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Energy and economic growth: Grounding our understanding in physical reality ☆

David G. Ockwell *

Sussex Energy Group and Tyndall Centre for Climate Change Research, SPRU, University of Sussex, Freeman Centre, Falmer, Brighton, East Sussex BN1 9QE, UK

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ABSTRACT

This article attempts to summarise the complex, wide ranging and unresolved debate within the economics literature on the possibility of decoupling economic growth from energy use. It explores the difference between neo-classical and ecological economic worldviews and highlights how the ecological economic approach attempts to ground its analysis within the physical limits implied by the laws of thermodynamics. Once these laws are accounted for, the possibility of decoupling economic growth from energy use seems more limited than neo-classical economics implies. Analysis of empirical evidence also demonstrates that observed improvements in GDP/energy use ratios in the USA are better explained by shifts towards higher quality fuels than by improvements in the energy efficiency of technologies. This implies a need to focus on decarbonising energy supply. Furthermore, where energy-efficiency improvements are attempted, they must be considered within the context of a possible rebound effect, which implies that net economy-wide energy savings from energy-efficiency improvements may not be as large as the energy saved directly from the efficiency improvement itself. Both decarbonising energy supply and improving energy efficiency require the rapid development and deployment of new and existing low-carbon technologies. This review therefore concludes by briefly outlining areas of economic thought that have emerged as a result of engagement between economists and experts from other disciplines. They include ecological, evolutionary and institutional economics, all of which can make policy-relevant contributions to achieving a transition to a low-carbon economy.

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1. Introduction

Sustained economic growth is a mantra for governments worldwide and is seen as having a key role to play in poverty alleviation. But economic activity is predominantly linked to the use of energy, principally from fossil fuels, which account for over 60% of global greenhouse gas emissions. This implies an urgent need to decouple economic growth from energy use.

This review provides an overview of our current understanding of the relationship between energy use and economic growth. This understanding is fraught with controversy, particularly between neo-classical and ecological economic viewpoints (Sorrell and Dimitropoulos, 2007). Here I focus on the implications of the difference between neo-classical and ecological economic understandings.

I begin by exploring the differences between neo-classical and ecological economic worldviews and the implied relationship between energy and economic growth, before exploring some empirical evidence on decoupling and the implications of the 'rebound effect'. I conclude by briefly outlining relevant emerging areas of economic thought that have policy-relevant contributions to make towards achieving a transition to a low-carbon economy.

2. Neo-classical views of economic growth

The neo-classical economic worldview sees the economy as a closed system within which goods are produced by inputs of capital and labour, and then exchanged between consumers and firms (red square in Fig. 1). Economic growth is achieved by increasing inputs of labour or human capital. It is also feasible that growth could be achieved by improvements in technology or in the quality of capital and labour inputs. More recently, the role of natural capital in economic growth has also been considered. From the traditional, neo-classical perspective, natural capital consists of renewable and non-renewable natural resources such as water, fossil fuels and primary biological productivity.

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* Tel.: +44 1273 873541; fax: +44 1273 678166.
E-mail address: d.g.ockwell@sussex.ac.uk

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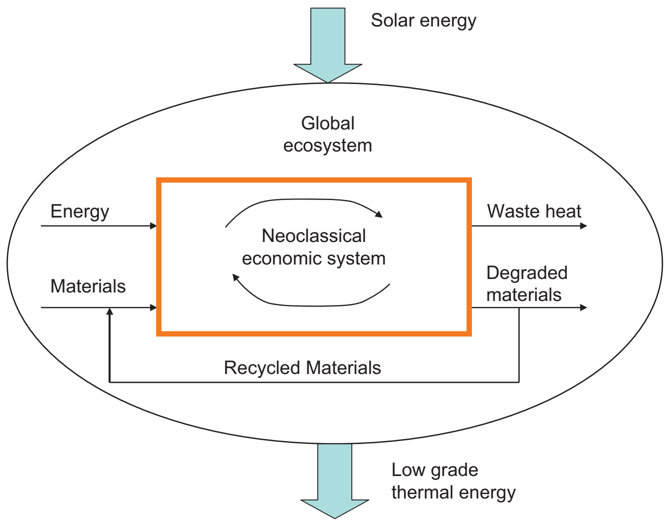

Fig. 1. Opposing worldviews of economic production (based on Hall et al., 1986).

There are essentially three mainstream categories of neo-classical growth models (Stern and Cleveland, 2004). The first focuses on technological change as the only means by which growth can be achieved (Aghion and Howitt, 1998; Solow, 1956; Stern and Cleveland, 2004). All economies grow until they reach an equilibrium level, the point where further returns to capital are no longer possible. Growth beyond equilibrium is then only achievable by increasing returns to existing capital via improvements in technology.

The second category focuses on the consumption of natural capital in determining sustained economic growth. These models assume *a priori* that it is technically feasible to substitute between man-made and natural capital (Stern and Cleveland, 2004). Achieving sustained growth then relies on the correct institutional conditions (including property rights, market structure, means of considering future generations) to ensure that any depleted natural capital is substituted for with the corresponding value of man-made capital.

The final category of growth model considers both natural resources and technological change as determinants of growth. As well as substituting between man-made and natural capital, the possibility of technology improving the output per unit of natural or man-made capital and labour is considered as an additional means by which growth can be sustained (Stern and Cleveland, 2004).

In all three of the above conventional models of economic growth, the contribution of energy to economic activity is only considered relative to its cost within production. In economic terms, the models consider energy to be an 'intermediate good' rather than a 'primary input' into production. In the context of all three of the above models, this implies that decoupling economic growth from energy use is a reasonable possibility, subject, in the case of the latter two models, to various sustainability constraints being conformed to with regard to the consumption of natural capital.

When economists have attempted to calculate economic growth, based on observed inputs of capital and labour weighted by their price, they have found that their models do not match empirical observations. A residual amount of unexplained growth is observed of around 1.2% per year (Simpson et al., 2004). It is therefore assumed that this residual represents technological change and/or qualitative changes in inputs of capital and labour. This assumption, however, is theoretical and has never been proven empirically.

3. The ecological critique—growth and the laws of thermodynamics

Ecological economists criticise the neo-classical worldview as failing to ground economic activity in physical reality. A more realistic view, they argue, is to see the economy as an open subsystem of the global ecosystem (the whole of Fig. 1). This accounts for inputs of natural capital, but takes a broader view of it as including the essential ecosystem services that make human life possible. These include the absorption of waste from economic activity and the maintenance of the climate that facilitates human life. Most importantly, the ecological economists' worldview attempts to account for the laws of thermodynamics.

The first law of thermodynamics, often known as the 'mass–balance principle', asserts that energy cannot be created or destroyed. In the Earth's semi-closed global ecosystem, this means that the only available energy source is solar energy. This can either be used directly, or in an embodied state such as fossil fuels. It also implies that the by-products of the use of embodied energy, such as carbon dioxide emissions from fossil fuels, will be returned to the environment as waste. Solar energy flows into the economic system, and then flows out again into the global ecosystem as low-grade heat and waste. This waste imposes a cost on the environment that is not traded within the closed economic system recognised within the neo-classical economic worldview. The first law also conflicts with two of the three neo-classical economic growth models outlined above, which assume that it is possible to substitute between man-made and natural capital. If the ability of the environment to absorb waste from economic activity is depleted, then the ecosystem services and life-support functions upon which economic activity, and human life, rely may be, and in practice often have been, compromised, sometimes irreversibly. They cannot be substituted for by any corresponding gains in man-made capital. Examples include commercial fish stocks, the provision of clean air, the maintenance of global temperatures and weather patterns, and supplies of clean water.

The second law of thermodynamics, sometimes termed the 'entropy law', implies that while energy and materials can be reused, they will increasingly reach a less useful state, that is, their entropy will increase. It also implies that in order to transform one material to another, additional energy is required. This implies limits to the extent to which energy can be substituted for by other inputs into the production process. At the macro, economy-wide level, this limit to substitution may be even more difficult to overcome. Essentially, in order to manufacture more man-made capital, even without direct reliance on natural capital, energy is required to drive the manufacturing process. Labour is also required, which in turn consumes energy (food and water and often transport, light, heat, etc.). By only accounting for energy in terms of its relative cost within economic production, neo-classical economists may therefore have under-estimated its importance for economic activity.

For ecological economists, energy is a fundamental factor enabling economic production. Some commentators even argue that energy availability actually drives economic growth, as opposed to economic growth resulting in increased energy use (e.g. Cleveland et al., 1984). From this perspective, the possibility of decoupling energy use from economic growth seems more limited.

4. Empirical observations on decoupling

Empirical evidence on economic growth in the USA over the last century seems at first sight to suggest some degree of decoupling. As Fig. 2 illustrates, since the 1940s the amount of

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