Electricity demand elasticities and temperature: Evidence from panel smooth transition regression with instrumental variable approach

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ABSTRACT

This study applies a non-linear model, i.e. the recently developed panel smooth transition regression (PSTR) model, and takes into account the potential endogeneity biases to investigate the demand function of electricity for 24 OECD countries from the period 1978–2004. Our empirical results demonstrate that there is a strongly non-linear link among electricity consumption, real income, electricity price, and temperature, a result that is new to the literature. As real income rises, electricity consumption rapidly increases first, and after the level of real income exceeds approximately US$2500, its increasing rate turns slow down. An increase in electricity price has a negative or no influence on electricity consumption. Evidence of a U-shaped relationship between electricity consumption and temperature is supported, and the threshold value of temperature is approximately 53 °F, which is endogenously determined. Furthermore, the estimated elasticities of time dynamic indicate that electricity demand is income inelastic, price inelastic, and temperature inelastic. As time goes on, the absolute elasticities of electricity demand gradually decrease with respect to real GDP and electricity price, whereas they gradually increase with respect to temperature, suggesting that the impact of temperature on electricity demand is becoming more important in recent years.

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1. Introduction

Electricity plays an important role in economic development and technological progress in many countries. "No country in the world has succeeded in shaking loose from subsistence economy without access to the services that modern energy provides" (World Bank, 1996). For developed countries, Ferguson et al. (2000) indicate that there is a strongly positive correlation between wealth and energy (or electricity) consumption, and the correlation between electricity and wealth is stronger than the correlation between total energy and wealth. However, the process of electricity production and consumption may emit air pollution and greenhouse gasses. The long-run accumulated greenhouse gas emissions are an important factor for global warming, which accelerates unusual climate change in the world.

Many countries have paid attention to greenhouse gas emissions and problems of global warming. In 2005 the Kyoto Protocol was drawn up and co-signing countries agreed to reduce greenhouse gas emissions by 5.2% from the level in 1990. Since the greenhouse effect and the reduction of pollution emissions are global concerns, one needs to clarify the determinants of electricity demand, which include real income, own price, climate change, and so on. Accurately estimating and analyzing the determinants of electricity consumption can provide some information for governments to discuss and anticipate the supply and demand of electricity, and then provide the basis of setting up appropriate environmental policies, i.e. pollution and energy taxes. Thus, in the framework of global data, it is more important to investigate electricity demand.

The paper aims to make the following contributions to the electricity demand literature. First, we apply the panel smooth transition regression (PSTR) model of González et al. (2005) to investigate the relationship among electricity consumption, real income, electricity price, and temperature for 24 Organization for Economic Cooperation and Development (OECD) countries from the period 1978–2004. Which economic variables could possibly explain the transition from one regime to another? In order to find out the optimal threshold variable of the electricity demand model, this study carries out non-linear tests by way of the potential threshold variables (Fouquau et al., 2008; Huang et al., 2008), which are real GDP per capita (Model (1)), electricity price (Model (2)), and temperature (Model (3)).

Second, most studies in the literature focus on analyzing the demand elasticities of electricity with respect to electricity price and income, but they seldom consider the impact of climate change on electricity consumption. How significant is temperature for the rising electricity consumption? We enrich the existing literature by simultaneously examining the impacts of real income, electricity price and temperature on electricity consumption and take into account endogenous determination of the types of our PSTR models for electricity demand.

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Third, based on the characteristics of the PSTR model, we can consider the elasticity of electricity demand changes with country and time to analyze the elasticities of heterogeneous countries and the potential impacts of structural breaks (parameter instability) on the electricity demand's elasticities in the panel framework. The structural breaks are a common problem in macroeconomic series when they are usually affected by exogenous shocks or regime changes in environmental or economic events, i.e. economic development, energy crisis, global warming, the Kyoto Protocol, renewable energy technology, and so on (Lee and Chang, 2007; Lee and Lee, 2009).

Fourth and finally, many existing studies have found unidirectional causality from electricity consumption to real income and/or from real income to electricity consumption (Jumbe, 2004; Lee and Lee, 2010; Mozumder and Marathe, 2007; Ouédraogo, 2010). On the other hand, greenhouse gas emissions may increase with electricity consumption and then lead to rising temperatures (global warming), whereas an increase in temperature also influences electricity consumption. Thus, the problem of potential endogeneity exists in the electricity demand model.[1] To the best of our knowledge, none of the studies on electricity demand in the existing literature to date notice this problem. To consider the potential endogeneity biases, we apply the PSTR model with instrumental variables developed by Fouquau et al. (2008).

The remainder of this study is organized as follows: In the next section, we discuss the reasons why it is important to test for nonlinearity in the energy demand model. Section 3 introduces the PSTR model with instrumental variables and illustrates the variables' definitions and data sources. Section 4 describes the data specification. Section 5 provides the empirical results, and a conclusion is offered in Section 6.

2. Importance of the non-linear analysis of the energy demand model

Looking at history, the two energy crises were a clear sign of their very strong shocks to the world's energy markets, which undoubtedly impacted the economic activities of almost every country, forcing them into a recession and causing them to adopt severe energy-cutting measures. However, a change in an administration's energy policy results in a heavy impact on people's energy consumption habits, and this surely brings about structural change in the relationship between energy consumption and macroeconomics. If one neglects the possibility that the function of demand for electricity could be non-linear, then the results obtained by using linear time series specifications often cause bias, due to using a false estimation method. The non-linear model provides a fair discussion in line with the relationship proposed in earlier studies. The full information is made available to policy-makers, which indicates that the government plays a useful role in establishing the energy policy and that policy-makers should grasp the economic structure associated with different stages of economic development.

Gabreyohannes (2010) shows that the inclusion of the non-linear part, which basically accounts for the arrival of extreme price events, leads to improvements in the model's explanatory abilities for electricity consumption. In order to reflect the non-linear characteristic of energy demand, Olatubi and Zhang (2003) arbitrarily add the energy price squared and income squared terms into the energy demand model. Pao (2006) considers the temperature squared and income squared terms in the electricity demand model. Fouquau et al. (2009) utilize the PSTR model to estimate the energy demand model. They find evidence of a non-linear (inverted U-shaped) energy-income nexus. Wirl (1991), Walker and Wirl (1993) and Haas and Schipper (1998) indicate that price elasticities of energy are different for rising and

falling prices—that is, higher price elasticities for price increases, and lower price elasticities for declining prices. It means that price elasticities of energy are asymmetric, and there is a non-linear relationship between energy consumption and own price.

Climate change is related to the concentration of greenhouse gasses in the atmosphere. There is an obvious connect between climate change and energy consumption. In theory, Jager (1983) indicates that there is a V-shaped relationship between temperature and energy consumption. Hsing (1994) investigates the determinants of residential demand for electricity in five southern states of the U.S. Hsing finds a V-shaped electricity–temperature nexus. Fung et al. (2006) also show a V-shaped relationship between total electricity consumption and averaged temperature in Hong Kong.

By using heating degree-days (HDD) and cooling degree-days (CDD),[2] Valor et al. (2001), Pardo et al. (2002) and Al-Iriani (2005) assume that the reference temperature is 18 °C to investigate the electricity–temperature nexus for Spain and the United Arab Emirates. Mirasgedis et al. (2006) assume that the reference temperature is 18.5 °C and examine the impacts of temperature on electricity demand in Greece. Ruth and Lin (2006) assume that the reference temperature is 53 °F or 60 °F to investigate the impacts of climate change on electricity and natural gas. The above five studies find that an increase in HDD and CDD will raise electricity consumption, meaning that there is a non-linear (V-shaped) relationship between temperature and electricity. Furthermore, using the non-linear models, Moral-Carcedo and Vicéns-Otero (2005) evidence of a U-shaped relationship between electricity and temperature, and the threshold temperature is approximately 15.42 °C in the LSTR model. Bessec and Fouquau (2008) adopt the PSTR model to examine the non-linear relationship between electricity consumption and temperature in Europe and find that this non-linear pattern with 16.1 °C of threshold temperature is more pronounced in warm countries. Thus, this study adopts a non-linear PSTR model with instrumental variables to analyze the function of demand for electricity consumption within a panel framework.

3. Methodology

Following González et al. (2005) and Fouquau et al. (2008), the two-regime PSTR model with fixed effects is defined as follows[3]:

$$LELE_{it} = a_i + b_1 LRY_{it} + c_1 LELEP_{it} + d_1 LTEMP_{it} \\ + (b_2 LRY_{it} + c_2 LELEP_{it} + d_2 LTEMP_{it})g(q_{it-1}; \gamma, \theta) + \varepsilon_{it} \quad (1)$$

Here, $LELE$ represents log-transformed per capita electricity consumption; LRY is log-transformed per capita real GDP; $LELEP$ is log-transformed real electricity price; $LTEMP$ is temperature; ε is the error term; $t = 1, 2, …, T$ time periods; and $i = 1, 2, …, N$ countries. Coefficients a_i allow for the possibility of unit-specific fixed effects. As noted by van Dijk et al. (2002), the threshold variables may be exogenous variables or a combination of the lagged endogenous one. In this study we adopt the lagged variables as the potential threshold variables q_{it-1}, including LRY_{it-1} (Model (1)), $LELEP_{it-1}$ (Model (2)) and $LTEMP_{it-1}$ (Model (3)), and investigate which one is the optimal threshold variable. The function $g(q_{it-1}; \gamma, \theta)$ is a transition function of the observable variable q_{it-1}, continuous and bounded between 0 and 1. The threshold variables q_{it-1} may be exogenous variables or a combination of the lagged endogenous one (van Dijk et al., 2002). Following González et al.

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[1] We use a non-linear causality test developed by Diks and Panchenko (2006). The results show evidence of a reversed causality running from electricity consumption to real income and electricity prices.

[2] HDD and CDD are defined as $HDD = \max(T_{ref} - T_t, 0)$ and $CDD = \max(T_t - T_{ref}, 0)$, where T_{ref} is the reference temperature.

[3] The main advantage of this formulation compared to other models presented in the literature (Fouquau et al., 2009) is that it allows not only the effect of real GDP on electricity consumption to differ across regimes, but also allows for the effects of real electricity price and temperature to differ across regimes.