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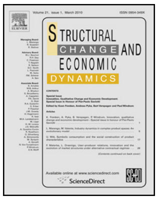

Net energy ratio, EROEI and the macroeconomy

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ABSTRACT

In an input–output model of a two-sector economy (energy and manufacturing), we analyse the macroeconomic implications of the quality of secondary energy production. We measure it by the net energy ratio (NER for short), i.e. the fraction of produced energy available for net final production. NER is shown to be related to the EROEI concept encountered in energy science and to affect (a) the energy intensiveness of final output, (b) the capital requirements of the two sectors of the economy and the aggregate capital–output ratio, and (c) the rate of capital accumulation and the growth rate of the economy at given saving rate. As a consequence, an energy transition characterized by a decreasing NER would exert a drag on economic growth.

1. Introduction

As for any being or system, the existence and development of our societies heavily rely on their ability "to gain substantially more energy than [they] use in obtaining that energy" (Hall et al., 2009, p. 25). If several sources of primary energy (i.e. coal, shale gas or solar energy) remain obviously abundant, the extent to which they can contribute to economic prosperity crucially depends on the ease with which man can transform these primary energy sources into a form of secondary energy useful to the economy. All primary energy sources do not offer the same quality in this respect. In order to assess the quality of an energy source, energy scientists have recently favoured[1] the concept of Energy Return On Energy Invested (EROEI for short). The EROEI of an energy production process[2] is the ratio of the quantity of energy it delivers to the quantity of energy used directly or indirectly by the process. As Cleveland (2008) notes, economies with access to higher EROEI fuel sources (i.e. to energy sources of higher quality) can allocate relatively more of their labour and man-made resources (capital) to other activities than energy production; they so have greater potential for economic expansion and/or diversification.

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[1] See e.g. Hall et al., 2009, the papers in the special issue of Sustainability edited by Hall and Hansen (2011) or Yaritani and Matsushima (2014).

[2] Each time we use the terms "energy production" in this paper, we mean the transformation of a primary energy source into a useful form of secondary energy.

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To the eyes of many energy scientists and energy economists, a declining trend of the global EROEI of energy production seems hardly avoidable. On the one hand, non-renewable energy resources of high quality are progressively depleting and the exploitation of the residual resources is accompanied by a fall in their EROEI, either because their energy density is lower and/or because their processing gets – directly or indirectly – increasingly energy consuming. On the other hand, renewable energies might offer lower EROEI ratios than conventional fossil fuels (see e.g. Cleveland (2004), Murphy and Hall (2010)). Several authors (e.g. Hall et al. (2009)) suspect that a declining EROEI would have negative implications on the prosperity prospects of our societies.

If widely acknowledged in energy economics, the importance of the quality of energy (or of its EROEI) is little studied in macroeconomics.[3] Bridging a gap between these two strands of literature, we analyse the macroeconomic implications of the quality of energy in an input–output model of a two-sector economy (energy and manufacturing). By describing the intra- and inter-sectoral dependancies, the input–output framework makes explicit that a part of the produced energy is absorbed in the intermediary consumption flows and that only a fraction of the produced energy is available for final production. We call this fraction the *Net Energy Ratio* (or NER for short). In an economy that has access to energy resources of high quality, energy production requires relatively little intermediary consumption of energy (either directly or indirectly) and NER is high. We show that NER is a key determinant (a) of the energy intensiveness of final output and (b) of the capital requirements of the economy. This is also a driver of capital accumulation and growth. *Ceteris paribus*, an energy transition characterized by a falling NER increases the capital requirements of the two sectors of the economy and the aggregate capital/output ratio; it simultaneously slows down capital accumulation and economic growth at given saving rate.

Section 2 presents the input–output framework and introduces the concept of NER. Section 3 shows that it is closely related to a concept of enlarged EROEI and affects the energy intensiveness of final production. Section 4 analyses the impact of NER on the capital requirements of the two sectors of the aggregate capital output ratio and on the average productivity of capital. Section 5 highlights its impact on capital accumulation and economic growth. Section 6 summarizes our results.

2. Input–output description of the economy

We consider a continuous time input–output model of a closed-economy consisting of two production sectors: an energy sector (named sector e) and a sector manufacturing other goods and services (named sector y). Sector e transforms primary energy into secondary energy, i.e. a form of energy that can be used in production activities. Variable E denotes sector e output and is measured in units of energy (u.e. in short). Sector y produces intermediary and final products. Variable Q denotes its total output and is measured in units of goods and services (u.g. in short). Both sectors use outputs e and y as intermediary inputs and variable x_{ij} represents the quantity of output i ($i=e, y$) delivered to sector j ($j=e, y$) for intermediary consumption. Sector y also serves final demand and variable Y denotes the quantity of product y sold to final users. The two following equations describe the balance between resources and uses in each sector at time t:

$$E(t)=x_{ee}(t)+x_{ey}(t) \tag{1}$$

$$Q(t)=x_{ye}(t)+x_{yy}(t)+Y(t). \tag{2}$$

$Y(t)$ consists of final (private and public) consumption $C(t)$ and gross investment $I_j(t)$ by sectors $j=e,\ y$: $Y(t)=C(t)+I_e(t)+I_y(t)$ is the gross domestic product. From now on, we will omit the functional argument (t) for notational convenience.

Let a_{ij} ($\in[0, 1]$) be the technical coefficient associated to x_{ij}, i.e.,

$$a_{ie}=_{def}\frac{x_{ie}}{E}, \quad \text{for} \quad i=e, y \tag{3}$$

$$a_{iy}=_{def}\frac{x_{iy}}{Q}, \quad \text{for} \quad i=e, y. \tag{4}$$

Both productions require physical capital. Let K_j be the productive capital stock of sector j and b_j the technical coefficient of capital (or capital output ratio) in this sector, i.e.

$$b_e=_{def}\frac{K_e}{E}, \tag{5}$$

$$b_y=_{def}\frac{K_y}{Q}. \tag{6}$$

Note that Eqs. (3)–(6) are pure definitions which do not rely on any particular technological assumption.

Assuming that capital is sector specific but homogeneous at the sector level, the accumulation equation of sector j writes as:

$$\dot{K}_j=I_j-\delta_j K_j, \tag{7}$$

where δ_j ($\in[0, 1]$) is the depreciation rate in sector j. The time derivative $\dot{K}_j$ is net investment in sector j, i.e. gross investment I_j net of depreciation $\delta_j K_j$.

Using (7), (2) may be rewritten as

$$\begin{aligned} Q &= x_{ye}+x_{yy}+C+\dot{K}_e+\delta_e K_e+\dot{K}_y+\delta_y K_y \\ &= [a_{ye}+\delta_e b_e]E+[a_{yy}+\delta_y b_y]Q+\underbrace{C+\dot{K}_e+\dot{K}_y}_{=_{def}Y_n}, \end{aligned} \tag{8}$$

where the last equality follows from the definitions of a_{ij} (Eqs. (3 and 4)) and b_j (Eqs. (5 and 6)). Y_n is the net domestic product. The first (resp. second) term between square brackets at the right-hand-side of (8) gives the total number of u.g. absorbed by the production process of 1 u.e. (resp. 1 u.g.), fixed capital consumption included. We name respectively $\widetilde{a}_{ye}$ and $\widetilde{a}_{yy}$ these adjusted technical coefficients:

$$\widetilde{a}_{ye}=_{def}a_{ye}+\delta_e b_e \tag{9}$$

$$\widetilde{a}_{yy}=_{def}a_{yy}+\delta_y b_y. \tag{10}$$

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[3] An exception is Fagnart and Germain (2014).