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U.S. Disaggregated renewable energy consumption: Persistence and long memory behavior

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ABSTRACT

This study examines the degree of time persistence in U.S. disaggregated renewable energy consumption (hydropower, geothermal, solar, wind, wood, waste, and biofuels) using innovative fractional integration and autoregressive models with monthly data for the period 1994:2 to 2011:10. The results indicate that in the case of hydropower, solar, wind, waste, and biofuels the estimates of fractional integration are higher than 0.5 but less than 1.0 implying nonstationary, but mean reverting behavior. In the case of geothermal and waste the estimates of fractional integration are around 0.5 and in the boundary case between stationarity and nonstationarity. For wood, the estimate of fractional integration is significantly smaller than 0.5 and thus showing stationary behavior with long memory behavior. Furthermore, the study incorporates the presence of breaks in the data with the absence of breaks in hydropower, geothermal, solar, wind, wood, and biofuels, but a single break in the case of waste due to the inclusion of non-renewable waste from non-biogenic sources through 2000. The results reveal that U.S. disaggregated renewable energy consumption measures are better explained in terms of a long memory model that incorporates persistence components and seasonality.

1. Introduction

In the wake of the Kyoto Protocol policymakers and researchers have begun to invest heavily in the development of renewable energy resources and technology to alleviate the dependence on fossil fuel energy sources. The investment of renewable energy sources and technologies will not only enhance the modernization of the energy sector as a whole, but also alleviate the limitations associated with current energy consumption mix in the promotion of a more sustainable one (Kaygusuz, 2007; Kaygusuz et al., 2007). Unlike fossil fuel energy sources, renewable energy sources (hydropower, geothermal, wind, solar, wood, waste, and biofuels) are sustainable and can be regenerated.

According to the U.S. Energy Information Administration *International Energy Outlook 2011*, renewable energy is the fastest growing energy source in the world with renewable energy consumption increasing by 2.8% per year. Renewable electricity generation is also the fastest growing source of electric power increasing 3% per year with hydroelectric and wind power as the two largest contributors to the increase in renewable electricity generation. In the U.S., renewable energy consumption contributes roughly 8% of total energy demand and comprises 10% of total U.S. electricity generation. In 2009, U.S. renewable energy consumption included hydropower (35%), wood (24%), biofuels (20%), wind (9%), biomass waste (6%), geothermal (5%), and solar (1%). The recent growth in renewable energy stems in part from higher prices for fossil fuels along with a number of incentives through federal and state government legislative initiatives.[2] Over the period of this study from the early 1990s onward, there have been a number of U.S. federal legislative actions to reduce carbon emissions, improve energy efficiency along with the promotion and development of the renewable energy sector and technologies: Energy Policy Act of 1992, Energy Policy Act of 2005, Energy Independence and Security Act of 2007, Energy Improvement and Extension Act of 2008, and the American Recovery and Reinvestment Act of 2009. In addition, 37 states currently have either mandatory or voluntary renewable energy portfolio standards for electricity generation. Such legislative actions have resulted in policies to expand the use of renewable energy via renewable energy production tax credits, tax credits and financial incentives for renewable energy systems, customer net metering services, feed-in tariffs, market share quotas, renewable energy portfolio standards for

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[2] *Energy in Brief*, "How Much Renewable Energy Do We Use?", www.eia.gov/energy_in_brief/renewable_ energy.cfm.

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electricity generation, green power programs, and the establishment of markets for renewable energy certificates.[3]

Given the use of government policies to expand the renewable energy sector, this study disaggregates renewable energy consumption by energy source to determine whether shocks (i.e. policy-oriented) to the respective renewable energy sources have permanent or temporary effects. If renewable energy consumption contains a unit root, shocks will have permanent effects in which case the behavior of renewable energy consumption exhibits hysteresis or path dependency. On the other hand, if renewable energy consumption is stationary, shocks will result in a temporary deviation from the long-run growth path. The distinction between the permanent or temporary response of renewable energy consumption to shocks has several implications for policy and modeling. First, if renewable energy consumption contains a unit root positive shocks associated with a permanent policy stance, such as the establishment of renewable portfolio standards, will have a greater positive impact on the energy consumption mix between renewable and fossil fuel energy sources than if the shocks are temporary as such policies will have a minimal impact. Second, to the extent the renewable energy sector is integrated with the overall economy, shocks to renewable energy consumption that are permanent in nature (i.e. persistent) may be transmitted to other sectors of the economy.[4] Third, whether renewable energy consumption contains a unit root is useful in the modeling and forecasting of future renewable energy consumption. If renewable energy consumption is stationary, then the past behavior of renewable energy consumption can be used in the generation of forecasts whereas if renewable energy consumption is nonstationary, the past behavior of renewable energy consumption provides little or no use in forecasting.[5]

Previous research on the permanent or transitory nature of shocks to energy consumption and production has focused on determining whether the energy variable in question follows either a stationary, I(0), or nonstationary, I(1), process. However, the number of differences required to render a time series stationary, I(0), may not be an integer value, but any point in a real line in which case the time series is said to be fractionally integrated, I(d), where d can be a value between 0 and 1, or even above 1. This is relevant in the sense that it allows us a much richer degree of flexibility in the dynamic specification of the time series, at the same time including the classical cases of I(0) and I(1) behavior as particular cases of interest with $d = 0$ and $d = 1$, respectively. We apply the fractional integration methodologies used by Lean and Smyth (2009), Gil-Alana et al. (2010), Apergis and Tsoumas (2011, 2012), Barros et al. (2011, 2012) with allowance for seasonality and structural breaks to estimate the degree of persistence and long memory behavior of U.S. disaggregated renewable energy consumption. Specifically, the fractional integration approach permits one to determine whether the respective time series is I(0) stationary ($d = 0$); stationary with long memory ($0 < d < 0.5$); nonstationary but mean reverting ($0.5 \leq d < 1$); or nonstationary and non-mean reverting ($d \geq 1$). Thus, the higher the value of d is, the higher is the degree of dependence in the data and the long effects of the shocks. This study extends the recent work on persistence and long memory behavior of U.S. renewable energy consumption by Apergis and Tsoumas (2011) and Barros et al. (2012) by investigating the consumption of various renewable energy sources: hydropower, geothermal, solar, wind, wood, waste, and biofuels, and allowing for seasonality and structural breaks. Specifically, Apergis and Tsoumas (2011) in their examination of U.S. solar, geothermal, and biomass energy consumption find that shocks to these energy sources are largely transitory whereas Barros et al. (2012) reveal that aggregate U.S. renewable energy consumption is nonstationary with mean reverting behavior. The main contribution of this study is to show that U.S. renewable energy consumption by energy source displays a high degree of persistence and long memory behavior, in line with other energy sources examined in the literature. Moreover, since fractional integration and structural breaks are issues which are intimately related (Diebold and Inoue, 2001; Granger and Hyung, 2004), we also investigate the long memory feature in the context of structural breaks.

Section 2 provides an overview of the literature pertaining to the integration of energy consumption and production. Section 3 discusses the data and methodology. Section 4 presents the empirical results with concluding remarks given in Section 5.

2. Overview of the literature

Research on the integration properties of energy consumption and production have only recently emerged in the literature (Smyth, 2012). Narayan and Smyth (2007) estimate augmented Dickey–Fuller (Dickey and Fuller, 1979) unit root tests of energy consumption per capita for 182 countries to find only 31% of the countries reject the null hypothesis of a unit root while Im et al. (2003) panel unit root tests yield stationarity. Using the Carrion-i-Silvestre et al. (2005) panel stationarity test with structural breaks for energy consumption per capita, Chen and Lee (2007) show stationarity in each of the seven regional country panels. Hsu et al. (2008) utilize the panel SURADF unit root test of energy consumption across five regional country panels to find nonstationary behavior. Mishra et al. (2009) uses the Carrion-i-Silvestre et al. (2005) panel stationarity tests with structural breaks of energy consumption per capita for 13 Pacific Island countries to find stationarity for roughly 60% of the countries while energy consumption per capita for the entire panel of countries is stationary. Narayan et al. (2010) employ the Lee and Strazicich (2003) unit root tests with structural breaks to investigate sectoral energy consumption in Australia and its six states to yield rejection of the null hypothesis of a unit root for most sectors except in the electricity sector of Tasmania and the transportation sector of South Australia. With the exception of aggregate energy consumption in South Australia, the rest of the states and Australia aggregate energy consumption is stationary.

Aslan and Kum (2011) estimate linear and nonlinear unit root tests for energy consumption in Turkey across seven sectors. In the sectors where linearity is not rejected, the Lee and Strazicich (2003) unit root tests with structural breaks yield stationarity; however, for the remaining sectors, Kruse (2011) nonlinear unit root tests yield non-stationarity. Hasanov and Telatar (2011) find that with the ADF tests of primary energy consumption per capita is stationary in 55 countries; the nonlinear unit root test by Kapetanios et al. (2003) reveals primary energy consumption per capita is stationary in 71 countries; and the nonlinear unit root test of Sollis (2004) yields primary energy consumption per capita is stationary in 121 countries. Ozturk and Aslan (2011) investigate energy consumption per capita by sector in Turkey using the Lee and Strazicich (2003) unit root test with structural breaks to show energy consumption per capita is stationary. Using the Lee and Strazicich (2003) unit root test with structural breaks, Kula et al. (2012) find that electricity consumption per capita is stationary for 21 of the 23 OECD countries.

Other studies have examined the integration properties of specific types of energy consumption. Lean and Smyth (2009) use the Nielsen (2005) fractional integration approach to examine the long memory behavior of U.S. disaggregated petroleum consumption to find that the commercial and industrial sectors are fractionally integrated whereas the residential sector is stationary. Apergis et al. (2010a) investigate natural gas consumption for the 50 U.S. states using the Levin et al. (2002), Im et al. (2003), Maddala and Wu (1999), and Hadri (2000) panel unit root and stationarity tests to show that natural gas consumption contains a unit root. However, once allowance is made for structural breaks, the Carrion-i-Silvestre et al. (2005), Im et al. (2005), and Westerlund (2005) panel unit root and stationarity tests reveal that

[3] *Energy in Brief*, May 1, 2008 from the Energy Information Agency (www.eia.doe.gov).
[4] Maslyuk and Smyth (2009), Mishra et al. (2009), and Smyth (2012) also discuss the relevance of whether energy consumption contains a unit root and its impact on output within business cycle theories.
[5] Understanding the degree of integration of renewable energy consumption is important in the construction of error correction models used to examine the energy consumption-growth nexus (see Payne, 2010a,b).