The Ultimate Dilemma For Artificial Capitals: ever scarcer natural resources claim ever larger artificial capital

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The theory of "Weak Sustainability" has long presupposed a favorable substitutability of artificial capitals for natural resources. However, long-run lavish consumption of fossil fuels brought forth deterioration of reserve quality and of remarked degradation of ERoEI (Energy Return on Energy Investment), which reciprocally implies ever larger artificial capital to be claimed for extraction.

1. Traditional growth theory

Solow (1957) offered a GDP model with a stable growth path like:

$g_Y = A + \alpha g_K + \beta g_L$ (1),

where g_Y denotes the GDP growth rate; A (Solow Residual) or technology concerned contribution to the aggregate production function; αg_K, growth rate of capital and its weight (α); βg_L growth rate of labor and its weight (β)

The Solow Theory says that there can be a stable growth path on the following assumptions. Assumption 1: Capital K and Labor L are entirely substitutable and self-adjusting toward a possible optimum. Assumption 2: "A" term concerned with technological development brings forth the greater part of the GDP growth.

Solow's Growth Theory has come to be considered as questionable because: Assumption 1 (K & L substitution) is doubtful because there is no guaranty that K&L could be flexibly substitutable for the full range. Assumption 2 (the enormous productivity of 'A' term) is doubtful because any actual technology needs a certain hardware consisting of its proper K&L, and an adequate energy (exergy) input.

2. The Transitional Period: 1970s

Meanwhile, *The Limits To Growth* (LTG, 1972) raised an essential problem that the present world economy will meet with dual constraints of natural resource depletion and the environmental degradation. Then Oil Shock 1 took place in 1973 as if to confirm the alarm brought forward by the LTG. However, growth-oriented (majority) economists almost indignantly tried to refute the framework set up by the LTG.

For example Solow (1974) announced his conviction that the growth could retain itself intact despite of any natural resource diminution. In fact he said "If it is very easy to substitute other factors for natural resources, then there is no 'problem'. The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe." Stiglitz (1974) also gave a similar comment against the LTG.

Growth-oriented theories remained untested during the 1970s of the Oil Shock period because the next 1980s brought forward a decade of Oil Glut. And the presupposed 'substitutability' hypothesis between the natural and artificial capitals was exempted of the final test.

3. Historical Depletion of Technological Innovation Seeds

On the other hand, the once flamboyant series of innovative technological progress in the 20th century had virtually ceased in 1973, with the final prize of 'optical fiber' technology. The scientific and technological achievements during 19th and 20th centuries are compiled in Fig. 1. Thus the then popular expectation for the innovative S&T progress failed completely, yet this did not directly caused prolonged stagnation owing to the temporary recovery of oil and other energy supply in 1980s.

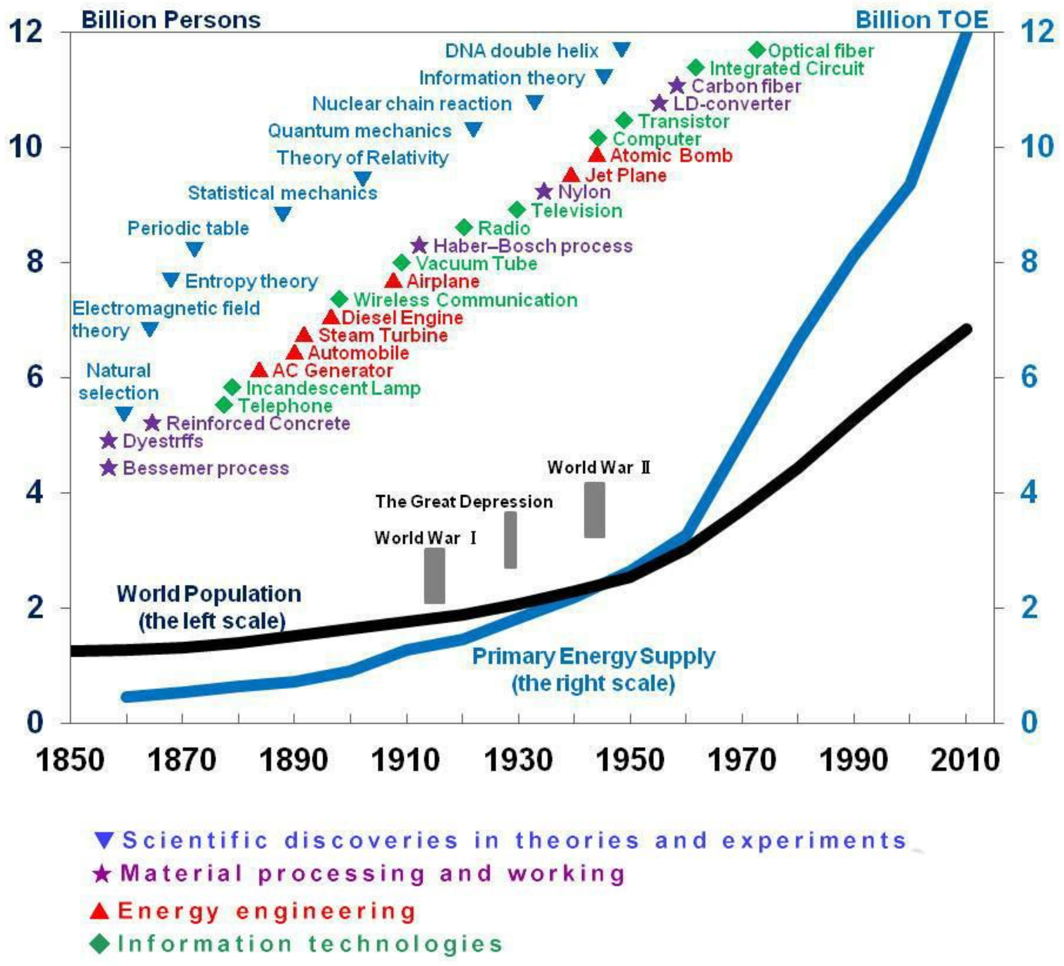

Fig.1 Scientific discoveries and technological inventions of great importance

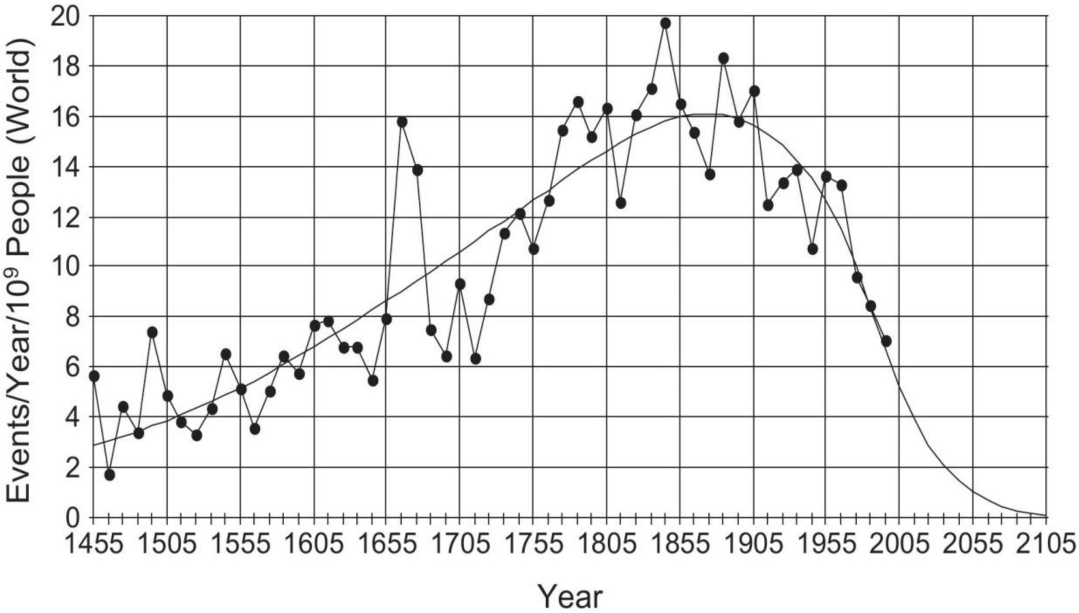

Fig.2 A Declining Trend in the Worldwide Innovation

A more quantitative analysis was given by Huebner (cf. Fig. 2). This chart shows that innovative technological achievement saw a markedly steep decline in the late 20th century. Points are an average over 10 years with the last point covering the period from 1990 to 1999. The smooth curve is a least-square fit of a modified Gaussian distribution to the data.

Tyler Cowen (2011) said, "The average rate of innovation peaks in 1873, which is more or less the beginning of the move toward the modern world of electricity and automobiles. The rate of innovations also plummets after about 1955, which heralds the onset of a technological slowdown. Huebner also shows that, relative to national income or expenditures on education, we are innovating less than in the nineteenth century. Meaningful innovation has become harder, and so we must spend more money to accomplish real innovations, which means a lower and declining rate of return on technology."

4. Primary Energy controls the GDP growth and is controlled by ERoEI

Ayres et al. (2009) offered an epoch making growth theory to reasonably replace that of Solow (1957), giving the following formula:

$$g_Y = \alpha g_K + \beta g_L + \gamma ex \quad (2),$$

where ex denotes the growth rate of exergy supply: exergy = i.e. primary energy times energy conversion efficiency. Condition $\alpha + \beta + \gamma = 1$ corresponds to linear homogeneousness and scale-independence. L/K/ex substitutability is severely restricted. Unlike Solow's 'A' term, the 'γ ex' term of Ayres can be derived from the extant statistical data on primary energy supply and the technical efficiency of energy conversion. Ayres' result is essentially important (a Copernican change to Solow's approach) because it reconfirms the inseparability of growth and primary energy supply (a kind of natural capital).

Heretofore, we have confirmed (1) that the primary energy supply is indispensible and (2) that technology to efficiently use energy is now in stagnation. Besides these serious constraints, there has appeared the ultimate menace against the economic growth in general: the qualitative degradation of primary energy.

Fig. 3 shows the historical trend of ERoEI, Energy Return on Energy Investment.

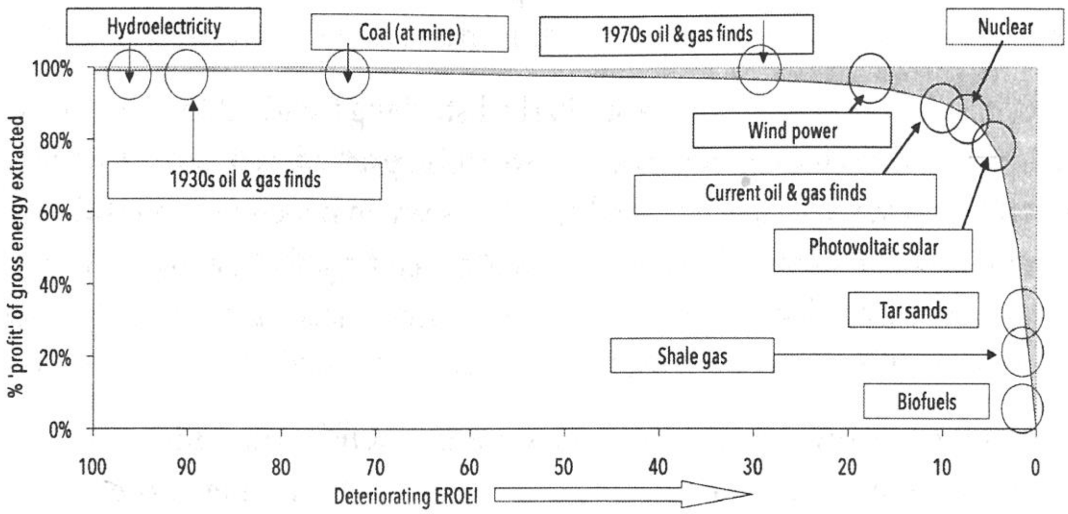

Fig. 3 EROEI for various primary energies (represented in the horizontal scale)

The vertical scale shows corresponding 'profit' which is equal to <acquired energy (in %) – invested energy (in &)>. This ERoEI deterioration directly means that primary energy extraction will need ever increasing reparation of artificial capitals.

In conclusion, this fact is a decisive blow to all the pro-growth theoreticians based on the substitutability of natural resources and artificial capitals. These two are not replaceable but complementary.

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