Available online at www.sciencedirect.com

SCIENCE DIRECT®

Ecological Economics 55 (2005) 96–118

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

ANALYSIS

A theory of economic growth with material/energy resources and dematerialization: Interaction of three growth mechanisms

Robert U. Ayres[a,b,*], Jeroen C.J.M. van den Bergh[c]

[a]*Department of Physical Resource Theory, Chalmers Institute, Gothenburg, Sweden*
[b]*Center for the Management of Environmental Resources, INSEAD, Boulevard de Constance, Fountainebleau 77305, France*
[c]*Department of Spatial Economics, Faculty of Economics and Business Administration, and Institute for Environmental Studies, Free University, De Boelelaan 1105, Amsterdam 1081 HV, The Netherlands*

Received 20 February 2003; received in revised form 4 October 2003; accepted 26 July 2004
Available online 7 April 2005

Abstract

The nature of energy and material resources in a non-optimizing growth theory framework is clarified. This involves two modifications of the conventional theory. Firstly, multiple feedback mechanisms or "growth engines" are identified, such that the impact of the cost of production through demand on growth is accounted for. Secondly, a production function distinguishes between resource use, technical efficiency, and value creation. The resulting model is analytically solved under the condition of a constant growth rate. Given model complexity, numerical experiments are performed as well, providing relevant insights to the academic and political debates on 'environmental Kuznets curves' and 'dematerialization'.

Keywords: Environmental Kuznets curve; Growth mechanisms; Production function; Structural change; Value creation

JEL classification: O11; O33; O41; Q32; Q43

1. Introduction

It is indisputable that environmental pollution and scarcity of natural resources, as well as public policies aimed at recycling of materials, dematerialization, and increasing energy efficiency, impose certain constraints on economic activity. The nature of those constraints as applied to economic growth is both subtle and contentious, and has been insufficiently addressed in 'applications' of standard growth theory to environmental resources (Beltratti, 1996; Chichilnisky et al., 1997; Dasgupta and Heal, 1979; Pezzey, 1989; Toman et al., 1995). The reason is that these applications

* Corresponding author. Center for the Management of Environmental Resources, INSEAD, Boulevard de Constance, Fountainebleau 77305, France.
E-mail addresses: ayres@insead.fr (R.U. Ayres), jbergh@feweb.vu.nl (J.C.J.M. van den Bergh).

0921-8009/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2004.07.023

remain too abstract in the sense that the adopted model structure allows for multiple interpretations about what is changing in the economy and its physical structure. As a consequence, quantifying for empirical testing and modelling is virtually impossible. This in turn means that existing growth theory with environment and resources does not give rise to theoretical and empirical information that is useful in a debate on structural economic change aimed at reducing the use of energy and materials.

An alternative approach to modelling growth with environment that meets the needs of information for current debates involves at least two modifications of the conventional theory. First, to explain the growth of output, be it in monetary (income) or physical terns, it must reflect the existence of self-reinforcing feedback mechanisms or 'growth engines' apart from population growth and the traditional savings–investment–capital accumulation mechanism. The knowledge-accumulation mechanism proposed by various versions of endogenous growth theory is one candidate, but not the only one. The role of learning and 'experience,' as well as the role of declining natural resource (notably fossil fuel) prices, as drivers of past and present economic growth needs to receive attention in formal models of economic growth. We refrain from using the term 'endogenous growth' because it is too much associated with a particular conception–different from the one here–of 'growth engines.' In particular, it is limited to models that assume–adopting the standard Neoclassical view–that firms always act rationally and that growth occurs in equilibrium. Note in this respect that an alternative approach, namely neo-Schumpeterian theories of growth, has emphasized bounded rationality and lock-in, which cause persistent economic disequilibria (Nelson and Winter, 1982; Dosi et al., 1988). Our study, although not explicitly evolutionary, is more in the latter spirit.

Second, a modified growth theory should explicitly reflect the fact that important (i.e., scarce) factors of production in economics can and do change over time. When non-renewable natural resources were perceived as available without limit (i.e., not scarce), they could be formally regarded as intermediate products of scarce labor and scarce produced capital.[1] However, in the future, as growth continues, both renewable and non-renewable natural resources may become scarce and even limiting, whereas unskilled human labor and produced capital will be increasingly plentiful. This requires a model that explicitly reflects structural change. Such a model would differ from the models in the literature that extend traditional growth theory by including a natural resource or pollution flows and stocks (see Dasgupta and Heal, 1979; Smulders, 1999).

These ideas will be elaborated in a formal model of income growth that includes two major innovations relative to existing growth models. A general production function distinguishes between resource use, technical efficiency, and value creation. In addition, the impact of cost of production on demand and, in turn, on growth is included. The production and demand submodels render separate insights. The combination of the two leads to a complicated model; this will be solved under an extra condition, namely, that the growth rate is constant. The reason for this is not merely complexity, but the belief that optimal growth is not the only, and not even necessarily a relevant, issue to be dealt with in the realm of environment and growth. This is partly related to the aforementioned conception of growth as an out-of-equilibrium process resulting from agents characterized by bounded rationality. The resulting model is capable of generating new insights about questions regarding limits to growth, sustainable development, "environmental Kuznets curves" (EKC), and dematerialization (see van den Bergh and Hofkes, 1998). Up until now, EKC studies have not been based on models allowing for structural change (see Selden and Song, 1994; Stern et al., 1996; de Bruyn and Heintz, 1999).

The organization of this paper is as follows. Section 2 briefly discusses neoclassical growth theory from theoretical and empirical perspectives. Section 3 presents an alternative view on growth, by distinguishing three growth mechanisms. Section 4 presents a related alternative view and formalization

[1] One referee suggested that a more fundamental and longer-term perspective shows that all labor and physical capital result from biological and technological evolution, which has been driven ultimately by the exergy input from the sun into the Earth system. Basing the analysis of economic growth and physical resources on such a fundament is, however, unnecessary for our purpose.