. To apply it to our estimation of $\gamma_{aF}$, it is necessary to convert both the input and the output energies into exergies. Since the output exergy of rice is equal to the labour force generated from its ingestion, the output energy is multiplied by its efficiency (0.2) to convert it into exergy. On the other hand, as for the input exergy, we need to subtract human power from the total energy input and also to take into account the efficiency of the machinery and energy consumption in chemical fertilizers. Here, we suppose that the conversion coefficient from input energy to exergy is more or less equal to 0.2. Thus we see that $\gamma_{aF}$ is approximately 0.4. As the final result, the following are obtained:

$$\kappa_{aF} \sim 1.6, \quad \gamma_{aF} \sim 0.4. \quad (23)$$

In 1900 in Japan, the real GNP per capita was $810 and it vaulted by 11 times to $8800 per capita by 1979. Since an enormous amount of exergy was consumed during this period, we can presume that the increase of GNP by $\lambda \sim 11$ is realized by the consumption of exergy from energy resources. This leads to $\gamma_{aF} \sim 0.4$ from Eq. (22), which shows good agreement with Eq. (23).

Combining Eqs. (18) and (23), we obtain

$$Y = \kappa_{aF} L + \gamma_{aF} E \sim 1.6L + 0.4E, \quad (24)$$

and from Eq. (24) we have

$$\Phi = \varphi + \xi; \quad \Psi = \psi + \zeta + \sigma; \quad a = \gamma_{aF} E/Y, E = \eta E'. \quad (26)$$

$\varphi = (\Delta L/L)/(\Delta Y/Y)$: labour elasticity against GNP

$\psi = (\Delta E/E)/(\Delta Y/Y)$: elasticity of energy consumption $E'$ against GNP

$\zeta = (\Delta \eta/\eta)/(\Delta Y/Y)$: elasticity of efficiency against GNP

$\xi = (\Delta \kappa_{aF}/\kappa_{aF})/(\Delta Y/Y)$

$\sigma = (\Delta \gamma_{aF}/\gamma_{aF})/(\Delta Y/Y)$

$E' = E_t \theta$: energy consumption in the industrial sector.

During the industrialization process after the Meiji era in Japan, people have experienced several big socio-economic fluctuations such as the Russo–Japanese War (1904–1905), World War I (1914–1918) followed by the reactionary depression, and the financial crisis (1927). Nevertheless, from 1880 to 1941, just before the beginning of the Pacific War, real GNP kept growing by 2–3%/year and energy consumption also kept growing by 3–6%/year [9] thus indicating that the increase in energy consumption realized the economic growth. Thus, the elasticity of energy consumption against GNP was as high as $\psi \sim 1.5$ except in 1900 during the economic depression.

Although $\psi$ decreased below unity temporarily after World War II, the “income doubling plan” (1950) brought it up above unity again. From 1960 to 1970, just before the oil crisis, $\psi$ increased to around 1.21, i.e. lower than that before World War II, which continuous efforts made by the manufacturing sector to improve
Fig. 1. Change rate of labour, exergy/capita and GNP/capita during 1965–1993 in Japan.
Fig. 2. Comparison of change rate of actual GNP/capita with evaluated results from Eq. (24).
thermal efficiencies realized. Take the steel industry as an example, the basic unit of energy consumption of electric power (kWh/t-steel) declined by 2.1%/year, while that of crude oil fell to less than one tenth in 10 years. As a whole, the basic unit of energy consumption in the industrial sector kept falling by 0.76%/year during this period.

Then until 1990, through the double oil crises (1973, 1978), ψ had been far below unity (0.1~0.7); the growth of the economy by 4%/year was achieved. Since the average basic unit of energy consumption per unit amount of industrial production declined by 47% during the period from 1973 to 1900 [9,11], it is obvious that serious energy-saving efforts based on improvements in efficiencies made it possible to achieve this low ψ.

By using Eq. (25), the economic growth rate ΔY/Y is evaluated in terms of exergy input. Now Ψ as well as Φ are evaluated as shown in Fig. 1, from 1965 till now because data are easily available and trustworthy, for energy consumption, basic unit of energy consumption against production index and working population [9]. The result is shown in Fig. 2, where a = 0.7 was assumed, as an average value during the period in concern. From the figure, we can see that Eq. (25) shows a good indication of actual growth, despite big economic fluctuations such as the oil crises and the recent bubble economy and its collapse.

One may also observe that Eq. (25) is an alternative expression for the production function, but exergy is used instead of capital as in the conventional Cobb–Douglas production function. As we have seen that exergy well corresponds to the capital there will be no contradiction in this substitution. Actually, those two production functions show a very similar form in the short term. By using a relation ΔY/Y = Δ(lnY) and integrating Eq. (25) with assumptions a, ξ, ζ, σ = constant, we obtain

\[ Y = AE^a L^{(1-a)} = (A\eta^a)E^a L^{(1-a)}; \]  

i.e. a very similar form to the usual Cobb–Douglas production function. It is noted that Eq. (27) clearly shows the factor \( A \), which is simply referred as the technical innovation term, is expressed in terms of efficiency, improvement of productivity or \( A(\xi, \zeta, \sigma)\eta^a \) with an explicit form.

5. Conclusion

We have revealed, in this paper, the essential role of energy from energy resources in our economies, by utilizing a newly proposed, simple framework of economics where labour or food exergy is adopted as the absolute measure of exchange value. Since exergy from energy resources and our labour force are the only origins of surplus of exchange value, the energy from natural resources should be properly be given a more important role in economics, than the conventional one as mere intermediate raw materials. To accomplish all the tasks facing us, protection of global environment, and achieving a sustainable society to withstand the population explosion and increasing individual desires namely, the role of energy in our economic system needs to be understood.
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