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Energy and CO_2 emissions efficiency of major economies: A non-parametric analysis

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A B S T R A C T

Excessive energy consumption and carbon dioxide emissions are long lasting issues and need continuous research to improve efficiency evaluation and performance monitoring of economies. The static and dynamic aspects of efficiency need to be dealt with simultaneously to thoroughly analyze the performance of economies. This paper aims at conducting a static and dynamic analysis of energy and CO_2 emissions efficiency of major economies. In this paper, we applied slacks based model of Tone (2001) with the treatment of undesirable output in objective function and constraint assuming free disposability of undesirable output and built a dashboard. The results can be summarized by saying that the larger economies with intensive production strategy, larger secondary industry, and weaker carbon tax laws are more likely to be inefficient. China, India, and Russia have the greatest potential for improvement in both energy efficiency and carbon dioxide emissions efficiency. The suggested dashboard has the ability to dig out the potential for efficiency improvement of countries like the USA, which mostly appear at the efficient frontier with other techniques. Concluding it can be suggested that economies in lower ranks of dashboard need stricter policy measures to cut energy consumption, carbon dioxide emissions and encourage a shift from fossil fuels to other renewable resources of energy.

1. Introduction

Although both global energy consumption and greenhouse gas emission have had an ever increasing trend, but combined efforts of local and international regulatory bodies have resulted into diminishing trends in last few years. In 2000, global demand for energy was 10063 Mtoe (million tons of oil equivalent) and CO_2 emissions were 22805MtCO_2 (million tons of CO_2), and in 2014, those were 13737Mtoe and 31220MtCO_2 respectively (Enerdata, 2015), with average growth rates of 2.2% and 2.3% respectively. Notably, between 2013 and 2014, energy demand grew only by 0.48% and CO_2 emissions recorded a decrease of −0.1% first time in history (Enerdata, 2015). Despite these trends of decreases in overall demand for energy and CO_2 emissions it is obvious from the data that not all economies have contributed equally to this success story, on the contrary, many of the economies have nullified the effect of combined efforts of all other economies. For example, among BRICS except China, all other countries of the group had an increase in energy consumption thus making up an aggregate increase of 1.2% in energy consumption of BRICS between 2013 and 2014. In the same way except BRICS, all other groups of countries like G7, EU and OECD countries observed a decrease in energy demand yet it is very clear that not all the countries in the groups mentioned above have managed to lower their energy demand. Hence, it is of utmost importance to analyze the potential for a further decrease in energy use of the countries, which successfully curtailed their demand for energy and reduced their environmental footprints, and the others, which observed increases in those factors. The above stated facts set the background for this paper.

Energy being an input the term energy efficiency refers to the lesser use of it for producing a certain amount of outputs, on the contrary, CO_2 is an undesirable output thus CO_2 emissions efficiency would imply lesser emissions of CO_2 for same amounts of inputs and desirable outputs. Henceforth the term CO_2 emissions efficiency will refer to reduction in CO_2 emissions in this paper. Energy efficiency and CO_2 emissions efficiency are somewhat related concepts unless fossil fuels remain the main source of

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energy. While considering both energy efficiency and CO_2 emissions efficiency together, an economy is considered efficient only if it manages to appear efficient at both fronts simultaneously. In turn, energy consumption and CO_2 emissions are related to the economic output that is larger the economy the more likely it is to demand more energy and emit more CO_2. Thus, the purpose of this study is to analyze energy and CO_2 emissions efficiency (ECEE) of major economies and suggest policies that may help them to improve efficiency.

This paper undertakes an analysis of ECEE of major economies of the world using slacks based model (SBM) of data envelopment analysis (DEA) so that it can be ascertained how much energy resources they could spare without undermining their economic growth while contributing to environmental restoration. This paper also proposes a performance dashboard capable of providing static and dynamic analysis of DEA results in more user-friendly and visually dynamic way as compared to contemporary techniques. Finally, the paper brings forth important policy suggestions for major economies struggling with energy efficiency and CO_2 emissions issue based on the analysis of successful economies. The rest of the paper consists of several sections. Section 2 is about literature review, Section 3 provides details about material and methods, Section 4 presents and discusses results and Section 5 concludes the paper.

2. Literature review

As CO_2 emissions are an essential part of all environmental efficiency studies, we have taken all environmental efficiency studies as essentially CO_2 emissions efficiency studies for the sake of literature review. M.-L. Song et al. (2013); Gómez-Calvet et al. (2014) and Makridou et al. (2015) measured the energy efficiency of BRICS and European Union countries. Makridou et al. (2015) tabulated previous research studies using DEA for energy efficiency. Similarly, Woo et al. (2015) measured the environmental efficiency of renewable energy in OECD countries, they also tabulated the previous research studies conducting environmental efficiency analysis at economy level. The research studies mentioned above span their research over a number of economies but there are other research studies targeting to measure the energy efficiency of the single economy where provinces act as decision-making units (DMUs). For instance, Hu and Wang (2006); Shi et al. (2010); Song et al. (2013) and Wu et al. (2013) measured energy efficiency, Lin and Fei (2015) and Lin and Du (2015) measured environmental efficiency and Wang et al. (2013) and Zha et al. (2015) measured energy efficiency and carbon dioxide emissions in regions of China. Most of these energy efficiency studies measure only energy consumption efficiency using GDP as single output and ignore undesirable outputs, which are useful to measure environmental aspects of energy consumption. Environmental efficiency studies consider a number of undesirable outputs, for example, Wang et al. (2013) considered undesirable outputs to assess energy and environmental efficiency of regions in China, but most of them ignore energy efficiency. However, the studies that aim at energy and environmental efficiency together are fewer but they are much related to our research.

In economy level energy and environmental efficiency studies, DEA has been used in last few years (Gómez-Calvet et al., 2014; M.-L. Song et al. (2013); Woo et al., 2015). DEA requires minimal a priori assumptions and does not require specifying the types of relations among inputs and outputs (Cooper et al., 2000), that is its advantage over other parametric techniques. After the initial presentation of basic CCR model exhibiting a constant return to scale a number of variants of this model were presented among which BCC is representative of the variable return to scale and additive model treats slacks directly in the objective function (Cooper et al., 2000). Since then a number of new models have been introduced to take into account types of inputs (desirable, undesirable, discretionary and non-discretionary, controllable and non-controllable) (Cooper et al., 2000), treat undesirable output (Lozano and Gutiérrez, 2011; Seiford and Zhu, 2002; Yang and Pollitt, 2010; Zhou et al., 2007, 2006), and take into account the internal structure of DMUs (Cook and Zhu, 2014; Tone and Tsutsui, 2009).

Treating undesirable output in DEA models is a critical issue. A number of methods have been suggested. Seiford and Zhu (2002) identified five possibilities for treating undesirable output in DEA-BCC models. However, their model was radial and had shortcomings as stated by Chang et al. (2013). Zhou et al. (2007, 2006, 2007); Hernandez-Sancho et al. (2011) and Chang et al. (2013) used SBM of Tone (2001) that is none radial and Chang et al. (2013) and Zhou et al. (2006) modified it to include undesirable output in objective function and added a separate constraint for it as well. This non-radial and non-oriented model has an advantage over the previous attempts made by others to include undesirable output. The approaches used by others (Fare et al., 1989; Seiford and Zhu, 2002; Wang et al., 2013; Woo et al., 2015; Zhou et al., 2006) are radial and oriented. Thus those either fail to measure potential for reduction in undesirable output (Chang et al., 2013), or they cannot measure slacks for individual inputs and offer a proportionate change in all inputs to make DMUs efficient (Lozano and Gutiérrez, 2011).

Similarly, weak disposability assumption does not hold true for CO_2 emissions efficiency of economies. Yang and Pollitt (2010) and more recently Dakpo et al. (2016) and Y. Li et al. (2016) discussed weak and strong disposability among undesirable outputs but it worth noting that their studies are at industrial level. Weak disposability for undesirable outputs holds true unless we are discussing the efficiency of machines, plants, factories or industries, which have pollution generating inputs as irreplaceable inputs in both short run and long run. However, for an economy assumptions of weak disposability cannot be induced directly from studies of DMUs fully dependent on fossil fuel because economies have a combination of renewable energy sources and fossil fuels as input and they are not strictly dependent on fossil fuel. In other words, it is at least theoretically possible to assume that an economy can shift its all operations from fossil fuels to other energy resources without undergoing any change in desirable outputs in short and long run when change is systematic, well planned, well managed and slow enough to give time to fully depreciate fossil fuel dependent assets. Hence, unlike other systems where undesirable outputs are not freely disposable, CO_2 emissions in an economy can be reasonably considered as freely disposable and can be reduced to approximately zero by shifting to renewable and non-fossil resources of energy. Thus weak disposability approach (Fare et al., 1989; Zhou et al., 2007) does not suit here. The modification offered by them is suitable for free disposability of undesirable output as it is the case with CO_2 emissions in the economy.

An extensions of Tone (2001) model that can deal with undesirable output includes dynamic SBM (DSBM) (Tone and Tsutsui, 2010). It takes advantage of including carryover from last period in performance calculations (N. Li et al., 2016). On the other hand, network SBM (NSBM) is another extension of Tone (2001) which takes into account the components of the network of internal structure for performance calculations (Tone and Tsutsui, 2009). Although NSBM of (Tone and Tsutsui, 2009) is an extension of Fare and Grosskopf (2000) idea but it is built on different lines. Both DSBM with NSBM can be combined as well to take advantage of both models (Tone and Tsutsui, 2014). However, for studying energy and CO_2 emissions efficiency of an economy these models cannot be applied because identifying carryover and components