Energy Economics 32 (2010) 43–53

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Solow meets Leontief: Economic growth and energy consumption☆

Marcelo Arbex *, Fernando S. Perobelli

Department of Economics, University of Windsor, Windsor, ON, Canada N9B 3P4
Department of Economics, Federal University of Juiz de Fora, Juiz de Fora, MG, 36036-330, Brazil

ARTICLE INFO

Article history:
Received 23 July 2008
Received in revised form 14 May 2009
Accepted 15 May 2009
Available online 21 May 2009

JEL classification:
C67
F43
O13
O41
Q20
Q30
Q40

Keywords:
Growth
Input–output models
Model integration
Natural resources and energy

ABSTRACT

This paper proposes a methodology that integrates a growth model with an input–output model to analyze the impacts of economic growth on the consumption of energy. The integration between the models is carried out by calibrating the growth module, which incorporates energetic inputs (renewable and nonrenewable) in the production function, and implementing shocks by the supply side (capital, labor, renewable and nonrenewable energy) in the input–output model. This allows us to verify the pattern of energy consumption for each sector in the input–output matrix. We apply this methodology to study the energy consumption of eleven economic sectors in Brazil, using data from the Brazilian National Accounts and Input–Output Matrix (IBGE) and the National Energy Report (BEN). We conduct experiments involving changes in technological progress growth rate, extraction and regeneration rates of both renewable and nonrenewable resources and population growth to analyze the impact of changes in the parameters of the model on the sectoral output growth rate and, consequently, on the consumption of energy in each economic sector.

1. Introduction

The relationship between energy use and output growth has received increasing attention in recent years. While energy is an essential input for growth and development in modern economies – economic production uses both renewable and nonrenewable resources as sources of energy – energy use is also expected to be a limiting factor to economic growth, as other factors of production such as labor and capital cannot do without energy. Limited natural resources imply a serious drag on growth that may eliminate most or all of the positive influence of technological progress on income per capita. However, the use of renewable resource may allow a sustained growth despite natural environment limitations. It can also be argued that the impact of energy use on growth will depend on the structure of the economy, energy intensity and the stage of economic growth of the country concerned. Moreover, if energy use and environment policies affect the rate of productivity and the growth of the population, they will also have effects on long-run growth.

The process of economic development has involved a strong growth of energy demand. Economic growth is a critical determinant of demands for energy and growth projections are essential for estimates of future demand and supply of energy. However, the expansion in energy consumption concomitant with economic development can potentially create serious problems. For instance, the growth in industrial production can place a severe strain on available domestic energy supplies, which in turn can lead to high energy prices domestically or an increase in imports of energy resources with consequences for the country's balance of payments. Economic growth can also create energy shortages since the rates depletion of exhaustible resources and regeneration of renewable resources may differ from the output growth rate.

Over the past years there has been an increase in the literature that deals with the energetic topic. The use of different methodologies to study empirical questions is widely accepted in the literature. Although this paper does not seek to address and discuss advantages or disadvantages of different methods, we recognize the existence of a large range of approaches to model energy and natural resources. For instance, (*i*) econometric models (Adams and Shachmurove, 2008;

☆ This paper is part of the research project "Sectoral and Regional Economic Growth: Energy Use and the Environment", partially funded by HSSRG – University of Windsor (Canada) and CNPq (Brazil). We have benefited from discussions with Edson P. Domingues, Eduardo A. Haddad, Ian Sue Wing and seminar participants at the 55th Annual North American Meetings of the Regional Science Association International, International Input–Output Association and Small Open Economies in a Globalized World conferences. All remaining errors are ours.

* Corresponding author.
E-mail addresses: arbex@uwindsor.ca (M. Arbex), fernando.perobelli@ufjf.edu.br (F.S. Perobelli).

0140-9883/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.eneco.2009.05.004

Gan and Zhidong, 2008; Lee and Chang, 2008; Stern, 2007); (*ii*) input–output models (Anderson et al., 2007; Marriot, 2007, Morán and González, 2007; Kagawa and Inamurra, 2004; Alcantara and Padilla, 2003; Hawdon and Pearson, 1995; Hsu, 1989; Park, 1982); (*iii*) integrated models — econometric + input–output models (Rey, West and Janikas, 2004; Rey, 2000; Rey, 1998; Rey and Dev, 1998) and macro econometric models (Barker et al., 2007) and (*iv*) computable general equilibrium models (Sue Wing, 2008; Allan et al., 2007; Bjertnaes and Faehn, 2007; Wissema and Dellink, 2007; Vanden and Sue Wing, 2007; Otto and Reilly, 2007; Naqvi, 1998).

The main goal of this paper is to contribute in this discussion by proposing a novel approach to investigate the relationship between economic growth and energy consumption. This approach integrates an exogenous growth model and an input–output model to analyze energy use and economic growth at an economic sectoral level. Our point of departure for modeling economic growth is the neoclassical theory of growth originated by Solow (1956, 1974). This theory has been developed over the last years with important contributions to questions related to energy, the environment and economic growth (Cass, 1965; Koopmans, 1967), natural resources extraction and growth (Dasgupta and Heal, 1974; Stiglitz, 1974, Chakravorty et al., 1997, Martinet and Rotillon, 2007), environmental quality and income levels (Lopez, 1994; Brock and Taylor, 2004, 2005).

The input–output framework of analysis was developed by Wassily Leontief in the late 1920s and early 1930s. The input–output analysis is a method of systematically quantifying the mutual interrelationships among the various sectors of a complex economic system. The input–output model is based on a fully determined general equilibrium model, where all the intermediate goods were expressed as a set of equations with sales and purchases of the intermediate industries forming the core of the system. Leontief (1941) designed a “closed model”, namely a model where all final demand and value added components were taken as endogenous. Later, Leontief (1951) reformulated the system to what is known as an “open model”, with the final demand and value added components treated exogenously.

It is important to highlight that the input–output literature covers issues across a wide range of topics (e.g. growth, welfare, interdependence); policy issues (e.g. income distribution, employment, investments, migration, energy consumption, and the environment); analytical frameworks (e.g. static, comparative static, dynamic, structural, spatial, and open versus closed); units and levels of analysis (e.g. enterprises, industries, metropolitan areas, regions, multiple regions, single nations, groups of countries, and the world)[1]. One of the most important features of input–output models is the idea of fixed technical coefficients. Economic policy, however, induce changes in these input–output coefficients. The literature presents a different range of approaches to address this issue, such as econometric models (Jorgenson and Wilcoxen, 1993), macroeconomic production functions (Raa, 2005) and applied general equilibrium models (Johansen, 1960).

Different input–output models are specified in order to study the interrelations between economic activities and their impacts on the environment, pollution and natural resources use. Park (1982) puts forward an input–output model to study direct, indirect and induced energy effects of a change in final demand and estimates the effects of technical change on energy consumption. Hawdon and Pearson (1995) constructed an input–output model to study interactions between energy and economic activities for the United Kingdom. Henry (1995) discusses the idea of capacity growth and the impacts on energy in an input–output framework and shows how a forward year by year uniform capacity growth across all sectors can be reached based on a specific annual growth rate. The specification of an energy sector in the model allows to deal explicitly with the importance of energy to any capacity expansion. Murthy et al. (1997) study carbon dioxide (CO_2) emissions from energy consumption in India and argue that the input–output framework fits very well this kind of analysis due the possibility of verifying the direct and indirect emissions caused by variations in each category of final demand. Machado et al. (2001) measure the impacts of foreign trade on energy use and CO_2 emissions using a hybrid input–output calibrated to the Brazilian economy for 1985, 1990 and 1995[2].

We present a growth model with renewable and nonrenewable resources and perfect mobility of commodities. Economic sectors differ with respect their capital intensity and energy use. Nonrenewable resources are depleted as they are used. The stock of non-exhaustible resources is renewed each period at a given rate. Economic sectors differ with respect to their capital intensity and energy use. To the best of our knowledge, this is the first study to propose an integrated exogenous growth model and input–output model to analyze energy consumption and economic growth at the economic sectoral level. The neoclassical growth model is a useful tool for gaining insights into the key factors that determine the ability of an economy to sustain itself in the long-run. An advantage of our analysis is that shocks to the input–output model are consistent with the solution of a well defined growth model, which minimizes the *ad hoc* structure of the shocks. The relationships between the economic agents are established in the input–output framework, which eliminate the necessity to model such complex interactions. This integrated framework offers a simple methodology to study the relationship between growth and energy consumption, which relies mainly in the solution of the growth model and in the input–output structure of the economy. No econometric methods are used in our methodology.

Energy consumption is often used as a proxy for economic growth. On average, the consumption of energy grows at a rate of 2% per year and it is expected that it will double in 30 years. The growth rate is not uniform across countries. While the energy consumption grows at 1% in developed countries, this rate is four times higher in developing countries. In this paper, we contribute to the ongoing debate about the link between economic growth and energy consumption by studying the Brazilian economy and its economic sectors.

To study the impact of economy growth on energy consumption, we use the Brazilian National Accounts and Input–Output Matrix (IBGE) and the National Energy Report (BEN). We analyze eleven economic sectors: Agriculture, Mining, Nonmetallic minerals, Steel and nonferrous metals, Paper products and printing, Chemicals, Textiles, Food and beverages, Trade and services, Transportation and Public administration. More than 80% of the energy consumed by sectors such as Food and Beverages, Trade and Services, Public Administration and Paper Products and Printing comes from renewable natural resources. On the other hand, Mining, Chemicals, Transportation and Nonmetallic Minerals consume energy from nonrenewable resources heavily.

The calculated sectoral output growth rates indicate that the Trade and Services, Public Administration and Agriculture sectors have a much higher long-run growth rates than the other sectors as well as the economy. We observe that these three sectors have the lowest renewable and nonrenewable resources shares among all sectors analyzed. The remaining sectors have a very low output growth rate, lower than 1%. For all sectors, except Public Administration, the consumption of energy in 2003 (our baseline year) is above the level of energy consumption associated with the sectoral long-run output growth rate. We then forecast the long-run energy consumption by sector in Brazil for the period 2004–2014, assuming that economic sectors grow at their long-run growth rates. We also conduct several experiments to analyze the impact of changes in the parameters of the

[1] See Leontief (1986), Ciaschini (1988) and Dietzenbacher and Lahr (2004) for more detailed discussions.

[2] For other studies and references, see Lenzen and Dey (2002), Morán and González (2007), Ma and Stern (2008) and Bartz and Kelly (2008).