Energy consumption, fuel substitution, technical change, and economic growth: Implications for CO₂ mitigation in Egypt

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ABSTRACT

Energy consumption propels economic growth but the level of CO₂ emissions associated with a fossil-dominated energy structure raises concerns for the fight against climate change. To draw consensus, this study develops a translog-causality-based model in order to study causation between electricity, natural gas, petroleum, and economic growth in Egypt. In addition, the models' results are used to estimate the substitution possibilities between various energy pairs and to subsequently test the CO₂ mitigation benefits arising from fuel substitution. Results support a bidirectional relationship between all energy types and economic growth in Egypt and suggest, also, that these energy types are substitutes. Although technical progress is estimated to be a bit slow (varying between 4.5% and 7.5%), there appears to be substantial CO₂ emissions mitigation benefits from fuel substitution amounting to reductions in the range of 1.5 and 2.2 million metric tons under a 5% investment scenario and 2.5 and 4.5 million metric tons under a 10% investment scenario. These results have broader implications for energy conservation policies and industrial merger policies in developing countries. Moreover, by studying technical change, insights are provided on future CO₂ mitigation potential driven by energy efficiency.

1. Introduction

A large number of studies have suggested that the consumption of energy is important for a country's economic growth. However, the associated CO₂ emissions from energy usage have become an issue of concern, especially as climate change persists. In fact, the International Energy Agency (IEA) reports that about 49% of worldwide CO₂ emissions come from energy utilization and developing countries, due to high energy intensity as a result of their transition towards industrialization and urbanization, are expected to account for a greater portion of energy-related CO₂ emissions.

There are three prominent ways through which governments could reduce the rate of CO₂ emissions. First, this could be done through energy efficiency measures like the application of new technologies such as insulation upgrades, furnaces of high efficiency, compact fluorescent bulbs, etc. The second approach to mitigation could be through the expansion of investment in clean energy sources like wind, solar, geothermal, biomass, hydro, etc. Finally, governments could also consider instruments like carbon taxes, emissions trading schemes, carbon capture and storage, etc. (Wesseh and Lin, 2016d).

Egypt, as surrogate for a developing open economy in transition, is no exception to this debate. The levels of energy consumption and CO₂ emissions have soared with the rate of growth and expansion of the economy (Fig. 1). It also appears clear from Fig. 1 that energy consumption and CO₂ emissions have a direct co-movement – rising and falling at similar points (these break points are obvious in the years 2005 and 2008). This co-movement between energy consumption and CO₂ emissions is not surprising considering that Egypt is Africa’s largest oil consumer with about 41% of electricity and 45% of primary energy sourced from oil (EIA, 2014). These conditions make Egypt a suitable case in which to study the mitigation potential of inter-fuel substitution and how energy consumption really impacts on economic growth.

As we show in the next section, the problem of energy consumption and economic growth has been addressed by use of several methods ranging from Granger causality approaches to Sim’s technique, from Cointegration methods to Error Correction Models (ECM) and Vector Error Correction Models (VECM), from Multivariate Vector Autoregressive (VAR) models to Autoregressive Distributed lags (ARDL) bounds techniques, and from Toda–Yamamoto method to bootstrap empirical distributions (Omri, 2014). Even though there have been numerous contributions to the literature from the use of these different modeling approaches, these have also come with mixed results. This inconclusive nature of the literature becomes an issue of concern especially considering the arbitrary nature in which variables are
selected for these models. In other words, commonly used approaches to causality analysis in the energy–economy literature do not clearly define a definite theoretical relationship between output and input, and hence, paves the way for either omitted variable biased or over-defined models. Furthermore, energy substitution effects due to environmental regulations, price and demand changes are neglected. For these reasons, further insights based on improved modeling would provide opportunities.

Therefore, in order to address these problems, we develop a translog-causality-based approach\(^1\) to energy–economy modeling in order to study the direction of causation between various energy forms and economic growth. Subsequently, these results are used to estimate the substitution possibilities of various energy forms and to quantify the mitigation potential arising from energy substitution. Our applied production approach does not only define a definite relationship between output and input, but it also incorporates the interactions among various energy forms and the level of technical progress with which these inputs are used. Against these backdrops, the present study serves to contribute to the literature not only in terms of Egyptian energy policy design, but also with regards to methodological issues inherent in the energy–economy literature. For we incorporate dynamic components into the traditional translog production model.

The remainder of this study proceeds as follows: The second section introduces the literature and how the problem has been addressed. The third section describes the dataset. Section four presents the model framework and the procedures used for deriving various estimates. Section five presents the results and discussion. Section six draws the conclusions.

2. Literature review

In terms of how energy consumption affects economic growth, a number of contributions have emerged. A review of this literature shows that several approaches have been employed to address the problem. From Granger causality approaches to Sim’s technique, from Cointegration methods to Error Correction Models (ECM) and Vector Error Correction Models (VECM), from Multivariate Vector Autoregressive (VAR) models to Autoregressive Distributed lags (ARDL) bounds techniques, from Toda–Yamamoto method to bootstrap empirical distributions. There have been mixed results from these diverse approaches (Omri, 2014).

There are studies that evaluate how energy consumption on the aggregate affects the economy. According to Wesseh and Lin (2016a), results are quite mixed with 29% of the studies pointing to a unidirectional causality from energy to economic growth, 27% showing bidirectional relationship between energy and economic growth, 23% supporting a unidirectional causality from growth to energy, and 21% suggesting no form of relationship between energy and growth.

As opposed to aggregate primary energy, some contributions have used total electricity to represent energy and to examine how electricity uses impact on economic growth. A review of these results shows 40% support for energy to growth, 33% support for a bidirectional relationship, and 27% support for growth to energy. For country-specific studies which use electricity to represent energy use, there is no evidence of neutrality between energy and growth.

The effects of nuclear energy on economic growth have also been considered. 60% of existing evidence supports no form of relationship between nuclear energy and growth while 40% suggests a unidirectional relationship from nuclear energy to growth. No evidence of bidirectional relationship and conservational relationship has been found.

Few authors have attempted to study how renewable energy consumption impacts on economic growth. Again, results are quite mixed and show 40% support for no relationship between renewable energy and growth, 40% support for growth to energy, and 20% support for energy to growth. No support for the feedback hypothesis has been found. For detailed list of international studies, interested readers are referred to Omri (2014) and Wesseh and Lin (2016a).

In terms of African countries in particular, be it single-country or multi-country study, results have supported all hypotheses. A detailed review of energy consumption – economic growth studies for Africa since the year 1996 is presented in Table 1.

Quite a great number of contributions focusing exclusively on African countries have suggested a unidirectional causality running from energy consumption to economic growth (or growth hypothesis). These studies point to the importance of energy for growth and development suggesting that energy conservation policies aimed at reducing the levels of CO₂ emissions would constrain economic growth. Contributions in this category have employed diverse approaches. For instance, Wolde-Rufael (2009) utilizes the Toda and Yamamoto approach to analyze the impact of energy consumption on economic growth in 17 African countries. Odhiambo (2009b) use the Autoregressive Distributed lag modeling technique to study the impact of energy consumption on the economy of Tanzania over the period 1971–2006. Akinlo (2009) employs the Autoregressive Distributed lag technique to study the impact of energy consumption on the South African economy over the period 1965–2006. Al-mulali and Sab (2012) use panel cointegration model to determine how energy consumption affects economic growth in 30 African countries over the period 1980–2008. Ouedraogo (2013) use panel cointegration model to study the impact of energy consumption on economic growth in the ECOWAS region over the period 1980–2008. Kumar and Kumar (2013) employ the Autoregressive Distributed lag modeling technique to test the influence of energy use on economic growth in South Africa and Kenya. Mensah (2014) applies the Autoregressive Distributed lag technique to examine how energy use affects economic growth in 6 African economies. Lin and Wesseh (2014) employ the Bootstrap testing technique to evaluate the impact of energy consumption on the South African economy over the period 1971–2010. Aïssa et al. (2014) adopt Panel Error Correction modeling approach to study the impact of energy consumption on economic growth in 11 African countries over the period 1980–2008. Another contribution which shows a unidirectional causality running from energy consumption to economic growth in an African country is Kebede et al. (2010).

On the contrary, one contribution on African countries (Richard, 2012) finds that causality runs from economic growth to energy consumption (conservation hypothesis) and not the other way around. These authors argue that it is the growth of the economy that gives rise to energy use. Richard (2012) employs the Hidden cointegration modeling technique to test the impacts of energy consumption on 12 African countries over the period 1971–2008. Furthermore, to the conservation hypothesis, some results also pointed to the growth hypothesis.

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\(^1\) The static production model has mainly been used to estimate energy substitution effects (e.g. Lin and Wesseh, 2013b; Wesseh et al., 2013).
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