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Technology invention and adoption in residential energy consumption A stochastic frontier approach

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ABSTRACT

In this paper we analyse the electricity consumption of a set of four traditional 'white goods' in a panel of ten EU countries observed over the period 1995–2013 with the aim of disentangling the amount of technical efficiency from overall energy saving using a stochastic frontier approach. The efficiency trend is modelled as a function of energy efficiency policies and innovation dynamics that combines invention and adoption processes using specific patents weighted by granular production data and worldwide bilateral import flows. Our model also accounts for potential endogeneity arising when innovation processes and economic growth are considered. With this replicable approach, the stochastic frontier framework allows for explicit modelling of innovation processes. Our results show that the efficiency component is related to changes in the energy efficient technological content of appliances. The 'international' component represents a predominant share of technological advancement and exerts a significant influence on the transient efficiency. Our evidence calls for an active role to be played by policy makers in focusing on innovation and trade policies in order to achieve more ambitious energy efficiency targets.

1. Introduction

Energy efficiency (EE) constitutes one of the most cost-effective strategies for reducing the amount of primary energy consumption, thus contributing to increased energy security and lower greenhouses gas emissions (GHGs). It is thus not surprising that EE has scaled up its role in EU climate and energy strategies. The "2030 Climate and Energy Framework" approved by the European Commission in 2014 combines a target for GHGs reduction (40% by 2030 compared with 1990 levels) with a specific target on energy efficiency in the order of 27% of energy efficiency improvements by 2030 with respect to the business as usual scenario (EC, 2014).

Despite numerous studies that analyse the contribution that energy efficiency makes to reducing energy consumption, we identify two major gaps in the literature. First, although EE is intrinsically related to technology (Linares and Labandeira, 2010; Hartman, 1979; van den Bergh, 2011), the role of innovation is not explicitly accounted for in existing studies. The second gap relates to the limited focus of the existing literature on the household sector, which nowadays represents a major concern for policy makers given its increasing role in the portfolio of energy services.

In this paper we attempt to fill these gaps by employing an original panel dataset of 10 EU countries observed over the period 1995–2013 to analyse the drivers of households' electricity demand for a set of four traditional large electrical appliances. We go beyond the original contribution of Filippini et al. (2014), who analysed the role of policies as a major determinant of efficiency gains, by enriching the framework with explicit modelling of EE-related innovation (invention and adoption). In particular, we account for innovation dynamics to explain the mechanism that triggers a substantial reduction in electricity consumption for major large home appliances. A stochastic frontier analysis (SFA) is employed to disentangle the amount of energy saving observed in the demand estimation due to improved technical efficiency. The derived demand frontier allows for explicit modelling of technical efficiency

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which includes the contribution made by both EE policies and technology invention and adoption as sources of efficiency improvements that impact overall electricity consumption.

In line with previous studies, our results confirm that the gains in technical efficiency and associated consumption reduction are related to the number of in-force EE policies which include demand-pull instruments aimed at stimulating households to purchase more efficient appliances (e.g. labelling of appliances, price schemes, etc.). However, this evidence does not account for the role of supply-push regulations (e.g. incentives to manufacturers for eco-design) and other endogenous firms' activities (e.g. voluntary agreements based on corporate social responsibility and market opportunities for better technologies) which guarantee a growing availability of innovative energy efficient appliances on the market. Both these components are captured by our innovation proxy. When the latter enters the efficiency equation, the significance of policy disappears in favour of a strong significant impact of our innovation proxy. The magnitude of the estimated impact of our indicator of technological change, which also accounts for novel technologies embodied in imported electrical appliances, induces a consideration to be made regarding the importance of looking at the key complementary roles of supply side regulations and trade policies, whose effects trigger the invention process of more advanced appliances and its diffusion in (international) markets.

The rest of the paper proceeds as follows. In Section 2, we describe the conceptual framework on which our analysis is based and review some relevant studies that analyse the determinants of EE in the residential sector. We stress the limitations of these studies and introduce the main contributions to our analysis. In Section 3, we describe the data and empirical strategy used to estimate the electricity stochastic frontier demand function. Section 4 presents the econometric results together with the efficiency scores obtained from our model and Section 5 concludes the paper with some policy implications. The limitations of the present work and further research insights are also discussed.

2. Conceptual framework

2.1. Trends of residential electricity consumption and EE

Official statistics (EC, 2012a; Bertoldi et al., 2016) suggest that the residential sector accounted for about 30% of total final electricity consumption in the EU27 (year 2010) and that such a share does not seem to be slowing down. In particular, traditional large home appliances (freezers, refrigerators, washing machines and dishwashers) were responsible in 2007 for 25% of households' electricity consumption as opposed to other appliances such as information and communication technologies characterized by smaller energy needs than the so-called "white appliances" (Bertoldi et al., 2016).[1] Moreover, home appliances generally consume electricity instead of renewable fuels or direct combustion fuels, with a significant carbon footprint in countries where electricity production is carbon intensive (Cabeza et al., 2014). According to IEA forecasts, appliance consumption is expected to increase at a higher rate than the building sector as a whole (IEA, 2013) given the increasing demand for new goods. Since the latter are crucial to fulfilling primary needs such as food conservation or washing, they can be characterized as fully complementary goods to household dwellings. It is thus not surprisingly that white appliances, in particular refrigerators, have almost reached saturation point among EU dwellings (IEA, 2009) and that their market is characterized by a high rate of substitution of old equipment rather than by an increase in household stock. Consequently, the residential sector represents a special target of the EU mitigation strategies to ensure future patterns of decreasing electricity consumption and a low-carbon transition (EC, 2011; IEA, 2013; OECD, 2003). Among others, EE emerges as an effective, low-cost strategy to reduce households' electricity consumption without limiting the utility associated with energy services (Ramos et al., 2015).

EE is strongly linked to the technological level of the equipment that is used to obtain a certain energy service. For instance, a more efficient dishwasher provides a higher number of washes while using the same or less electricity. The availability of new energy efficient appliances developed by manufacturers and progressively adopted by households to replace older ones represents a key driver of electricity saving. Even though constituted by mature technologies, both cooling and washing appliances still offer a great saving potential given their widespread presence among a multitude of household dwellings. A study by McKinsey (2009) points to the cost-effectiveness of EE gains deriving from electrical appliances compared with those deriving from other sectors and a more recent one (McKinsey, 2012) shows how the impacts of technology, policy regulations and consumer behaviour are likely to transform the EU residential energy market in the coming years.

2.2. Barriers to EE and the role of policies

Despite the fact that EE gains imply a large saving potential, market forces alone do not seem to achieve this potential. Several studies point out that available EE technologies are often adopted at sub-optimal levels, identifying barriers of a different nature (Brown, 2004; Jaffe et al., 2004). This phenomenon is known as the "EE gap" and can be defined as the perceived gap in uptake of existing energy efficient technologies despite the fact that the latter are characterized by positive net present values (Jaffe and Stavins, 1994; Gillingham and Palmer, 2014). This translates into slower-than-optimum paces of EE technology adoption (demand side) and, consequently, in weaker market stimuli for firms to innovate (supply side). The studies also stress the active role of regulation in boosting technological development and adoption which facilitates the replacement of older equipment with more efficient models. Consequently, the initial political interest in increasing residential EE is nowadays a political priority considering the multiple benefits of EE. This is translated into a growing, complex regulatory activity aimed at closing the EE gap with a combination of EU legislation (energy labelling and minimum energy performance standards[2]), national programmes (e.g. purchase incentives in Italy, price rebates in Spain, supplier obligations and White Certificate schemes in France, Italy and the UK) and Corporate Social Responsibility strategies (e.g. voluntary agreements of manufactures[3]). In particular, the 'Eco-design Directive' for Energy-Using Products (EuP Directive 2005/32/EC), the introduction of energy labelling for electric devices (Directive 92/75/ECC) or more recently, the Energy Efficiency Directive approved in 2012 (EC, 2012b), establish a set of binding measures to help the EU reach ambitious energy efficiency targets.

Several empirical studies have analysed the effectiveness of policies aimed at improving EE in the residential sector. Jaffe and Stavins (1995) measure the impact of energy prices, adoption subsidies and building codes on the home EE level in the United States between 1979 and 1988, and find that government subsidies have a stronger effect on the buildings' average level of EE than that induced by increasing energy prices. Unlike technology standards, energy taxes were associated with an increasing adoption of new technologies. Even though the effect is found to be relatively small, the authors conclude that building codes are often set too low to be effective. Newell et al. (1999) test the

[1] The portfolio of energy services available for households has massively increased over the last 40 years with a strong penetration of new devices and appliances aimed at satisfying these services. See Burwell and Sweezey (1990).

[2] The Eco-design of the Energy-Using Products Framework Directive 32/2005/EC (Eco-design Directive), the end-use energy efficiency and energy services Directive 32/2006/EC (ESD), the Energy Performance of Buildings Directive 91/2002/EC (EPBD, under recast) as well as the Labelling Directive 75/1992/EC (under recast) contribute significantly to implementing the energy-saving potential in the European Union. Accompanying and completing EU legislation, many energy efficiency measures concerning financial incentives, supplier obligations, information, etc. have also been adopted by the Member States.

[3] An example is the Conseil Européen de la construction d'appareils domestiques (CEDEC).