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REXS: A forecasting model for assessing the impact of natural resource consumption and technological change on economic growth

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Abstract

This paper describes the development of a forecasting model in the tradition of system dynamics. It is called Resource EXergy Services (REXS). The model simulates economic growth of the US through the 20th century and extrapolates the simulation for several decades into the next century. The REXS model differs from previous energy–economy models such as DICE and NICE [Nordhaus, W.D., 1991. The cost of slowing climate change: a survey. The Energy Journal 12 (1), 37–66] by eliminating the assumption of exogenously driven exponential growth along a so-called 'optimal trajectory'. Instead, we suggest a simple model representing the dynamics of technological change in terms of decreasing energy (exergy) intensity and endogenously increasing efficiency of conversion of raw material and fuel inputs (exergy) to primary exergy services ('useful work').

In our model, the traditional assumption of exogenous technological progress (total factor productivity) increasing at a constant rate is replaced by two learning processes based, respectively, on (i) cumulative economic output and (ii) cumulative energy (exergy) service (useful work) production experience. The initial results of simulation for the period 2000–2050 have significant implications for future trends in economic output. These implications are important for purposes of scenario analysis. The REXS modules are the focus of ongoing research. We discuss briefly the many possibilities

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for elaboration of each module to enrich the feedback dynamics, policy levers and post-scenario analyses.

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1. Introduction

Integrated assessment (IA) models are at the heart of efforts to assess policies and prospects for the future. The relationships between technological progress, economic activity and global environment are the focus of most of this research. Each model is designed to address different policy questions, for example, to quantify the potential costs of climate stabilisation policies such as the Kyoto protocol (Manne and Wene, 1994; Weyant, 1999), or to assess our ability to meet future energy demands (Nakicenovic, 1993) and maintain future rates of economic growth (Gerlagh and van der Zwaan, 2003). Examples include 'top–down' (or macroeconomic) models, GEMINI-E3, MERGE, CETA, DICE and RICE (Bernard and Vielle, 2003; Manne and Wene, 1994; Manne and Richels, 2004; Peck and Teisberg, 1995; Nordhaus, 1993, 1994a,b); and 'bottom–up' (energy system) models, MESSAGE, DEMETER or FREE (Messner, 1995; Fiddaman, 1998; Gerlagh and van der Zwaan, 2003). Whether bottom–up or top–down, most share a common set of assumptions based on a neoclassical theory of economic growth applied both system dynamics (SD) and computable general equilibrium (CGE) models. We argue in this paper that the neoclassical theory fails to address critical issues relevant to integrated economic modelling and energy forecasting, namely the representation of technological change, and the role of materials and energy consumption in the economy.

Technology has been included in IA models by a variety of methods: (i) carbon emissions reducing, (ii) cost reducing and (iii) output augmenting. In top–down models, technological progress is often only included as an output augmenting coefficient in the production function. DICE is a direct application of the standard neo-classical theory, and provides a typical example[1]. The top–down DICE model (Nordhaus, 1991)[2] was one of the first integrated-assessment models of the economics of climate change, wherein the costs of mitigating climate change today were measured against the future "benefits" to be derived from economic growth. Gross output is given by a two-factor (capital and labour only) Cobb–Douglas production function. Results from his analysis led Nordhaus to claim that global warming might not actually be such a big problem. Some of the assumptions specific to the DICE model were challenged immediately[3] (Cline, 1992; Tol, 1994;

[1] A system dynamics version of the DICE model programmed by Fiddaman (1996), can be downloaded from http://www.sd3.com. It can be simply modified to test alternative theories and policy choices.

[2] An updated version of the model Regional Integrated model of Climate and the Economy-99 (RICE-99) has since been published Nordhaus (1998). Roll the DICE again. The economics of global warming. New Haven CN, Yale University. The major innovation being its regional disaggregation.

[3] Criticisms of the DICE model, which are not the focus of this paper include: the choice and sensitivity of the model to the assumed discount rate (Cline, 1992). The economics of global warming. Washington DC, Institute