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Residential electricity consumption in Portugal: Findings from top-down and bottom-up models

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ABSTRACT

An econometric study of the Portuguese residential electricity consumption is presented, with a focus on the influence of dwelling characteristics on consumption. The relationship between the dwelling and household characteristics on per capita residential electricity consumption is estimated at two different scales, involving two distinct databases: the first includes data at the municipality level for 2001, the second is the most recent Portuguese consumer expenditure survey that was collected in 2005 and 2006. The results of the analysis at both scales are consistent and indicate that household and dwelling characteristics have a significant influence on residential electricity consumption. Our results show that in Portugal the direct effect of income on electricity consumption is low and becomes smaller when more relevant control variables are included in the analysis. Future demand of electricity in Portugal will be significantly influenced by trends in socioeconomic factors as well as changes in the building stock. These trends should be taken in consideration in the formulation of policy measures to reduce electricity consumption.

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1. Introduction

Obtaining a better understanding of the drivers of energy consumption has become an increasingly pressing issue over the last decades. It is an important issue for a number of reasons, but the most prominent ones are security of energy supply, climate change and affordability of energy. All of these concerns are directly linked to the way our societies consume energy. The strong dependence on fossil fuels has been recognized as a security threat in countries that are major importers of energy (Umbach, 2010; Bielecki, 2002) and affordability is an issue for transition economies (Fankhauser and Tepic, 2007). Climate change is largely driven by greenhouse gas (GHG) emissions that originate from the combustion of fossil fuels (IPCC, 2007). As a reaction to these facts, many countries committed to reduce GHG emissions under the Kyoto protocol (UNFCCC, 2010). Also, the promotion of renewable energy forms and diversification in energy sources is on the agenda of many of these countries.

Portugal is no exception in this regard. It is currently not meeting its GHG emission reduction targets that have been negotiated with the European Union (Eurostat, 2009b) and it imports 83% of its energy needs (Eurostat, 2009a). This has motivated the country to diversify its energy sources and brought energy policy to the forefront of the country's concerns. Portugal has significantly shifted its electricity production system by introducing natural gas power plants, new hydroelectric power plants and wind energy. Electricity production from natural gas has increased from zero to 12.3 TWh between 1996 and 2006 and has become a significant part of the total yearly electricity consumption of 46.9 TWh. The total installed capacity for production from all types of renewable energy sources has doubled from 1995 to 2009 and has reached 9.2 GW, by March 2010. Although the production capacity has grown for all types of renewable energy, the increase in this period has largely been driven by the introduction of 3.6 GW of capacity for the production of electricity from wind energy (DGEG, 2010).

Despite this significant increase of installed capacity, the share of renewable energy sources for electricity production has not yet increased. The five year average of the production of electricity from renewable energy sources in the period from 1994 to 1998 was 35%, whereas the five year average from 2004 to 2008 was 26% (DGEG, 2010). The reasons for this decrease are twofold. On the one hand the average production from renewable energy sources is almost the same for both periods. The higher capacity for production from renewable energy sources in the later period has not resulted in higher production due to the weather conditions. On the other hand the total electricity demand has constantly increased. The combination of both of these facts resulted in a relative decrease of the share of renewables.

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Compared with the European Union, Portugal has still a relatively low per capita consumption of energy (Eurostat, 2009a). With gross inland energy consumption per capita of 2.45 toe, the average Portuguese citizen consumes 30% less energy than the average citizen of the European Union. This difference goes down to 20% when only electricity consumption is considered. Similarly, the per capita GHG emissions are low by European standards, the emissions of CO_2 equivalent per capita are 7.7 tCO_2e in Portugal versus 10.2 tCO_2e in the European Union. The mix of primary energy consumption in the Portuguese residential sector by energy source in 2009 was as follows: liquefied propane gas 16%, natural gas 8%, other oil derived fuels 1%, electricity 38%, solar thermal 1% and biomass 36% (DGEG, 2011).

The council of ministers of Portugal has recently formulated an ambitious national energy strategy for 2020 (Presidência do Conselho de Ministros, 2010). The goals of this strategy include the reduction of energy dependence to 74% and to increase the share of renewable energy sources in final energy consumption to 31%. The goal for electricity generation is to reach 60% from renewable energy sources by 2020. The strategy also proposes to create economic clusters around the production of renewable energy and energy efficiency.

Policy measures targeted to reach these ambitious goals have to be well informed and, therefore, a good understanding of the drivers of electricity consumption is important. In this paper we study the residential electricity consumption in Portugal using multivariate regression analysis. The residential sector is responsible for about 17% of the country's total final energy consumption and for 21% of the total electricity consumption. We test variables describing household characteristics as well as the corresponding dwelling characteristics. We do so both at an aggregated level (top-down) and at the individual household level (bottom-up). This allows a direct comparison of results from different scales of analysis and increases the reliability of the estimates. We test a number of proxies that can be used to describe the housing stock at the aggregated level and that could possibly be integrated in future top-down studies.

Portugal provides a relevant case study as it represents a transitional economy, as discussed by Niza and Ferrão (2006). Its development pattern in the last decades show a linear correlation between natural resources consumption and GDP. This is a pattern that is being followed by the major emerging economies in the world, therefore analyzing its electricity demand structure can provide relevant insights for the global effort of sustainable development.

The rest of this paper is organized as follows: in Section 2 we provide an overview of the most recent literature that is relevant for this study. A description of the regression models and the data sources is given in Section 3. The main insights are summarized Section 4 and discussed in Section 5.

2. Literature review

There are few studies that are concerned with the electricity sector in Portugal, and to our knowledge there is only one study that has analyzed the Portuguese electricity consumption from an econometric perspective (Carmona, 2006). In his master's thesis, Carmona (2006) uses cointegration techniques to analyze residential electricity consumption between 1957 and 2002. The study found an income elasticity of 1.1, which is in contradiction with the literature where electricity consumption is usually found to be price inelastic. The value for Portugal was obtained without having other control variables in the model and is, therefore, a simple and possibly biased estimate.

Ferreira et al. (2007) provide an analysis of the Portuguese electricity market from a regulatory and economic perspective. They find that although the electricity market was liberalized in 2004 it is still strongly dominated by one player, Energias de Portugal (EDP). Also they point out that in practice the final consumer could not choose the provider freely until September 2006.

Due to its particular geography, Portugal has a large potential for solar, wind and wave energy. There are a number of studies that approach the topic from an engineering perspective and analyze the potential for electricity production from renewable sources and also nuclear power (Estanqueiro et al., 2008; Mollison and Pontes, 1992; Gomes, 2008).

On the international stage, residential energy consumption is a heavily studied subject. There is a large body of literature that has recently been summarized by Swan and Ugursal (2009) in a comprehensive review. The reviewed studies are divided into top-down and bottom-up studies, based on the level of aggregation of the data that is used. Since we analyze electricity consumption in Portugal at two scales, this distinction is relevant for our case and we adopted it, but with a focus on electricity.

Top-down studies often use time-series data that is aggregated to the national or regional scale to estimate price and income elasticities of electricity demand. Typically, the per capita electricity consumption is regressed on its own price, the price of a substitute for electricity and a measure of income such as gross domestic product. Due to data constraints the use of other control variables is limited and the only variables that are sometimes included are climate (degree-days) and the level of urbanization. For example, Halicioglu (2007) studies residential electricity consumption in Turkey using a cointegration approach (autoregressive distributed lag, ARDL). The estimated model relates the natural logarithm of per capita residential electricity consumption with income per capita, price and the level of urbanization. The level of urbanization is proposed as a measure of economic development and an increased urbanization has been found to drive energy consumption up. A series of other studies have used very similar methodologies to estimate price and income elasticities for residential electricity demand (Holtedahl and Joutz, 2004; Narayan and Smyth, 2005; Dergiades and Tsoulfidis, 2008; Amusa et al., 2009). The first international comparison of price elasticities has recently been published by Azevedo et al. (in press) using panel data methods and testing different model specifications. In all the studies cited there, the short-run elasticity is found to be smaller than the long-run elasticity and most of the studies find that electricity consumption is price and income inelastic.

The studies using a bottom-up approach have more diverse goals and methodologies, but at that scale data is mostly cross-sectional and time-series data is scarce. Micro-scale electricity consumption data is usually collected in surveys or measured directly. In contrast to the literature that uses a top-down approach, multivariate analysis is still rather scarce in bottom-up analysis. Poulsen and Forrest (1988) point out that using multivariate regression techniques enable the importance of income to be disaggregated from other socioeconomic and dwelling characteristics. They observe that dwelling size and family structure are significant determinants of consumption. A more recent example for multivariate analysis using survey data is given in Filippini and Pachauri (2004). In agreement with the literature at the aggregated scale, their findings show that the short-run elasticity is smaller than the long-run elasticity. Dwelling characteristics, demographic and geographical variables are found to be significant. An analysis where data is directly measured is Yohanis et al. (2008). For this study the consumption profiles of 27 households in the UK have been measured in half hour intervals during a period of three months. The profiles are

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