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A Consideration on Relations between Exergy and Economics

by

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Abstract

A simple theoretical framework is developed to show the direct connection of exergy with the real economics. The history of economies of human beings, from the primitive society to the industrialized one with much energy consumption is explained within this framework. It is shown that the 'general labor value theory' holds with energy usage taken into account. The overall productivity of labor with energy included is defined. An expression for the production function in terms of labor and energy instead of the conventional one with labor and capital is presented.

Keywords: Exergy, Effective energy, Economics, Productivity, Economical development

Introduction

It is well understood that energy plays an essentially important role not only in our actual economical/political world or in our daily lives, but also in all biological system of lives on earth living under the blessings of the energy from the sun. Looking directly into the fact that, in our economic system, only energy, including our labor forces, can transform materials into products for exchange in the market, energy should be given more proper seat in the economics. In this paper, our labor forces and the energy from energy resources are dealt as exactly the same 'exergy': a term of the thermodynamics, with the meaning of the "effective energy". The classical labor-value theory is formulated and developed, with exergy from energy resources taken into account, to apply to explain the historical changes of productive activities, to evaluate GNP in terms of labor and energy, and to discuss on the role of energy in economics.

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1. Surplus of exergy acquired from foods

Food produces the surplus of exergy ΔE '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 larger exergy by a certain amount of exergy input does not follow a principle of thermodynamics; but the solar energy enables this because it grows plants and makes up for the difference ΔE. In this chapter, we discuss on the labor productivity, advent of the market economy, and the value of labor in agriculture.

1.1 From hunting and food-gathering to agriculture

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

Ponting[1] resolved a question; "What made people move into the agricultural society accompanied with the intensification of labor, from the 'rich' society supported by hunting and food-gathering?" , that it is because people living in the area with high density of population had no choice but to survive in poorer living conditions as human race increased its population through the conquests of food-chain in the nature. In short, the population pressure brought out the agricultural society.

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

$$\kappa_F = E_L / E_F \qquad (1)$$

E_L: exergy gained from food
E_F: exergy input to food production

is much higher though workload is heavier than hunting and food-gathering. For Hair Indian in Canada κ_F was given to be 4.6, San tribe 9.6, farmers who were breeding horses and cattle at Yunnan province in China 54. As to the individual food gathering, it was estimated for Machigenga tribe 17 for garden works, 1.4 for fishing, and 0.8 for food-gathering in the forest[2]. It was evaluated that all labor force of San tribe was 820 hours 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 fact shows that the high productivity of labor κ_F has been achieved at the cost of intensified labor.

Focusing on the productivity of labor κ_F, we obtain an equation:

$$\kappa_F = 1 + \Delta E / E_F; \quad \Delta E = E_L - E_F. \qquad (2)$$

From this equation, we can say that the surplus of exergy ΔE is positive if κ_F is bigger than 1. 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 labor into other productive activities. With this extra labor, they could produce tools, houses, cookware, housework equipments, and clothes for the purpose of exchange. As more people started settled lives, the demand of those products increased. It would be the beginning of the market economy.

1.2 The value of labor

At the very first stage of division of labor, people might exchange handicraft products such as farming tools, cookware, fabrics, porcelain, food and animals. Moreover, if the necessity to hire helpers in constructions or hunting arises, they must have treated labor forces as goods for exchange. We can consider that the price of a product was originally valued in terms of working hours needed for its production as A. Smith manifested. If a head of deer captured in one-hour-hunting is exchanged equivalently with a head of beaver in two-hours-hunting, the beaver-hunters feel it a bad bargain and think of changing to aim more profitable targets.

Harris formulated a relation between food exergy F produced and consumed in society per day as follows[2]:

$$F = \kappa_F \alpha_F t_F r_F; \quad \alpha_F = m_F / N \tag{3}$$

F: food-exergy from food needed by one person per day (food-cal/capita day)
N: number of family member (capita)
m_F: number of food producers (capita)
t_F: working hour of food producer for food production per day (hour/day)
r_F: labor exergy of food producer per hour (labor-cal/hour capita)
κ_F: productivity of labor in food production (food-cal/labor-cal)

The productivity of labor κ_F corresponds to that appeared in eq.(2). Equation (3) relates the exergy of total labor required for food production (labor-cal/day) to the exergy of food (food-cal/day) demanded by the total population per day.

Now, we will add a condition:

$$F = t_F r_F \tag{4}$$

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

2. Labor 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 economical lives, as well. Settlement should enable people to possess much more living goods which couldn't be kept before for the sake of easiness of carrying in moving. As the agriculture started, surplus of labor-exergy as well as their demand for goods other than food would increase simultaneously. In response to the increased demand, in amount and variety, the surplus of labor might be appropriated into producing goods other than food. In this process division of labor developed to augment activities of production and exchange. These finally would make private possession, storing of property as well as exchanging goods with money prevail among the economical life of people, thus the money market economy system manifested itself. In this chapter, we will discuss on production and exchange of the industrial goods and their 'exchange value' measured with labor-exergy as the 'absolute value' for human beings.

2.1 The relation between labor productivity of agriculture and that of industry, Proof of the 'theory of labor', The ceiling of GNP

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

$$p_G G' = p_G \kappa_G' \alpha_G t_G r_G; \quad \alpha_G = m_G / N, \tag{5}$$

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)
κ_G': quantitative productivity of labor (quantity/labor-cal)
m_G: number of workers in the industrial sector (capita)
t_G: labor hours in industrial sector per day (hour/day capita)
r_G: labor exergy of industrial worker per hour (labor-cal/hour capita)

where, $\alpha_G t_G r_G$ shows the amount of labor-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;

$$G' p_G \alpha_F = F \alpha_G. \tag{6}$$

This bargain explains that 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 $F m_G$. Combining eqs.(5) and (6), we have

$$\kappa_G t_G r_G = \kappa_F t_F r_F \tag{7}$$

$$Y = F + G = \kappa_F t_F r_F = \kappa_G t_G r_G; \tag{8}$$

$$G = G' p_G; \quad \kappa_G = p_G \kappa_G'. \tag{9}$$

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 κ_G is the 'qualitative labor productivity' (food-cal/labor-cal), or the food exergy exchanged equivalently with the industrial products produced by a unit labor-exergy input. In the following sections, discussions are made on the basis of general simplifications $r_G = r_F = r$ and $t_G = t_F = t$. We will then obtain

$$\kappa_G = \kappa_F = \kappa \tag{10}$$

$$G'/F = \alpha_G / p_G \alpha_F = (\kappa_G' / \kappa_G)\, \alpha_G / \alpha_F \tag{11}$$

$$Y = G + F = \kappa_F L; \quad L = rt \tag{12}$$

$$G = \kappa_G \Delta L; \quad \Delta L = L - F/\kappa_F = F(1 - 1/\kappa_F) \tag{13}$$

$$\kappa_F = 1/\alpha_F \sim 1/\ddot{E}; \quad \ddot{E} \sim \text{Engel's coefficient} \tag{14}$$

where ΔL denotes the net surplus of labor-exergy and the total value of products G is obtained from ΔL multiplied by the labor productivity κ_G (eq.(13)). Here, α_G and α_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 labor value theory built by K. Marx and A. Smith. Second, eq.(12) indicates that food productivity multiplied by food expense, $\kappa_F F$, gives a ceiling on GNP which stands for all food-value of products by all labor input.

These relations hold regardless of the number of economic agents;

$$\kappa_G = \kappa_H = \text{、、} = \kappa_F \tag{15}$$

$$Y = F + G + H + \text{、、} = \kappa_F L. \tag{16}$$

After all, the main suggestion in this section is to adopt labor (=food) exergy as the universal measure of the 'absolute value', and $\kappa_F L$ as the exchange value of labor or the labor value. This is the generalized idea of labor by Marx and Smith, or grain by Ricardo as the measure of value.

2.2 Labor productivity in agriculture

The labor productivity in agriculture κ_F is an important factor, which defines the scale of economic activity, population ratio among industries, Engel's coefficient and so on. The productivity of labor in industry κ_G and that in agriculture κ_F will eventually agree in the long term even if they temporarily deviate from each other.

Unlike the quantitative productivity of labor in the industrial sector κ_G', κ_F is influenced to a great extent by natural environment. The objects to invest labor 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 labor is to saw a field with seed which itself does not require high labor force, but just to support operation of mothering nature where right timing with the climate and weather conditions plays a crucial role. None the less, it is doubtless that surplus of labor force over that to produce food to support the population is what to produce the industrial products.

As the growing population causes decreasing marginal returns from lands, i.e. people might have to go father to obtain food, or they are forced to use poorer soils, κ_F will decrease finally to 1. At this point people must work just for living without rest; it is impossible for them even to preserve human species. Therefore, the very minimum condition for species to preserve and to keep economic activities is given by $\kappa_F > 1$.

From eq. (14) an approximate value of κ_F can be estimated using a data of α_F. In Japan, κ_F was estimated to be 1.6 in 1900[3], while it was 1.7 in Choshu-han (feudal domain) in 1840 's, since a statistics on Edo-era tell that final consumption was 57 thousand Kan of silver coins in agricultural sector and 44 thousand Kan in non-agricultural sector[4]. These levels of κ_F are so low that the industrial products as much as only 60–70% of food could have been provided in the market, though in the current market in Japan is presumed to be more than 10 times of food.

2.3 Intensified agriculture by intensification of labor, the usage of oxen-and-horses

The usage of oxen-and-horses in agriculture holds a significant meaning from exergy-economical point of view.

When the 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 of hunting. However, in the agricultural society the division of labor as well as the sense of possession arose. Finally a farmer 'A', for example, might have succeeded to possess and utilize other labor forces: oxen-and-horses to improve his productivity. This usage of other labor 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 labor force. Outwardly, workload of the farmer 'A' increases by $k (> 1)$ times; thus, in the same working hours, the farmer 'A' can produce more than a farmer 'B' who does not own oxen-and-horses. Though the total amount of labor-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 among productivities of the farmers 'A' and 'B'. The usage of oxen-and-horses is, in nature, an increase of the substantial workload input or an intensification of labor, but it additionally means an improvement of the superficial labor productivity attributed to 'A'.

3. Surplus of exergy from energy resources

Similarly to food, surplus of exergy ΔE is generated 'physically' from each energy resource by its burning and converting to yield larger exergy than that required for mining and refining. This function of producing the surplus of absolute exergy value makes it possible to give the position to energy resources as the inherent means of producing the surplus of exchange value, just as food does. We will describe, in this chapter, the relation between labor-exergy and resource-exergy in productive activities, GNP and the production function.

3.1 Improvement of productivity by division of labor and tool using

Primitive systems for a master to avail of external exergy other than that of himself appeared in the notorious slavery mode of production where slaves were driven hard to supply power, or in labor intensive industries where workers were forced to repeat monotonous load simply as a part of assembling line. Those systematization of labors, or the substantial labor intensification, enabled the master to achieve high productivity of labor.

A. Smith pointed out that the division of labor is a very important way to improve the labor productivity by taking a pin factory as the famous example. Such a labor intensive method as the division of labor in industrial productions 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 as the thermodynamics' terminology. The division of labor 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 intensity of input exergy. In other words, increases in efficiency and intensity of labor increase the quantitative productivity κ_G'.

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

3.2 Distribution of exchange value of exergy from energy resources

Exergy can be treated as a commodity which has exchange value in itself. In process of being mined, burnt and converted, energy resources produce 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 the 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: the exergy input (kWh/kg) to mine 1 kg of resource, Δ_1: 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 Δ_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 gifted to the society is $\Delta = \Delta_1 + \Delta_2 + \Delta_3 = e\Delta E$; $\Delta E = Z - X - Y > 0$, thus all surplus of absolute exergy value generated from the energy resource ΔE is transformed into an surplus of exchange value $e\Delta E$ which are distributed to all members of the society. Notice that none of the profit is shared by the energy resource itself here unlike the case of labor.

Now it is clear that what food is to human beings corresponds to the energy resources to the society. But, what makes the latter relationship special is that human beings utilize ΔE from the energy resources and convert it into the surplus of exchange value as if it all belongs to them. In other words, by using energy resources, human beings as the thermodynamic engine make firm and amplify their own functions to create the exchange value from labor. Actually, human beings convert the surplus of exergy value from natural resources ΔE into an exchange value larger than $e\Delta E$, as discussed in later sections.

3.3 Labor productivity in industry

In response to increasing demand for goods other than food, human beings introduced machinery to avail of exergy from energy resources.

Like the case of improvement in agriculture with oxen-and-horses, only human beings enjoy economical profits from this progress. This explains that enhancing the productivity by using exergy-from-energy-resources is one of the general forms of increasing the productivity by using external exergy, with substantial labor increase and/or its intensification. Here the machinery, as the capital in industry, correspond to the tools in hand-manufacturing. Through industrialization, human beings developed the mode of production: labor-exergy-plus-tools into a mode: exergy-from-energy resources-plus-machinery or capitals to yield increase in overall labor productivity.

Noteworthy is that the function of the industrial sector is to digest the surplus absolute labor value produced in the agricultural sector and to convert it into exchange value. In other words, manufactured commodities are to be produced, attached with exchange value high enough to be exchanged with food or absolute exchange value in the market. Manufactured commodities are valuable only when it meets consumers' demand; 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 usage of tools and machinery or by the division of labor. However, the basic principle of the 'labor value theory' works after all, and the industrial goods produced in a certain labor hours shall be exchanged with ones produced in the same labor hours.

At the transient stage of economy, demand for industrial products exceeds supply and the productivity κ_G in the industrial sector is larger than that in the agricultural sector[5]. Such an excess demand should improve quantitative productivity κ_G' or accelerate the population drift from the agriculture to the industrial sector. The improvement of quantitative productivity in the industrial sector at a transient stage has its significant meaning as far as it materializes the potential value produced in the agricultural sector to meet expanding demand for industrial products. However, this preferable condition will not last long. Soon or later, demand for industrial goods and/or purchasing ability of the agricultural sector will reach its ceiling as indicated by eq. (12).

3.4 Input of exergy from both labor and natural energy resources

Now we have revealed that we do not have to make any distinction between exergy-from-energy-resources and labor-exergy in productive activities, though they have to be distinguished in the exchange market. Therefore, it is enough to add their contributions in the very similar manner with introducing the productivity of exergy-from-energy-resources γ, to express the overall productive activity. Thus, we have

$$p_j K_j' = K_F \tag{17}$$

$$Y = \Sigma_j G_j = K_F L = \kappa_{aF} L + \gamma_{aF} E \tag{18}$$

$$\alpha_j = G_j / Y. \tag{19}$$

E: total input exergy per capita (resource-cal/capita day)

α_j: number ratio of labor force in j-sector

K_j': overall quantitative productivity in j-sector with usage of energy resources (food-cal/total exergy input)

κ_{aF}: average productivity of labor in productive works (food-cal/labor-cal)

γ_{aF}:.average productivity of exergy-from-resources in productive works (food-cal/resource cal)

Here, for the sake of simplicity, the price of natural resource is assumed to be as small as zero. The general discussions will be given in the next chapter. As a result, we can presume that the gross national product $Y = K_F L$ is increased by a factor λ with usage of energy-from-resources compared to that without energy resources:

$$\lambda = K_F / \kappa_F = \kappa_{aF} / \kappa_F + \gamma_{aF} E / \kappa_F L \tag{20}$$

$$E = E_T' * \eta * \theta. \tag{21}$$

E'_T: total consumption of primary energy (energy-cal/capita day)

η: thermal efficiency (−)

θ: ratio of total energy consumption into industrial sector (−)

3.5 Quantitative productivity of exergy in industry in Japan

Since, formulations presented here are based on a simplification that entire population of society is engaged in one of productive sectors, discussions 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 labor 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 4.7kW/capita and about its 55% was allotted to the industrial sector[6], we can estimate $E = 4.7 * 0.55 * \eta \sim 780$ W to yield $E/L \sim 40$ where $\eta \sim 0.3$ was assumed. Therefore, increase in the gross net production due to energy usage is estimated to be

$$\lambda \sim \kappa_{aF} / \kappa_F + 40 \gamma_{aF} / \kappa_F. \tag{22}$$

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

3.6 Labor productivity in industry and agriculture

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

As for γ_{AF} we also will use the productivity in agriculture. Utagawa[7)] 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 γ_{AF}, it is necessary to convert both the input and the output energy into exergy. Since the output exergy of rice is equal to the labor force generated from its ingestion, the output energy is multiplied by its efficiency 0.2 to convert 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 machinery and energy consumption in chemical fertilizers. Here, we suppose that conversion coefficient from input energy to exergy is more or less 0.2. Thus we see that γ_{AF} is approximately 0.4. As the final result, the followings are obtained:

$$\kappa_{aF} \sim 1.6、 \gamma_{aF} \sim 0.4. \tag{23}$$

3.7 Relation between GNP, energy elasticities and the production function

In 1900 in Japan, real GNP per capita was \$ 810 and it vaulted by eleven times to \$ 8800 per capita in 1979. Since enormous amount of exergy was consumed during this period, we can presume that the increase of GNP by $\lambda \sim 11$ is realized by 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

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

and from eq. (24) we have

$$(1-a)\Phi + a\Psi = 1 \tag{25}$$

$$\Phi = \phi + \xi; \quad \Psi = \psi + \zeta + \sigma; \quad a = \gamma_{aF} E / Y、 E = \eta E'. \tag{26}$$

$\phi = (\Delta L / L) / (\Delta Y / Y)$: labor 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 industrial sector.

During the industrialization process after Meiji era in Japan, people have experienced several big socio-economic fluctuations such as the Russo-Japanese War (1904-1905), the World War I (1914) 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

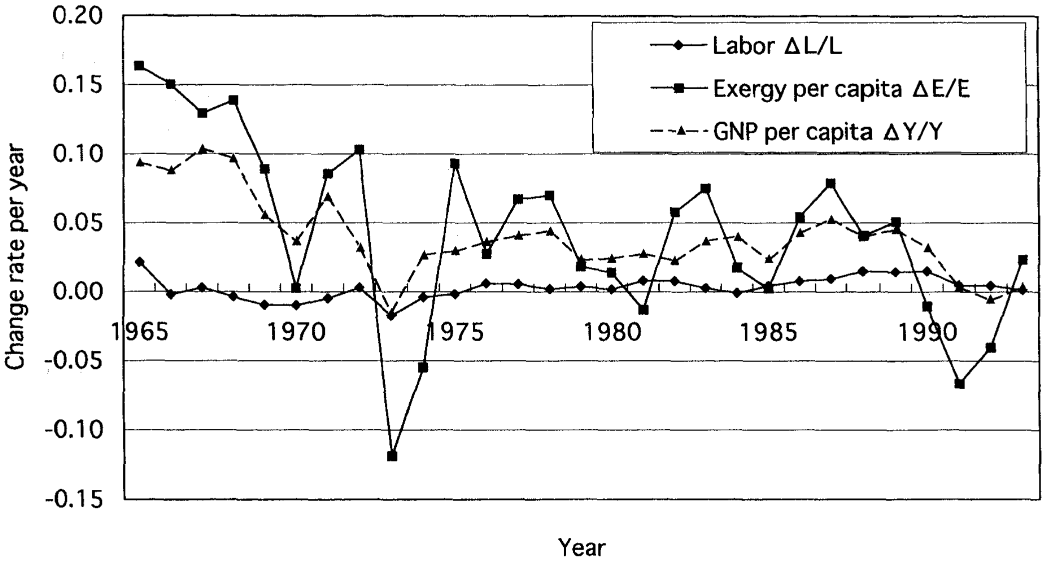

Fig. 1 Change rate of Labor, Exergy/capita and GNP/capita during 1965～1993 in Japan

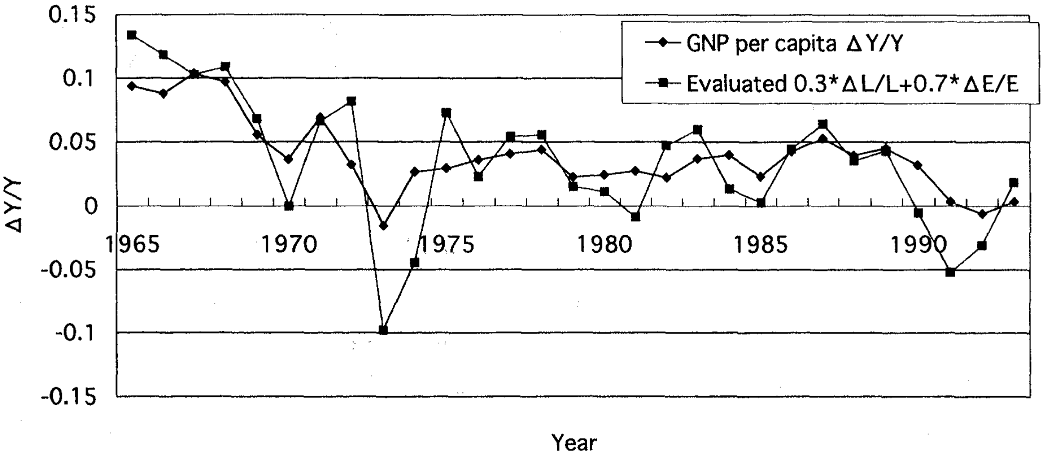

Fig. 2 Comparison of change rate of actual GNP/capita with evaluated results from Eq.(25)

growing by 2-3%/year and energy consumption also kept growing by 3-6%/year6) indicating that the increase in energy consumption realized the economic growth. Thus the elasticity of energy consumption against GNP was as high as ψ～1.5 except 1900 during the economic depression.

Although ψ decreased below 1 temporarily after the World War II, the "income doubling plan" (1950) brought it up above 1 again. From 1960 to 1970, just before the oil crisis, ψ increased to around 1.21, lower than that before the World War II, which continuous efforts made by the manufacturing sector to improve thermal efficiencies realized. Take the basic 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 ten 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 1 (0.1 ～0.7); the growth of economy by 4%/year was achieved, though. Since the average basic unit of energy consumption per unit amount of industrial production declined by 47% during the period from 1973 to 1900[6,8], it is obvious that serious energy-saving efforts based on improvement in efficiencies made it possible to achieve this low ψ.

With using eq. (25), the economic growth rate ($\Delta Y/Y$) is evaluated in terms of exergy input. Now Ψ as well as Φ are evaluated with using data, shown in **Fig. 1**, from 1965 till now because they are easily available and trustworthy, of energy consumption, basic unit of energy consumption against production index and working population[6]. 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 reflection of actual growth despite of big economic fluctuations such as the oil crises and the recent bubble economy and its collapse.

3.8 Production function

One may 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 a short term. By using a relation $\Delta Y/Y=\Delta(\ln Y)$ and integrating eq. (25) with assumptions: a, ξ, ζ, σ=constant, we obtain

$$Y=AE^{a}L^{(1-a)}=(A\eta^{a})E'^{a}L^{(1-a)}; \tag{27}$$

the 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.

4. Energy prices and income level

Although both labor and energy resources can be treated equally in production processes, it is essential to distinguish them in economic activities of exchange. In the market controlled by human beings, the most part of the profit is distributed to the master of labor, or human beings, while none to natural resources. In view of this important feature, let us now consider the relation between the prices of energy and labor, and the reason why energy prices are so low, in our present world.

4.1 Income level in society composed of agriculture and industry

In order to examine the income level, let us suppose a society which consists of two sectors: agriculture and industry. Then eqs.(3)~(14) hold and we recall eqs. (10) and (12) rewritten as

$$\kappa_G=\kappa_F;\quad Y=F+G=\kappa_F L, \tag{28}$$

Introducing w for the unit exchange value of labor, or average income level, we may write, with discrimination among labors of each sector F or G;

$$F=w_F\alpha_F L \tag{29}$$

$$G=w_G\alpha_G L. \tag{30}$$

We can say that w is the total exchange value produced by the labor, which the master of the labor or human beings can control and share in each sector. From these, together with the condition of exchange, we have

$$\kappa_F=\kappa_G=1/\alpha_F=w_F=w_G=w \tag{31}$$

$$Y=F+G=wL. \tag{32}$$

Those results explain that the average income level both in agriculture and in industry are equal at an equilibrium stage. Thus we confirm that, in a completely free market, 'the invisible hand of God' works. Moreover, κ is equal to the income level which is necessarily larger than 1, which corresponds to that the total income wL is enough not only for the expense of daily bread F but also for an additional industrial goods G.

In the advanced system with division of labor, the total profit gained by labors is distributed to the employer income, interests, depreciation cost of capital, tax rates, e.t.c, as the inter-industry table tells. The point of this discussion, however, is that all of the profit shared by all constituents of the society originally stem from labor.

4.2 Society composed of agriculture, industry and energy-related industry

Let us examine a more general society composed of agricultural F-sector, industrial G-sector and energy-related-industrial R-sector; all of them are supposed to consume energy for their productive activities. As we have seen before, the following equations hold;

$$F=\kappa_F\alpha_F L+\gamma_F\beta_F E \tag{33}$$

$$G=\kappa_G\alpha_G L+\gamma_G\beta_G E \tag{34}$$

$$R=\kappa_R\alpha_R L+\gamma_R\beta_R E \tag{35}$$

$$F=L \tag{36}$$

$$R=E. \tag{37}$$

F: exergy from food consumed per capita a day (food-cal/capita day)
E: total exergy input to produce F, G, R (resource-cal/capita day)
R: total exergy produced per capita a day (resource-cal/capita day)
β_K: proportion of exergy input to K-sector (−)
γ_R: productivity of exergy in R-sector (resource-cal/resource-cal)
γ_K $(K\neq R)$: productivity of exergy in K-sector (food-cal/resource-cal)

Equation (33), for example, explains that the same amount of food required is produced with a smaller amount of labor-exergy input than eq.(3) with using exergy from energy resources.

It should be noted that the standard measure for exergy-from-resources in the R sector, 'resource-cal' is not the same to food- or labor-exergy as is for food F or for industrial goods G, 'food-cal'. This is because that the economic agent is only human beings and they exploit all profit produced by exergy-from-energy-resources in the market.

Since the energy-related industries such as an electric company, which converts fuel (thermal energy) into electricity (exergy), are involved in the R-sector, eq.(37) should hold, thus we can regard that all absolute surplus of exergy value produced in the R-sector is distributed and consumed among the society. In the strict sense, however, exergy of resources is unchanged through all transforming processes, just changes its forms from chemical ones to thermal or mechanical ones. Also exergy of oxygen is added through burning or some loss of exergy (dissipation) is accompanied. Therefore, eq.(37) contains a sense of economy, not of the rigid physics, that "fuels are only useful when their energy are released" , together with, to some extent, idealizations to make our discussions simple.

Introducing prices with a measure of food-exergy value, eqs.(33)～(35) are rewritten as:

$$F = w\alpha_F L + e\beta_F E \tag{38}$$

$$G = w\alpha_G L + e\beta_G E \tag{39}$$

$$eR = w\alpha_R L + e\beta_R E, \tag{40}$$

where e is the price, or exchange value, of exergy from energy resources (food-cal/resource-cal), and $e\beta_F E$, for example, stands for its cost to produce food F while all other profit $w\alpha_F L$ is attributed to the master of labor. We suppose here that w is equal among society, otherwise population drift will occur between sectors to equalize the income levels.

Bargaining conditions among industries are given by;

$$(\alpha_R + \alpha_G)F = \alpha_F G + e\beta_F R \tag{41}$$

$$(\alpha_F + \alpha_R)G = \alpha_G F + e\beta_G R \tag{42}$$

$$e(\beta_F + \beta_G)R = \alpha_R(F + G); \tag{43}$$

some of these equations may redundant, though. Eq. (43) explains that the R-industry as a whole purchases $\alpha_R F$ of food and industrial goods $\alpha_R G$ at the same cost by which the agricultural as well as the industrial sectors purchase energy resources from the R-sector. Needless to say, our discussion here do not care about the detailed processes how incomes and each particular product are distributed within each sector.

From equations (38)~(40), we have

$$Y = F + G = wL \tag{44}$$

$$w = 1 + \Gamma = Y/L; \quad \Gamma = G/L, \tag{45}$$

Eq. (45) shows $w > 1$ here again, thus people can afford the expense for both food and the industrial goods. We, also, obtain equations as follows:

$$Y = KL \tag{46}$$

$$K = K_F = K_G = K_R = 1 + \Gamma = w \tag{47}$$

$$K_F = \kappa_F + (\gamma_F - e)\Lambda\beta_F/\alpha_F \tag{48}$$

$$K_G = \kappa_G + (\gamma_G - e)\Lambda\beta_G/\alpha_G \tag{49}$$

$$K_R = e\{\kappa_R + (\gamma_R - 1)\Lambda\beta_R/\alpha_R\}; \quad \Lambda = E/L. \tag{50}$$

From eqs. (46)~(50) we have the alternative expressions for the gross production of value as;

$$Y = \Sigma\alpha_j K_j L = \kappa_{aF} L + (\gamma_{aF} - e)E \tag{51}$$

$$\kappa_{aF} = \kappa_F\alpha_F + \kappa_G\alpha_G + e\kappa_R\alpha_R \tag{52}$$

$$\gamma_{aF} = \gamma_F\beta_F + \gamma_G\beta_G + e\gamma_R\beta_R. \tag{53}$$

We, now, can derive some important results.

First, we obtain the total productivity of labor K_F by subtracting the cost of energy $e\Lambda\beta_F/\alpha_F$ from the apparent productivity of labor:

$$K_F'' = \kappa_F + \gamma_F\Lambda\beta_F/\alpha_F. \tag{48'}$$

Eq. (18) was the limit of eq. (51) where e was negligibly small.

Second, the exergy from energy resources E is exactly an intermediate commodity which does not contribute to the gross national product explicitly. Rather, it contributes to GNP augmented by its productivity γ_{aF} being used to help the activity of labor to produce F+G.

Third, eq.(47) indicates that a 'general theory of labor' holds, even if a plenty of energy is in hand of human beings. It should be added that K_F, the overall productivity of labor in food production, is a measurable index; probably the most important one among K_j's.

4.3 Typical evaluation of energy price

From eq.(50) we have

$$e=K_R/K_R''; \quad K_R''=\kappa_R+(\gamma_R-1)\Lambda\beta_R/\alpha_R \tag{54}$$

With this, we can make a discussion on the reason why energy price is so low compared with labor. As an example, we will make use of data for the coal production, in Japan 1955 for an examination of eq.(54). The statistics[9] tell that $E_0=4.25\ 10^7$ t-coal is produced with $E_R=3.28\ 10^6$ t-coal of energy input per year. Since the productivity of labor in coal industry was $K_R''=12.9$ t-coal per month-worker, it gives $K_R=K_R''\ H\eta/(30\times24\ L\times0.86)\times(N_W/N_T)=840$, where we used values: labor force L=20W, calorific power of coal H=7700 kcal/t-coal, efficiency of thermal plant $\eta=0.205$, workers' number $N_W=274000$, number of persons engaged in the coal industry $N_T=535000$. We have also, $\gamma_R=E_0/E_R=13$ and $\Lambda\beta_R/\alpha_R=\eta(E_R/N)/L=28.3$ (Number of population $N=8.928\times10^7$). Since $K_R=K_F\sim1/\alpha_F$, we have $e\sim1.7\times10^{-3}$, which well coincides with another estimation from actual exergy expenses: $e\sim2.2\times10^{-3}$ (9). Thus we find that the price of exergy from energy resources becomes very cheap, as the productivity of labor in mining industry K_R as well as the multiplication factor of exergy of natural resource γ_R are very large.

In Japan now, however, the most energy resources are imported, thus the price of energy is given dependent on the trade conditions. In such a case, we have eq.(55) to determine the income level or GNP per capita.

$$w=\kappa_F(1-e\beta_F\Lambda)/(1-\gamma_F\beta_F\Lambda) \tag{55}$$

This explains that, as long as $\gamma_F>e$, the more energy consumption in the agricultural sector $\beta_F\Lambda$ increases, the bigger Y=wL is attained. However, if γ_F decreases because of diminishing returns or in the case of energy price increases Y becomes smaller.

Concluding remarks

We could reveal, in this paper, the essential role of energy-from-energy-resources in our economies, with utilizing a newly proposed, simple framework of economics where labor or food exergy is adopted as the absolute measure of exchange value. Since exergy from energy resources and our labor force are the only origins of surplus of exchange value, the energy from natural resources should be properly be given a more important seat in economics, than the conventional one as mere intermediate raw materials. To accomplish all our urgent facing tasks: protection of global environment, and achieving the sustainable society to stand the population explosion and their increasing desire, the role of energy in the economic system is believed to be necessarily puzzled out, theoretically.

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