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Modeling the nexus between carbon dioxide emissions and economic growth

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HIGHLIGHTS

- There is no universal model fitting every country.
- The inverted-N, M, inverted-U and monotonically increasing shape are found.
- M-shaped have received little attention but exhibits promising performance.
- The relationship is diversified by the different regions or economic development.
- Symbolic regression discovers reasonable models for a specific country or region.

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ABSTRACT

The effects of economic growth on the environment have received increased attention as global warming and other environmental problems become more serious. Many empirical studies explain the nexus between carbon dioxide emissions and economic growth with such models as the environmental Kuznets curve (EKC) theory. However, the assumptions of these models have never received strict verification with a large available data set and therefore may not be appropriate to describe the relationship. In this study, the nexus is modeled for 67 countries from 1971 to 2010 using a novel symbolic regression method. From the experimental results, several conclusions as follows could be reached. Firstly, there is no universal model fitting every country, and symbolic regression could discover a set of reasonable models for a specific country or region. Secondly, four models, including the inverted N-shaped, M-shaped, inverted U-shaped and monotonically increasing, are frequently found without domain experts' intervention in these countries, whereas the M-shaped model has received little attention in previous studies but exhibits promising performance. Thirdly, the relationship is diversified due to the difference of regions and economic development, where developed countries generally follow the inverted N-shaped and M-shaped models to explain the relationship, whereas developing countries are more likely to refer to the inverted N-shaped, inverted U-shaped and monotonically increasing models. Finally, several policy suggestions are presented.

1. Introduction

As environmental quality continues to deteriorate worldwide, public concern is increasingly focused on the issue of environmental degradation and economic growth. In particular, authorities seek to understand the effect of economic growth on the environment to balance environmental protection with the development process.

The relationship between environmental degradation and economic growth is commonly described by the environmental Kuznets curve (EKC) as an inverted U-shaped curve (Lieb, 2003; Dinda, 2004; Kaika and Zervas, 2013). The EKC hypothesis reveals that environmental pollution will increase until reaching a peak and then will start declining over time with economic growth. The relationship can be explained by the phenomenon that in the early stages of industrialization, people pay more attention to the growth of the economy than to the environment because they

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want a better standard of living. Later, as living standards improve, people become more willing to pay for better environmental quality than for economic growth. Thus, countries or regions become more effective in taking environmental protection measures, so pollution levels decline.

There are many empirical studies that use EKC theory to investigate the pollution–income relationship. Several empirical studies (Halicioglu, 2009; Kohler, 2013; Yavuz, 2014) show that there exists an inverted U-shaped relationship, whereas others (Moomaw and Unruh, 1997; Galeotti et al., 2006; Wang et al., 2011) are skeptical regarding the hypothesis and note that there exists an N-shaped model, a monotonically increasing model or other models (Haghnejad and Dehnavi, 2012; Alkhathlan and Javid, 2013) to explain the relationship. However, there are two primary critiques of EKC. First, the suitability of the EKC model for a country depends on the collection of data samples and the time period of the country′s data. In other words, a portion of data samples or periods of the country′s data follow the EKC, but others may not. Second, previous studies test different independent variables for economic growth. For example, Ahmed and Qazi (2014) included energy consumption as a variable in the model, but Lim (1997) and Lau et al. (2014) did not. Whether these other variables affect environmental conditions does not have a uniform answer. Despite surface imperfections, the fundamental problem is how to identify the underlying structural functions of the socio-economic system that lead to the relationship between the environment and the economy. By solving this fundamental problem, it will be possible to evaluate whether the models that use the EKC hypothesis really represent the relationship.

To investigate the nexus between environmental degradation and economic growth, this paper introduces symbolic regression to model the given data automatically by efficiently searching the huge solution space of mathematical expressions. Compared with the previous empirical studies, symbolic regression via genetic programming does not need the prior hypothetical form to fit the observed data. On the contrary, inspired by Darwin′s theory of biological evolution, which selects the superior solutions and eliminate the inferior ones, this method can evolve the form of the model to improve the fitting.

In the following, we will review the empirical analysis of EKC hypothesis, and briefly introduce the basic idea and application of symbolic regression.

1.1. Empirical analysis of EKC hypothesis on CO_2

Existing literature on the relationship between environmental pollution and economic development primarily examines the EKC hypothesis, which has been debated for many years. In the early 1970s, in the report of the Club of Rome, Meadows et al. (1972) paid attention to natural resources and noted that limited resources will limit economic growth unless renewable resources are found. However, it has been criticized by several empirical studies. For example, Auty (1985) proposed that the materials intensity of GDP had decreased along with economic growth, indicating that the ecological scenarios were not as severe as previously reported. In the early 1990s, the research introduces the Kuznets curve, describing the changing relationship between income and income inequality (Kuznets, 1955). This inverted U-shaped relationship between economic growth and environmental quality is also called the environmental Kuznets curve (EKC). One of the first empirical research on EKC theory appeared (Grossman and Krueger, 1993), which revealed that the EKC exists between pollutants (SO_2 and smoke) and per capita income on the environmental impacts of NAFTA. The EKC theory indicates that environmental quality will deteriorate in the early stage of economic development, but when economic development reaches to a certain degree, environmental quality will be improved along with the increase of per capita income.

From the empirical perspective, there are two primary methods to study the relationship between economic growth and carbon dioxide emissions. One method is based on a single region using time series data and the other is based on multiple regions of panel or cross-section data. As we can see from the existing literature, of the various relationships between the economic growth and carbon dioxide emissions, the inverted U-shaped model is the most widespread, but the linear increasing model and the N-shaped model are also relatively obvious relationships. Furthermore, different research may give different results for the same target. For example, Lau et al. (2014) note that there exists an EKC model in Malaysia during 1970–2008, while Azlina et al. (2014) argue that there was no EKC model in Malaysia from 1975 to 2011. Shahbaz et al. (2014) find an inverted U-shaped model when studying the effect of economic growth on the environment in Tunisia from 1971 to 2010, but Fodha and Zaghdoud (2010) propose that carbon dioxide emissions monotonically increase along with economic growth from 1961 to 2004. Halicioglu (2009) shows an inverted U-shaped model from 1960 to 2005 in Turkey, but Akbostanci et al. (2009) find using a time series model that carbon dioxide emissions were still getting worse with increasing economic growth from 1968 to 2003.

Regarding analyses based on panel or cross-section data, some research has confirmed that models obtained from this type of data cannot hold for a specific region. Dijkgraaf and Vollebergh (2001) study the relationship of 24 OECD countries from 1960 to 1997 and find that the model of panel data is the inverted U-shape, whereas only 5 countries have the inverted U-shape when a time series model is used. Jaunky (2011) uses the Blundell–Bond system generalized methods of moments (GMM) and a vector error-correction mechanism (VECM) to study 36 high-income countries from 1980 to 2005, with results showing that carbon dioxide emissions grow monotonically for the whole panel but that only 5 countries – including Greece, Malta, Oman, Portugal and the United Kingdom – have the inverted U-shaped model. When studying 89 countries for the time period of 1960–2000, Lee et al. (2009) find an N-shaped model for the whole panel but an inverted U-shaped model in middle-income American and European countries.

There may be many reasons for the different results in the same area, but the literature concerning EKC focuses on three main reasons (Hill and Magnani, 2002).

- The first reason is that different researchers select different environmental and economic variables. Miah et al. (2010) find the environmental pollutant sulfide (SO_x) to follow the inverted U-shaped model and carbon dioxide (CO_2) emissions to increase monotonically as the economy of Bangladesh grew from 1975 to 2000. Kunnas and Myllyntaus (2007) discuss that CO_2 increases monotonically and SO_2 meets the EKC hypothesis when studying the relationship in Finland from 1800 to 2003. Cole (2004) concludes that the relationship of volatile organic compounds (VOC) and CO is an inverted N-shaped curve but that CO_2 is the inverted U-shaped curve.
- The second reason is the different collections of data categories for the object under study, as observed in the different results for Malaysia (Lau et al., 2014; Azlina et al., 2014), Tunisia (Fodha and Zaghdoud, 2010; Shahbaz et al., 2014), and Turkey (Halicioglu, 2009; Akbostanci et al., 2009).
- The last reason is that the research uses different empirical methods, such as ARDL (Jayanthakumaran et al., 2012; Kohler, 2013; Shahbaz et al., 2014), the Johansen approach (Fodha and Zaghdoud, 2010; Nasir and Rehman, 2011; Ahmed and Qazi, 2014), panel GMM (Jaunky, 2011; Han and Lee, 2013), the