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On the relationships between CO_2 emissions, energy consumption and income: The importance of time variation

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ABSTRACT

The environment that governs the relationships between energy consumption, carbon dioxide (CO_2) emissions and gross domestic product (GDP) in the G7 countries changes over time due to variations in economic growth, regulatory policy and technology. Using a novel approach that may detect causalities when the time-constant hypothesis is rejected, we find significant time-varying Granger causalities among the variables under consideration. There is bidirectional causality between GDP and energy consumption for Japan, unidirectional causality running from GDP to energy consumption for Italy, and unidirectional causality running from energy consumption to GDP for the resource country Canada. Moreover, the results also show a bidirectional time-varying causality between energy consumption and CO_2 emissions for the United States, and causality from energy consumption to CO_2 emissions for France. Finally, while we find significant time-varying causalities running from GDP to CO_2 emissions for Italy and Japan, the finding of inverted N-shaped curves (Italy and Japan) lends no support to the traditional Environmental Kuznets Curve (EKC) hypothesis for these countries. It implies that environmental policy and economic growth should go hand in hand. Other policy implications of the empirical results have been proposed.

1. Introduction

The bivariate relationship between energy consumption and income, as well as between fossil-based environmental pollution and income, has been studied in depth in the fields of energy and ecological economics, but without gathering a consensus. The major cause of environmental pollution is carbon dioxide (CO_2) which contributes 76.6% of total greenhouse gases (GHG).[1] Interest in the CO_2 pollution has risen due to the lack of appropriate regulations on its emissions at regional and country levels. These emissions are closely linked to energy consumption, economic growth and the environment as they have serious effects on temperatures, sea levels, and global air pollution, with the ultimate result of damaging human health. Jacobson (2010) examines the effects of local CO_2 emissions on air pollution and human health through data-evaluated numerical modeling with telescoping domains from the globe to the U.S., California, and Los Angeles. Jacobson estimates that local CO_2 emissions in isolation may increase local ozone and atmospheric particulate matters. These findings suggest that the CO_2 emissions should be treated as a local and not only as a global pollutant.

On the other hand, the empirical studies on the larger tridimensional environmental pollution-energy use-income nexus have not garnered a consensus or even received an adequate investigation. Payne (2010) and Ozturk (2010), among others, point out that the evidence on the relationships varies according to the estimation techniques, the time periods and the country characteristics. While some studies find evidence of a unidirectional causality running from energy consumption to economic growth (e.g., Stern, 2000; Bowden and Payne, 2009; Warr and Ayres, 2010), others reveal a unidirectional causality running from economic growth to energy consumption (e.g., Ang, 2008; Zhang and Cheng, 2009) or even no causality between these variables (e.g., Payne, 2009). Belloumi (2009) and Fallahi (2011), among others, report bidirectional causality between energy consumption and economic growth. Mixed results are also provided by, for instance, Soytas and Sari (2003), Lee (2006), and Chiou-Wei et al. (2008).

A similar divergence of the results exists in the literature on the CO_2 emission-growth nexus (e.g., Halicioglu, 2009; Jayanthakumaran et al., 2012). Various environmental degradation indicators have also been examined in relation to economic growth and energy use (e.g., Coondoo and Dinda, 2002; Liu, 2005; Jaunky, 2010), but the results do not provide

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[1] This statistic comes from "CO_2 emissions from fuel combustion" 2012 highlights, Part III "Greenhouse-gas emissions", International Energy Agency.

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unanimous conclusions on the validity of the traditional Environmental Kuznets Curve (EKC) hypothesis.[2]

A major limitation of the above-mentioned studies is that they ignore the time-varying patterns in the relationships between income, CO_2 emissions and energy consumption, which may lead to erroneous conclusions on the EKC hypothesis and environmental policy. Our study contributes to this literature by making use of a time-varying Granger causality analysis in the sense of Sato et al. (2007) to investigate the dynamic relationships between income, energy consumption and CO_2 emissions for the G7 countries. The rationale for adopting a time-varying approach comes from the fact that the models' parameters may vary under the effects of changing economic conditions, geopolitical pressures, local and intergovernmental legislations, natural disasters (e.g., solar variations, volcanoes and tsunamis), and new technologies. More importantly, to the extent that more stringent environmental regulations are likely to be implemented gradually in the near future and are likely to have impacts on economic activity, a re-examination of the relationship between CO2 emissions, energy consumption and income generation is currently of particular interest.

Resorting to a time-varying approach may thus enable one to detect the time-varying causal links between these variables during certain periods, which may be neglected under the time-constant approach. This empirical framework also allows us to examine the EKC hypothesis through the time-varying "causality curve" relationships between the CO_2 emissions and GDP. The idea is that the EKC is likely to be predisposed to the impact of the time factor because the rising time trend of the CO_2 emissions persists as income continues to increase. For instance, only one study, Balcilar et al. (2010), uses a bootstrap rolling window to take the time-varying feature into account when examining the causality relationship between economic growth and energy consumption for the G7 countries. Our study examines the time-varying trivariate relationship between economic growth, energy consumption growth and changes in pollution. We hope that this contribution will add to the literature.

As part of the empirical analysis, we consider annual data on per capita for energy consumption, GDP and CO_2 emissions for the G7 countries excluding Germany.[3] The G7 countries are the most industrialized in the world and operate on the world scene as a recognized group that influences global policies. Excepting the United States, these countries have ratified the Kyoto protocol which obligates them as well as others to make economic sacrifices to combat CO_2 emissions. They have also legislated nuclear and/or renewable energy regulations which can lead to a changing environment that is more favorable to meeting the Kyoto protocol requirements. Our results provide evidence of a bidirectional time-varying Granger causality between GDP and energy consumption for Japan. A unidirectional causality running from energy consumption to GDP is observed for Canada, which implies that energy conservation can constrain economic growth for this resource country and from GDP to energy consumption for Italy. The results also show a bidirectional time-varying causality between energy consumption and CO_2 emissions for the U.S., and a unidirectional time-varying causality from energy consumption to CO_2 emissions for France. While we find a significant time-varying causality running from GDP to CO_2 emissions for Italy and Japan, our estimates of the causality curves provide no evidence in support of the traditional EKC hypothesis for the G7 countries. In fact, we only find inverted N-causality curves for these countries, which may reflect relationships between their policies and endogenous variables.

The remainder of the study is structured as follows. Section 2 briefly reviews the related literature. Section 3 presents the methodology. Section 4 describes the data used and discusses the empirical results. Section 5 concludes the article.

2. Literature review

There are three research strands in the literature on the relationships between economic growth, energy consumption and environmental pollutants (Zhang and Cheng, 2009). The first strand focuses on the environmental pollutant-output nexus. This strand is closely related to testing the validity of the traditional EKC hypothesis. It argues that the relationship between these two variables takes the shape of an inverted U-curve, implying that environmental degradation increases with output during the early stages of economic growth, but then declines with output after arriving at a threshold. The EKC hypothesis implies that the environment changes from an inferior good at lower income levels to a normal good at higher income levels. It also suggests that environmental degradation can be slowed at some point by policies that both protect the environment and promote economic development.

Researchers have carried out a large number of empirical studies to examine the EKC hypothesis, but the results are not conclusive as a higher national income does not necessarily harness greater efforts to contain the emissions of pollutants. For example, Coondoo and Dinda (2008) use the concentration curve methodology and Johansen's cointegration technique to investigate the shifts in the relationships between inter-country income inequality and CO_2 emissions as well as the EKC hypothesis, based on a cross-country panel data set. They find no credence to this hypothesis for a group of 88 countries over the period 1960–1990. However, using data for 43 developing countries from 1980 to 2004 and a panel data approach, Narayan and Narayan (2010) suggest that the carbon emissions fall with rising income for approximately 35% of the sample at the individual country levels and for the Middle Eastern and South Asian panels only. By contrast, Galeotti and Lanza (2005) use a dataset developed by the International Energy Agency for 108 countries and provide evidence for the validity of the EKC curves when two alternative distributional specifications based on the Gamma and Weibull functions are employed. Moreover, using data from 1980 to 2005, Jaunky (2010) uses the Blundell–Bond system generalized methods of moments to test the EKC hypothesis for 36 high-income countries for the period 1980–2005 in a panel vector error-correction model (VECM). This author finds evidence that attests to the validity of the EKC hypothesis for Malta, Oman, Portugal and the United Kingdom. Moreover, Katircioğlu (2014) uses causality and cointegration tests to analyze the relationship between tourism development and carbon emissions in Singapore over the period 1971–2010, and finds evidence to support the tourism-induced EKC hypothesis. Differently, Akbostanci et al. (2009) and Friedl and Getzner (2003) use panel data and the cointegration framework, and show the presence of an N-shape curve for Turkey and for Austria, respectively. This type of finding consistently depresses any hope for permanent improvement in the environment with greater economic prosperity. Barassi and Spagnolo (2012) employ a multivariate GARCH framework to examine the causal relationship on per capita basis in the mean and variance between CO_2 emissions and economic growth for Canada, France, Italy, Japan, United Kingdom and the United States. They find feedbacks in both types of causality and the volatility spillover between the two variables.

Recently, the interest in global warming and climate change has arisen mainly from the huge accumulation of the global CO_2 emissions. Indeed, CO_2 is considered to be the primary source of GHGs which are responsible for global warming, thereby its regulation has become an important intergovernmental issue. The 1997 Kyoto protocol has espoused the objective of reducing the GHG emissions which cause climate change and global warming. Thus, studying the causality relationship between income and CO_2 emissions allows

[2] The EKC hypothesis posits an inverted U-shaped curve relationship between per capita income and pollution. Accordingly, environmental degradation will increase up to certain level as income increases, and then decreases (see, Dinda, 2004 for a survey of theoretical developments and empirical studies related to the EKC hypothesis).

[3] Our sample of developed countries includes Canada, France, Italy, Japan, the U.K. and the U.S., but excludes Germany based on the availability of a unified data for this country.