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Productive energy use and economic growth: Energy, physical and human capital relationships

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ABSTRACT

Ecological and biophysical economists and historians of economics consider that availability of energy inputs has played a key role in driving economic growth in industrialized and emerging economies. Nevertheless, being very sensitive to structural characteristics or stages of economic development, the strength of this link differs among countries. This study analyzes the role of energy in economic growth from a geographical standpoint by estimating an aggregate translog production function, with human and physical capital and productive energy use as production factors, within a growth framework. Panel data of 38 major countries for the period from 1995 to 2007 were used. The strength of the link between energy and growth is analyzed for the whole sample and the following relevant country groups: OECD, BRIC, NAFTA, East Asian, East European and EU15 countries. Obtained results show that the calculated productivity elasticities with respect to energy use are positive for all country groups. BRIC countries have higher elasticities, around 0.37, and EU15 countries have lower elasticities, around 0.12. Weak substitutability relationships between energy and capital are observed for all groups, except for BRIC and East European countries, which show complementarity relationships.

1. Introduction

There is no widely accepted theory which shows the empirical relationship between energy and economic growth. According to Ozturk (2010) and Payne (2010), the empirical literature on the causal link between energy and economic output has produced inconclusive results for almost 35 years. This literature can be categorized into three strands, as stated in Sharma (2010). The first strand has examined the causal relationship between electricity consumption and gross domestic product (GDP). While evidence of co-integration has been found between electricity consumption and GDP, there has been mixed evidence on causation. In this sense, for example, while Abosedra et al. (2009), Hu and Lin (2008) and others found that causality runs from electricity consumption to growth, for Ghosh (2009) or Halicioglu (2007) causality runs from growth to electricity consumption. The second strand of studies has examined the relationship between oil prices and GDP. This area is relatively less researched and can be considered as nascent. Studies in this area include Hanabusa (2009), Lorde et al. (2009) and Narayan and Narayan (2007). The third strand of studies has examined the relationship between other energy sources (such as coal) and GDP, with evidence of causality running in different directions having been documented. For example, in Lee (2006) and Lise and van Montfort (2007) it is found that GDP Granger-causes these energy type variables, while in Stern (2000) and Yuan et al. (2008), it has been noted that energy variables Granger-cause GDP.

Recently, Coers and Sanders (2013) made a new review of the main studies on this subject, analyzing the methodology used and the results obtained. They consider that these studies can be divided into five categories, based on the methodology used (Simple tests of causality; Vector Error Correction Models –VECMs- with two or more variables; Panel VECMs with two or more variables), and into four categories, based on the results (without causality; with a causal direction running from energy to production; with a causal direction running from production to energy consumption; and that double causality exists). Thus, according to Grubler et al. (2012), this double causality exists because the provision of adequate energy services is needed for economic growth and economic growth is also critical for the provision of high quality energy

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services. Also, the recent meta-analysis made by Bruns et al. (2012) shows that the literature suggests there is indeed a link between energy consumption and economic output. Nevertheless, the authors find differences between the strength of this link for OECD and Non-OECD countries. As stated in Apergis and Tang (2013), causality results are very sensitive to idiosyncratic characteristics for each country, such as structural characteristics or stages of economic development. In this sense, the Global Energy Assessment 2012 (Yeager et al., 2012) shows that OECD countries have generally lower energy intensities than developing and transition countries in contrast to energy use per capita.

In spite of the interest in analyzing these causal relationships, the inclusion of the energy factor in the production function has been scarce. Mainstream neoclassical (models are said to have exogenous technological change) and endogenous economic models used to explain the growth process, usually focus on capital and labor as factors of production and neglect the role of energy (Pirlogea and Cicea, 2012; Stern, 2004, 2011). As Ayres and Warr (2009) and Fine (2000) pointed out, these models involve a set of extremely strong abstract assumptions that disconnect theory from real historical experience. Although resource economists have developed endogenous growth models that incorporate the role of resources, including energy, in the growth process, these ideas remain isolated in the resource economics field as they have not affected the core of growth theory and associated policy debate (Ayres et al., 2013). Di Maria and Valente (2008) and Pittel and Rübbelke (2011) provide references to the more recent literature.

Nevertheless, as stated in Ayres and Warr (2009), the availability of energy inputs has played a key role in driving economic growth in industrialized and emerging economies. Ecological economists (Daly, 1997; Georgescu-Roegen, 1971) and historians of economics (Allen, 2009; Moe, 2010) highlight energy as a key input factor for economic growth and also for development. In this sense, the co-evolutionary perspective suggests that energy has been both a cause and a consequence of economic growth, through positive feedbacks between decreases in energy input costs and increases in economic activity. Likewise, the limitations of its consideration of energy and other resource issues have been, according to Stern (2011), the subject of strong criticism grounded in the biophysical theory of the role of energy.

Biophysical economics regards energy as the key input factor in economic production (Ayres and Warr, 2005, 2009; Cleveland et al., 1984; Cook, 1971; Goeller and Weinberg, 1976; Hall et al., 1986, 2001, 2003; Murphy and Hall, 2010). Biophysical economics, according to Hall and Klitgaard (2006), are those with a system of economic analysis that is based on the biological and physical (as opposed to social) properties, structures and processes of real economic systems as its conceptual base and fundamental model. Thermodynamics implies that energy is essential to all economic production, so those authors consider that energy is necessary for economic production and, as a result, economic growth. They also argue that there must be limits to the substitution of other factors of energy production.

Since the seminal study by Berndt and Wood (1979), the substitutability between energy and capital has been an important topic of discussion. According to Kim and Heo (2013) the adoption of energy-saving technology can represent a substitution of capital for energy, mitigating greenhouse gas emissions and making economic growth sustainable. As Golub (2013) points out, the elasticity of substitution between energy and capital measures the degree of technological flexibility. Thereby, the higher the elasticity of substitution level then the lower will be the reduction in output required to achieve the target for reducing emissions. Empirical studies that include both capital and energy as input factors apply either a constant elasticity of substitution (CES) or a flexible production function such as a translog production function to estimate elasticities of substitution between energy and capital. Currently, as stated in Lin and Xie (2014), there is still no consensus on this aspect of substitutability between energy and capital. In this sense, while some authors such as Bentzen (2004), Koetse et al. (2008), Pindyck (1979), and Truong (1985) find evidence that supports the hypothesis of substitutability between energy and capital, other authors such as Anderson (1981), Fuss (1977), and Prywes (1986) refute it. Estimates vary according to the regions and time periods selected. Likewise, as stated by Costantini and Paglialunga (2014), the capital-energy elasticity of substitution also depends on the level of capital stock.

There have been few attempts to integrate growth theory with the ecological-economics approach, following the 'growth model' framework. Among these is the study by Moroney (1992) which demonstrates, with the use of a Cobb-Douglas production function, that energy, capital, and technological progress are the cornerstones of productivity growth in the USA. Also, following the same methodology, Dieck-Assad and Peralta (2013) reach the same conclusion in their study regarding Mexico. On the other hand, using a panel data sample of 66 countries, Sharma (2010) considers a production function that depends on inflation, capital stock, trade, labor force and energy. It was found that all six energy variables used in the model have positive impact on economic growth.

The aim of this study is to analyze and determine the magnitude of the role of energy in economic growth from a geographical standpoint, by integrating growth theory with biophysical and ecological economics, following the previous studies (Dieck-Assad and Peralta, 2013; Moroney, 1992; Sharma, 2010). In this sense, according to Apergis and Tang (2013), it is crucial to determine the magnitude of the impact that energy has on the economy to understand whether energy policies can provide a positive impulse to the economic system or if they are harmful.

With this purpose, this analysis has three new features. Firstly, a geographical perspective is considered by using a wide panel data sample of countries for which there are enough homogenous statistical data. This perspective allows a comparison of the magnitude of the impact that energy has on the economy between country groups with similar characteristics, following the Global Energy Assessment 2012 (Yeager et al., 2012). Secondly, a more flexible function is estimated with the purpose of being able to analyze the complementarity or substitutability between energy and capital, upon which there is no consensus, and include human capital in the production function. Thirdly, the concept of using productive energy versus total energy use is introduced, with the purpose of limiting the causality problems which usually exist between income and energy use, and suitably assessing the relationship between energy and production. Along these lines, there are studies which show that energy consumption varies with home incomes (Alberini, et al., 2011; Dergiades and Tsoulfidis, 2008), with the residential sector being a key sector from an energy perspective (Sánchez-Braza and Pablo-Romero, 2014), due to the importance of its energy demand with respect to total energy use (Pablo-Romero et al., 2013). The use of productive energy, which is defined as the total final energy consumption in the productive processes, does not include domestic energy consumption.

To make this study, an aggregate translog production function is estimated for 38 countries, including the major economies in the world, covering about 90% of world GDP, for the period 1995 to 2007. The translog production function is a flexible production function, which is obtained by a second-order approximation using Taylor series (Christensen et al., 1973). As stated by De la Fuente (2008), it can be considered a logarithmic quadratic proxy to an arbitrary production function. According to Østbye (2010), the translog function is more convenient than the CES function, because the former is more flexible, as it allows the substitution elasticity to vary along with factor intensity. The output elasticities of the productive factors, which vary throughout countries and time, are calculated from the estimated parameters for the whole sample and the following relevant country groups: OECD, BRIC, NAFTA, East Asian, East European and EU15 countries. Also, the Elasticity of Marginal Product (EMP) of factors are calculated with respect to other factors or to themselves for each of these groups. These parameters allow an interpretation in terms of the possible