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The underestimated contribution of energy to economic growth

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ABSTRACT

Standard economic theory regards capital and labour as the main factors of production that satisfy the “cost-share theorem”. This paper argues that when a third factor, namely energy, is added physical constraints on substitution among the factors arise. We show that energy is a much more important factor of production than its small cost share may indicate. This implies that continued economic growth along the historical trend cannot safely be assumed, notably in view of considerably higher energy prices in the future due to peak oil and climate policy.

1. Introduction

Virtually all of modern economic growth theory assumes that GDP growth per capita is driven by technological progress and capital investment, including knowledge investment (Romer, 1994; Aghion and Howitt, 1998; Barro and Sala-i-Martin, 2003). The current terminology is “technology-enhanced labour productivity”. Assuming that capital and knowledge stocks accumulate over time, most growth economists as well as politicians take for granted that incomes will increase on average at 2–2.5% p.a. whence our great-grandchildren 100 years from now would be up to 10-times richer than we are today. The standard theory of growth does not take into account energy availability or prices and cannot explain economic declines except as a consequence of reduced labour hours, which usually are a consequence, not a cause, of the decline.

Nonetheless, economic declines (recessions) are a fact of economic life. Most recessions, including the present one, have evidently been caused by a combination of factors, such as an oil price spike, hyper-inflation or the collapse of “bubbles” (Kindleberger, 1989). Given that the “Dot-Com” bubble of 1998–2000 and the real estate bubble of

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2003–2007 were not predicted, or even recognized, by most economists until after the collapse, how much credence can we give to another forecast of smooth growth independent of energy availability? Can we safely assume there are no limits to growth and that our grandchildren will be a lot richer than we are? We argue, on the contrary, that it would be prudent to assume that long-term growth, notably in industrialized countries, may not continue along the historical “track” but may be much slower than in the past.

Various types of evidence support the view that energy is important in economic growth and there is no substitute for energy, though some forms of energy can be replaced by others (e.g. wind power for nuclear power). Stern (2011) provides evidence that substitution between energy carriers has been an important driver of growth in the past but that such substitution has reached its limit. Many econometric studies of aggregate production functions find complementarity or weak substitutability between energy and capital for OECD countries (Berndt and Wood, 1979; Koetse et al., 2008; Fiorito and van den Bergh, 2011). Further support for this comes from so-called biophysical approaches, including system models that give much attention to direct and indirect energy use (Giampietro et al., 2011).

It is fair to mention that there is a branch of growth theory that includes environmental and resource variables (an overview is Smulders, 2005). However, this has not affected the core of growth theory and associated policy debate. Moreover, most growth models with resources exclude realistic constraints on the substitution possibilities between energy and capital. Notable exceptions are d’Arge and Kogiku (1973), Kümmel (1982), Kümmel et al. (2002), Gross and Veendorp (1990), van den Bergh and Nijkamp (1994), Lindenberger and Kümmel (2011). All of these arrive at the conclusion that future growth will be severely hampered by scarce energy and material resources.

Although natural resource prices have fallen more or less continuously since the industrial revolution (Barnett and Morse., 1963; Smith and Krutilla, 1979), there is no guarantee that discovery and technological progress will always compensate for geological scarcity and keep resource prices falling in the future. The price of oil, in particular, is unlikely to fall in the future, regardless of progress in off-shore drilling or extraction from tar sands or shale. Geological scarcity of some resources (notably rare metals available only as by-products of others) cannot always be overcome by increasing prices. Dramatic decreases in the energy return on energy investment (EROEI) since the 1930s suggest that further declines are inevitable as old oilfields are exhausted and drilling moves into ever-deeper offshore waters, and under the Arctic ice (Hall et al., 1986). In addition, recent studies indicate that prices of resources change inversely with EROEI. As EROEI decreases for depleting fossil fuel production, the corresponding energy prices increase King and Hall (2011). All this implies that the resource extraction sector and all contributing activities (production of equipment, transport) must become progressively larger to compensate for this decline, thus “crowding out” other economic activities. By the way, when the EROEI declines to unity, the resource ceases to exist, as such. The changing geopolitical implications of these trends are likely to have significant economic implications, not excluding resource-wars.

Here we will offer additional theoretical and empirical arguments for the view that energy will constrain future economic growth. In particular we will argue that a production function with energy as third factor besides capital and labour is better capable of tracing the pattern of production relations over time. This will then lead to the insight that energy is more important than indicated by its cost share. The policy implication of this is that the likely future scenario of peak oil and stringent climate policy through carbon pricing will cause much pressure on economic growth, and may well mean that past rates of growth are not feasible at all in the future. This argument has received some attention in environmental science and energy studies, but is neglected in economic journals. Our insights suggest that economists should take this argument more seriously and respond to it adequately in a theoretical and empirical sense.

The organization of the remainder of this paper is as follows. Section 2 discusses the neglect of energy in growth studies. Section 3 explains the core problem, namely the misinterpretation of cost shares. Section 4 proposes an alternative production function approach. Section 5 shows that the cost-share theorem no longer holds, if technological constraints on factors are taken into account. Using this insight, Section 6 examines the impact of increasing energy scarcity and higher energy prices on economic growth. Section 7 concludes and offers policy-relevant insights relating to energy efficiency and energy-climate policy.

2. Energy: the neglected factor of production

In standard economic growth theory following Solow, the crucial assumption was that there are only two factors of production that matter, capital and labour. This assumption can be traced to an identity, a stylized fact and an equilibrium condition arising from an old income allocation theorem. The identity is that the GDP is defined as the sum total of payments to capital (interest, dividends, rents and royalties) and payments to labour (wages and salaries). The stylized fact is that the cost shares of capital (30%) and labour (70%) in the US GDP have remained virtually constant for a long time. The income allocation (cost-share) theorem says that the output elasticity of each factor of production must be proportional to its cost share. Since primary energy still accounts for a very small fraction of total factor cost – even after oil price rises – influential theorists have argued that energy cannot be an important source of productivity (Denison, 1979). Moreover, the combination of the cost-share theorem and historically nearly constant cost shares seems to justify the simple standard Cobb–Douglas production function.

There is good reason to doubt that past GDP growth per capita is entirely explained by capital accumulation or non-specific knowledge accumulation, as most growth theorists seem to believe. In the first place, those factors of production rarely, if ever, decline. More important, the