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Energy Efficiency in Energy Policy: Empirical Evidence of Direct Rebound Effect in Portuguese Households' Demand for Electricity.

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Abstract

This project estimates the direct rebound effect for the household electricity demand in Portugal. While we find evidence of such an effect, the estimations also reflect the institutional arrangement that has characterized the electricity market in the country. Also, issues related to energy efficiency promotion are addressed in general putting into context the case study developed.

Keywords: Energy efficiency; direct Rebound effect; energy consumption; Energy efficiency gap;

1. Introduction

Proponents of energy efficiency in the context of energy policy have advocated its use to curb energy consumption and mitigate security concerns in the attempt to address the externalities related to energy production, as is the case of GHG emissions. However, the literature does point out to the existence of rebound effects (direct, indirect and economy-wide), whenever technological developments allow for the use of resources more efficiently, speeding up their rate of consumption and, subsequently, the rate of emissions – this is known as the Jevons Paradox.

When in the presence of the rebound effect, it's possible that the policies aiming at curbing energy consumption, as a means to alleviate energy production externalities via the allocation resources to energy efficiency, might lead to perverse incentives. Nonetheless, instruments intending to promote energy efficiency have been subscribed by several countries.

Under the Portuguese National Energy Efficiency Action Plan (NEEAP) a number of pecuniary and non-pecuniary policies are being implemented to promote energy efficiency. Notwithstanding, a more fundamental paradigm shift is occurring under the Memorandum of Understanding (MoU), where Portugal is hereby required to liberalize, at least partially, its energy markets with expected price increases in an attempt to reduce the energy deficit. Furthermore, externalities related to the production of electricity combined with subsidized energy prices, which muddle the information channels regarding the actual cost of production, possibly result in an over-consumption of electricity. As such, the point in contention requires that these two changing archetypes be addressed in a symbiotic perspective, accounting for possible rebound effects on the demand-side of the electricity markets. Therefore, it is important to acknowledge the magnitude of such effects the rebound effects both in the short-run and the long-run. This is an empirical question with relevant important implications. In this context, in this project, we attempt to estimate the direct rebound effect for household electricity consumption in Portugal, that is, the one that occurs when an improvement in energy efficiency for a particular energy service reduces the effective cost of the service leading to an increase in energy consumption.

Finally, despite the current policy efforts to promote energy efficiency, it's important to discern why exactly it is that consumers have not responded in accordance with what is perceived to be a fundamentally rational adoption of cost-saving energy efficient technology. An attempt to establish a possible venue for policy instruments to capitalize on the connection between behavioral factors and the adoption of energy efficient demand-side technology is undertaken.

2. Energy Efficiency in the Electricity Market

A recent study by McKinsey (2007) points out that the residential sector represents about 25% of total end-use energy demand and potentially harbors the highest opportunity for efficiency investment, equivalent to 21% of residential demand by 2020**.** As such, energy efficiency is usually linked to energy conservation and is commonly regarded as a possible solution to attenuate problems linked to production externalities, such as undesirable Greenhouse Gas (GHG) emissions and energy security, in a second-best scenario, to achieve a given level of energy-based services and good. As energy efficiency increases the amount of required inputs would decrease without resulting in output shrinkage along with energy consumption. However, for this rationale to be completely validated it is imperative to estimate the magnitude of the rebound effect.

Understanding whether or not, as well as when and how, intervening to promote energy efficiency under these auspices is justified is a central concern. Usually, efficiency investments are thought to represent a parallel shift in the demand for energy, where an increase in efficiency leads to less energy inputs demanded. This conception crumbles considering how individuals cannot gain utility from energy-based services when energy inputs are null, as energy is always required under current technology. If the impact of an increase in energy efficiency actually resulted in such a blanket curtailment in demanded electricity, total consumer welfare from a given amount of energy would increase along with energy efficiency, and the demand for energy would be subject to a completely different impact altogether for any variation in the level of energy efficiency. As such, a greater level of energy efficiency entails a higher electricity price elasticity, which can be traced back to the falling marginal effects of energy efficiency on the reservation price of electricity, at high levels of energy consumption.

When the aforementioned factors are considered, an increase in energy efficiency denotes that the marginal willingness to pay falls after a certain efficiency threshold is attained, causing the demand curve to pivot. This being the case, when the price level is sufficiently high, above the aforementioned pivot, energy and energy efficiency become complementary goods and are no longer substitutes, as happens for low energy prices (Brennan 2009, 2011). As the use of smart-meters and other demand-side infrastructure improvements also results in increasing prices, the same problem may arise. In this case, energy efficiency should be taxed or discouraged by policy.

3. The Rebound Effect

While the rebound effect is characterized by both direct and indirect components (Khazzoom, 1980), the indirect effect implies that efficiency gains generate potential economic growth that would otherwise not have been possible and as output increases the overall cost of goods decreases through an income effect, thereby increasing consumption of other goods and services, resulting in a higher demand for resources related to production. The direct effect, on the other hand, is associated with the substitution effect, linking energy efficiency gains to lowered costs of energy consumption. As increased efficiency implies that consumption becomes cheaper, an incentive for additional demand of energy-based services and goods exists, assuming that the price elasticity of demand is not null, thereby counterbalancing what would have otherwise been savings had the demand for energy not increased.

In the context of energy policy, where energy efficiency is often promoted as a means to reduce overall energy use, the rebound effect can generate significant problems depending on its magnitude. Therefore, it is crucial that the subsequent foregone savings are accounted for when assessing instruments to avoid skewed outcomes. An extreme example of the rebound effect, deemed as a “backfire”, results in expected savings from higher levels of energy efficiency being completely offset (Saunders 1992).

Measuring the rebound effect for each policy scope is extremely important due to its heterogeneous nature and interconnectedness with energy demand. For example, when the consumption of energy services increases, the saturation effect (from decreasing marginal utility) suggests that low income consumers would make up a larger share of the rebound effect, due to being farther away from satiation (Milne and

Boardman, 2000). Likewise, the lower cost of energy services implies an increase in consumer base, from first-time adoption, reflecting the lower discounted lifetime cost for affected appliances (Orasch and Wirl, 1997). Furthermore, empirical estimates of the direct rebound effect, based on household energy-based services, for OECD countries point towards a magnitude smaller than 30% (Sorrell et al., 2009), while in developing countries it may exceed unity (Sorrell, 2007), i.e. higher than 100%, due to a larger representation of marginal consumers, which reaffirms the consistency of the satiation hypothesis.

However, even in developed countries, individuals considered to be investing at the social optimum level in energy efficiency, despite a higher discount rate, are expected to utilize new, more efficient, appliances with higher intensity as a result of lower short-run marginal costs. If true, this tendency could potentially account for a significant portion of the direct rebound effect in developed countries (Sorrell et al., 2009).

Policy discussion on how to minimize the rebound effect in order to guarantee higher savings per efficiency investment is centered mostly on increasing the price of energy consistently, to mitigate the income effects, and by allowing energy prices to internalize the externalities related to energy production (Sorrell, 2007; Maxwell and McAndrew, 2011). However, special consideration is required when enacting such policies, if energy efficiency is being actively promoted, to avoid having higher energy prices leading to a complementary relationship between energy and energy efficiency, as previously discussed. Conceding that this is indeed the case, the higher energy price would imply that policy promoting energy efficiency would booster energy consumption instead, exacerbating the rebound effect. Under these circumstances, the promotion of energy efficiency motivated by energy conservation through policy instruments no longer makes sense, leading to increasing economic inefficiency.

4. Behavioral Issues and the Energy Paradox.

4.1 - The Efficiency Gap and Consumer Failure

Consumer choice failures regarding what's perceived as an underinvestment in energy efficiency technology are known as the efficiency gap (Stavins et al., 2004) and serves as a rationale to support government intervention by its proponents. The extent, or existence, of fault in consumer behavior is still a point of contention. Behavioral critique is mostly centered on bounded rationality notions, market failures, arguments giving clout to adverse responses towards energy conservation, lack of capital or diverging public and private discount rates as probable causes for the lagging adoption of cost-effective energy efficient technology (Jaffe and Stavins, 1994). A reasonable explanation for households under-investing in energy efficiency suggests that it could originate from a discrepancy between the social and the private discount rates, and doesn't necessarily justify public intervention (Hausman and Joskow, 1982), as it might simply reflect the uncertainty of cost and benefits of technology investments (Sutherland, 1991) or artificially low social discount rates (Sutherland, 2003).

To explain part of the efficiency gap, considering capital constraints and private discount rates might shed additional light on the subject. In essence, high median income households appear to apply discount rates consistent with the social optimum when purchasing appliances, whereas lower income households fail to do so (Sutherland, 2003). Furthermore, through a British household survey, Jamasb and Meier (2010) have shown that those with the low income present reduced income elasticity of energy spending. In Portugal, however, estimates point to overall residential electricity demand appears being relatively income inelastic. Instead, demographic, housing, as well as appliance characteristics seem to be more relevant and ought to be given more weight; as if policy is overly focused on income its effectiveness might drop unexpectedly (Wiesmann, et al., 2011). Overall, energy-related expenditure appears to be significantly driven by household characteristics (Meier and Rehdanz, 2010).

When scrutinizing technology adoption specifically, of all household characteristics, the average level of education is particularly relevant (Brill, Hasset and Metcalf, 1999). Empirical results based on German and Italian household data seem to corroborate this hypothesis (Carraro, 2011). Other factors, however, do come into play when considering the phase-out of old technologies via imposed standards: evidence provided by Mills and Schleich (2010) suggests that the number of CFL bulbs installed in household lighting sockets is relatively fixed across socio-economic groups. These findings reveal a negative relationship between income and CFL adoption, as well as a positive relationship between income and total lighting applications.

All the previous points highlight the heterogeneity between consumers, driven by socio-economic grouping, implying different levels of energy efficiency investment and, therefore, sway technology choice. That said, the efficiency gap still warrants focusing on just how rational consumers actually behave and whether or not agents properly consider the discounted lifetime savings of new appliances when making new purchases. Specifically, rational consumers are expected to react positively to variations in energy efficiency, as they would to a decrease in the price of energy since both generate a similar impact on the cost of energy-based services (Sorrell et al. 2009).

Finally, consumer failure can be illustrated through the common anecdotal sentiment of prices being too high in tandem with over-consumption of electricity, which portrays an inconsistent, or flawed, outlook regarding energy markets, giving further credence to the consumer failure hypothesis (Brennan, 2009).

4.2 - Non-pecuniary incentives as policy instruments

From a behavioral perspective, the use of non-pecuniary incentives can be a viable vehicle to overcome consumer failure, thereby stimulating investment in energy efficient technology. Abrahamse and Steg (2011) have studied both household energy consumption and the factors affecting individual alignment with energy conservation, apparently driven mainly by psychological determinants, from a socio-demographic stand-point, through customers of a utility company. Their empirical observations hint towards energy use being strongly dependent not only on household characteristics, but also on individual's preferences regarding energy conservation and self-enhancement values, such as tradition and motivation. As such, these findings seem to corroborate the importance of non-pecuniary incentives to influence individuals' choices.

Further evidence suggests that individuals respond more positively to certain stimuli – the salience effect, which describes how agents respond better to psychologically vivid or easily observed factors (Yates and Aronson, 1983). Framing also appears to be an important factor, as consumers are most sensitive when potential cost-savings are mentioned rather than earnings (Steg and Vlek, 2007). A study by Mills (1991) analyzed how receptive were consumers to the adoption of CFLs and concluded that the proneness to invest in energy efficiency increased when gradual monthly installment payments incorporated into the electricity bill were available. Energy audits have also been proposed by Yates and Aronson (1983) as powerful tools, if information is presented in a vivid and personalized fashion, when attempting to apply social-diffusion theory to curb skepticism in adopting new technologies.

Social pressure can be used as a means to propel technology adoption and diffusion through social recognition and approval, by capitalizing on psychological characteristics, such as altruism, to alter consumer behavior. This can be seen as an instance of the “warm glow” effect resulting in increased utility for individuals when contributing to public causes derived from moral satisfaction (Videras and Owen, 2006). Non-pecuniary instruments impact energy adoption along the extensive margin, whereas pecuniary incentives mostly affect consumers on the intensive margin, thereby implying the existence of a social norm elasticity (Herberich et al., 2011) – i.e. consumers which are pressured through social incentives are more likely to adopt new technologies whereas shifts in prices only work on the quantity, beyond adoption. Likewise, normative concerns play a role in supporting energy policy from different angles since pecuniary incentives tend to be fleeting, translating into relapsing behavior. However, if agents feel morally and positively linked to energy conservation, policy implications will be long-lasting and more easily accepted (De Groot and Steg, 2008). Furthermore, when products are aligned with consumers' values, experiences and needs, technology diffusion rates appear to increase (Wall and Crosbie, 2008).

6. Policy Instruments (EU context)

In a broader context, the PNEEAP is just part of a EU wide initiative to improve energy efficiency. A brief description of some of these instruments follows.

6.1 Financial Incentives

Various action plans have focused on reducing transaction costs and risks usually borne by early adopters of new technology through the use of pecuniary incentive schemes. Instruments aimed at favoring buildings, which account for a high percentage of energy expenditure, capable of providing higher levels of efficiency have been implemented in both Germany and Austria. Lithuania, on the other hand, has focused efforts on providing fiscal incentives, such as a lower VAT rate as a means to lower costs to suppliers of energy efficient construction components, while the Netherlands and Italy have opted towards allowing energy efficiency investments to count towards tax deductions. A group of countries, comprised of Denmark, the Netherlands, Finland, Spain and Poland have adopted voluntary agreements between private and public entities to ensure certain energy efficiency targets defined by accompanying government subsidized energy audits are set and achieved.

Market-based mechanisms are also featured in certain countries, with Italy and Poland planning to implement white certificate schemes in the near future, whilst other nations, such as the UK and Denmark, focus on more traditional instruments as energy efficiency quotas for consumers**.**

6.2 Technology Standards

EU-wide directives have been adopted to serve as guides to equalize energy efficiency among member states. The initiative has set minimum efficiency requirements for buildings, household appliances and office equipment - building codes and efficiency labels are the most common methodologies, while some home appliances are limited by Eco-design parameters such as to limit their life-cycle cost; office equipment, such as computers, incorporate efficiency compliant software, whereas lighting applications have been excluded from using incandescent light bulbs.

6.3 - Information Campaigns

Information campaigns have the ultimate goal of achieving higher end-use energy efficiency through the dissemination of information. These instruments work by raising awareness and education regarding energy efficiency in particular, possibly triggering agents to adapt their behaviors. Notable examples include an Irish multimedia campaign, ranging from press ads to TV programs and others, focused on informing individuals regarding different energy sources, inherent costs and other characteristics.

7. The Case of Portugal

7.1 The Portuguese National Energy Efficiency Action Plan (PNEEAP)

Portugal's economy has shown lagging improvements in its economy's energy intensity, assessed at 12.4% above the EU-27 average in 2004, leading to the creation of the PNEEAP in 2008. Convergence towards the EU average by 2015 was its main goal, which has since been extended to 2020. Energy intensity was to be improved via several policies promoting energy efficiency investments, amongst other elements, representing 9.8% energy savings, or a reduction in 1,792,493 tonnes of oil equivalent (toe), regarding the reference period defined by the European Directive (2001-2005), in final energy consumption by 2015.

Under the latest revision, in 2011, the Portuguese government committed to reduce energy consumption primarily through increasing energy efficiency by 25% until 2020, resulting in a predicted 12.1% drop in final energy consumption, approximately 2,239,973 toe. Predictions hinge on effects distributed across several sectors, spanning from industry to residential and services.

By the end of 2010, 36.7% of the target had been achieved, a result claiming that the plan is perceived as being on schedule with its timely goals. Specifically, the residential and services sectors have performed above expectations, with accounted cumulative savings of 215,189 toe, resulting from yearly growth in policy effects of 68% and 285% respectively during the 2008-2009 period. Inefficient equipment replacement is distinguished as a major driver of energy savings growth (e.g. filament light bulbs were phased, prompting an increase of 15 billion CFLs) along with shifting consumer behavior towards a more energy efficiency favorable predisposition - as evidenced by increased sales in high-performance energy household appliances. The latest revision also expects the residential and services sectors to generate savings of 643,417 toe by 2016 in contrast to the previous target of 421,908 to be achieved in 2015.

Nevertheless, the latest revision to the PNEEAP asserts that energy policy is currently being redefined, as a consequence of the Memorandum of Understanding (MoU), such that no more than general results were presented. However, a few ineffective plans have been replaced while the most successful initiatives were either renewed or given greater scope. Pending the final status regarding the electricity markets, a larger and more comprehensive restructuring of the plan is expected.

7.1.1 Incentive-based instruments

Policy instruments based on the impacts of pecuniary effects on demand, as several subsidies and fiscal rebates will be granted to promote energy efficient materials, buildings and appliances; older or just undesirable technologies will be taxed. Electricity tariff reductions in the order of 2.5%, in regard to the previous year, will be applied to consumers whose consumption is below 2 thousand kWh, only applicable to the main household; Investments in energy efficiency are eligible for fiscal rebates of 30% up until a maximum of 700 euros; Vouchers of up to 100 euros, based on efficiency grade, are to be exchanged for inefficient technology, which is to be recycled, when appliances considered to be more efficient are bought. Individuals reporting drops in electricity consumption of up to 10% or 20% regarding the previous year will also be eligible to receive an “Efficiency Check” which can be spent on energy efficient investments, capped at 10% or 20% of electricity expenditure over two years, respectively. On the other hand, electricity tariffs will increase by 5%, considering the previous year's tariff, for consumers whose consumption exceeds 4 thousand kWh - not applicable to large households or for those currently residing on A/A+ buildings; Technology regarded as inefficient will be taxed according to their carbon footprint - in the case of light bulbs, 41 cents per incandescent light bulbs, or in a whole life cycle cost optic in general. These pecuniary mechanisms are intended to be self-contained, in the sense that most of their financing is intrinsic, with the exception of a low interest rate credit fund and an insurance policy being set up to cover possible discrepancies.

7.1.2 Technology standards

Policy enforcing or recommending the use of certain technologies, such as CFLs, and materials, notably Low-Emissivity glass, through the use of energy efficiency grading (where A++ represents the highest EE, whereas G the lowest) for materials, buildings and appliances is also undertaken. Outside the scope of the PNEEAP's instruments, other relevant policies and initiatives had already been proposed to accelerate technology diffusion.

7.1.3 - Information campaigns

Non-pecuniary instruments ranging from simple educational programs in schools to full-fledged marketing techniques, just like the aforementioned energy efficiency grading for appliances and buildings, aimed at singling out energy efficiency as a desirable trait and through appropriate packaging and labeling as a means to captivate and disseminate knowledge regarding possible cost-saving opportunities, thereby effectively altering consumer choices and capitalizing on each individual's possible warm-glow effects.

7.2 Memorandum of Understanding

As of May 2011, Portugal is bound to comply with general economic policy guidelines, conditional to secure further financial assistance from the European Financial Stabilization Mechanism (EFSM), to be granted pending quarterly reviews for the duration of the programme, prescribed for the second quarter of 2014. Policies that are not in line with what has been agreed in the MoU require consultation with European Commission, the ECB and the IMF officials (the so called Troika) before implementation. The MoU ushers several implications for the Portuguese economy and, in particular, energy policy has to be reviewed. Consequently, energy markets for electricity and gas are to be liberalized, whilst promoting competition and fostering integration with the Iberian market for energy and gas (MIBEL and MIBGAS); Energy dependency and renewable energy promotion is to be achieved without comprising additional costs to electricity production and policy will be required to be consistent overall, such that several existing instruments require reassessment - implying that the PNEEAP might suffer further alterations in light of the new energy policy criteria.

The liberalization of electricity markets hinges on regulated tariffs being phased out by January, 2013 at the latest, in order to control the current energy deficit which not only distorts the price, but also implies an unsustainable burden on consumers. Excessive and extraordinary electricity production costs associated with the **ordinary regime,** associated with electricity production in conventional stations, are to be controlled and delimited, demanding renegotiation with electricity producers or a downward revision of the currently applicable guaranteed compensation mechanism **(**Custos para a Manutenção do Equilibrio Contratual – **CMEC)** to power generators, to be extended beyond the ordinary regime to the long-term power-purchase agreements

(PPAs) as well. Furthermore, increases in the VAT (from 6% to 23%) and excise taxes in the electricity market will be administered. Along with deregulated tariffs, the cost per unit of electricity faced by consumers will increase dramatically and behavioral repercussions are to be expected.

Energy policy instruments, such as taxes and subsidies, used to promote energy efficiency are, thus, subject to reconsideration under the MoU, to evaluate the risk of overlapping or inconsistent instruments with the underlying objective of ensuring the correct incentives for rational use, energy savings and emission reductions. Additionally, the Third EU Energy Package will be applied, such that the National Regulator Authority's independence and enforcement powers are guaranteed.

8. The Direct Rebound Effect in Portugal in Portuguese Households' Demand for Electricity: A Case Study

The total net consumption of primary energy in Portugal has risen by 11.4% between 1997 and 2008 (Nunes, 2010). Electricity consumption has also been steadily increasing in the last decade, except for a brief decline in 2009 of around 1.4%, a consequence of the economic crisis. Total electricity consumption resumed growth in 2010 by 4.7% relative to 2009 and by 3.2% when comparing to 2008; Residential consumption only increased by around 1% from 2009 to 2010 and represents 21% of total electricity consumption (Direcção Geral de Energia e Geologia, 2011). Electricity accounted for 38% of household primary energy consumption in 2009, followed by a 36% share held by biomass, 16% for liquefied propane gas. Various other fuel sources are less relevant. (DGEG, 2011) Nonetheless, in the EU context, Portugal ranks relatively low in per capita electricity consumption, with the average citizen consuming 20% less electricity when comparing with the EU average (Eurostat).

An in-depth account of current household electricity expenditure might be useful to contextualize this case study - an overview of the share of total electricity consumption by type of use in 2010 for Portuguese households is measured in Table 1. Cooking and small domestic appliances appear to be, by far, the top contributors whereas lighting and house heating are also prominent to a lesser extent.

Table 1 – Distribution of household electricity consumption in Portugal (2010)

Type of utilization	House Heating	House Cooling	Water Heating	Cooking	Small domestic appliances	Lighting	Total
%	9.06	1.60	2.40	40.52	32.86	13.56	100

Source: INE

8.1 Methodology

When energy efficiency data is unavailable, direct rebound effect estimates rely heavily on the use of proxies to capture the effect, namely through the use of demand elasticities. For a particular energy service, S, the following condition is obtained (Khazzoom, 1980; Sorrell et al, 2009). Following Berkhout et al. (2000),

$$\eta e(E) = \eta e(S) - 1 \quad (1)$$

where ηe(E) represents the elasticity of demand for energy (E) with respect to energy efficiency (e) and η*e(S*) is the elasticity of demand for energy services (S) with respect to energy efficiency. Energy services, S, equal the demand for energy regarding the efficiency level, eE, such that under this condition the elasticity of demand for energy with respect to energy efficiency equals the elasticity of demand for energy-based services with respect to energy efficiency minus one. Incorporating energy demand, which provides an upper bound for the direct rebound effect, (Sorrell and Dimitropoulos, 2007a) is one viable approach. Assuming that consumers respond proportionately to decreases in energy prices and improvements in energy efficiency, that energy efficiency is independent from energy prices, $\eta P_{\varepsilon}(E) = 0$, and since the price of a specific energy-based service is given by the ratio between the associated cost of energy and level of energy efficiency, $P_{s} = P_{E}/e$ (Sorrell, 2007), equation (1) can be rearranged as follows:

$$\eta e(E) = -\eta P_{\varepsilon}(E) - 1 \tag{2}$$

where $\eta P_{\varepsilon}(E)$ denotes the elasticity of demand for energy with respect to the price of energy. Nevertheless, it's important to note that direct rebound effect estimates using the own-price demand elasticity results are more appropriate when dealing with specific energy services and are somewhat biased against aggregation, such as the case of household electricity consumption. This can be easily seen when large own-price demand elasticity suggests that improvements in the overall efficiency of electricity would lead to large direct rebound effects or that the direct rebound effect for the energy services that dominate electricity consumption may be large (Sorrell, 2009).

8.2 Econometric Model

Estimations for the rebound effect can be derived from different approaches. We estimate the direct rebound effect in the short-run and the long-run by modeling the demand for electricity consumption of Portuguese households (heating, cooling, cooking) from 1994 to 2009. A Fixed Effects Model (FEM) provides estimates for the long-run elasticities, whereas an Error Correction Model (ECM) supplies estimates for short-term elasticities.

Data was gathered in constant prices according to the 7 NUTS-II territorial demarcations, according to municipal agglomerates. The series were constructed from data sets obtained from Instituto Nacional de Estatística, Banco de Portugal, DGEG, Eurostat and the National Climatic Data Center.

Given data availability constraints, both price and income elasticities are estimated through a constant elasticity demand dynamic standard function, specified in the log-log functional form (Haans and Biermayr, 2000). Besides price and income as explanatory variables of electricity demand, the heating degree days, given by the sum of daily mean temperature degrees below a reference temperature to account for annual disturbances, should also be included. Therefore, equation (3) below specifies the household electricity demand to be estimated,

$$lnC_t = \theta + \varphi_1 lnP_t + \varphi_2 lnHDD_t + \varphi_3 lnY_t \quad (3)$$

where C_t represents energy consumption in period t; P_t is the average price of electricity in period t; HDD_t are the heating degree-days in period t; Y_t is the disposable income of households in period t; c represents the intercept.

To estimate the long-run elasticities, the FEM with Cross-Section weights estimation was performed using the GLS (Generalized Least Squares) method, to capture time independent effects that are likely correlated with the dependent variable, resulting in the following equation:

$$lnC_{it} = \theta + \varphi_1 lnP_{it} + \varphi_2 lnHDD_{it} + \varphi_3 lnY_{it} + \rho_{it} \quad (4)$$

where “i” is the NUTS-II region, and “t” the year in question. As such, ρ_{it} are the estimation residuals for region i in year t.

The estimated results for the short-run are presented in Table 2. The presence of a low Durbin Watson statistic suggests the presence of serial autocorrelation.

Table 2 - FEM of household electricity demand, GLS/Cross-Section weights

Dependent Variable: lnC_{it}

Variable	Coefficient	Std. Error	t-Statistic	(CVs: 1%*; 5%* ; 10%***)Prob.
θ	10.60740	0.317894	33.36771	0.0000*
lnP_{it}	-0.247062	0.069857	-3.536682	0.0006*
lnY_{it}	1.045724	0.023041	45.38613	0.0000*
$lnHDD_{it}$	0.028102	0.013944	2.015314	0.0465**

R-squared	0.999064	Mean dependent var	23.03351
Adjusted R-squared	0.998982	S.D. dependent var	6.273530
S.E. of regression	0.044895	Sum squared resid	0.205585
F-statistic	12099.31	Durbin-Watson stat	0.926093
Prob(F-statistic)	0.000000		

Variables are statistically significant according to a 1%, 5% and 10% (*,,***)**

In order to deal with autocorrelation in the series, the model is adjusted by adding the dependent variable, Ct, with a one-period lag as an additional regressor, as suggested by Beck (2001)[1]. Table 3 presents the results of the new FEM estimation, see equation (5). As can be observed, the estimate for the price is deemed significant, and has the expected sign; the same is true for income and the HDDs. The R-squared value of 0.999 indicates an excellent fit. The estimate for the long-run rebound effect is around 21%.

$$lnC_{it} = \propto + \beta_1 lnP_{it} + \beta_2 lnHDD_{it} + \beta_3 lnY_{it} + \beta_4 lnC_{it-1} + u_{it} \quad (5)$$

Unit roots are a structural concern for the validity of the model, to avoid a spurious relation. When testing, as documented in annex A, towards the existence of unit roots in lnY and lnP. As such, these series are non-stationary. However, the cointegration test output shown in annex A indicates the existence of a I(1) cointegration relationship arising from a linear combination between the original series. Therefore, despite the presence of individual non-stationarity in lnP and lnY, a stable equilibrium is likely to exist, ruling out a spurious estimation. Therefore, the FEM in (5) can be

[1] This approach allows for the consideration of variables outside the model.

considered as a valid representation of the long-run relationship between the variables.

Table 3 - FEM of household electricity demand, GLS/Cross-Section weights

(Includes a lagged version of the dependent Variable: lnC_{it})

Variable	Coefficient	Std. Error	t-Statistic	(CVs: 1%*; 5%* ; 10%***)Prob.
$\propto$	1.120694	0.606772	1.846977	0.0679***
lnP_{it}	-0.213890	0.034703	-6.163399	0.0000*
lnY_{it}	0.159844	0.051096	3.128319	0.0023*
$lnHDD_{it}$	0.010473	0.005513	1.899659	0.0605***
lnC_{it-1}	0.854572	0.050113	17.05286	0.0000*
R-squared	0.999775	Mean dependent var		23.77820
Adjusted R-squared	0.999751	S.D. dependent var		9.460783
S.E. of regression	0.024005	Sum squared resid		0.054165
F-statistic	41793.61	Durbin-Watson stat		2.791246
Prob(F-statistic)	0.000000			

Variables are statistically significant according to a 1%, 5% and 10% (*,,***)**

In this context, capturing the short-run elasticities requires the use of an ECM, to exploit the existing I(1) cointegration which is itself stationary, by using the error term in (3), u_{it}, as the equilibrium error in the ECM.

Table 4 - ECM of household electricity demand, GLS/Cross-Section weights

Dependent Variable: ΔlnC_{it}

Variable	Coefficient	Std. Error	t-Statistic	(CVs: 1%*; 5%* ; 10%***)Prob.
ΔlnP_{it}	-0.308001	0.050751	-6.068842	0.0000*
ΔlnY_{it}	-0.020764	0.069678	-0.297992	0.7664
$\Delta lnHDD_{it}$	0.005157	0.004588	1.124010	0.2639
ΔlnC_{it-1}	1.061272	0.076826	13.81404	0.0000*
u_{it-1}	-1.861033	0.127350	-14.61356	0.0000*
	Weighted Statistics			
R-squared	0.628584	Mean dependent var		0.052649
Adjusted R-squared	0.612609	S.D. dependent var		0.033673
S.E. of regression	0.019372	Sum squared resid		0.034899
Durbin-Watson stat	1.949113			

Variables are statistically significant according to a 1%, 5% and 10% (*,,***)**

Thus, the ECM is constructed by lagging all variables in equation (5) one period while also adding the residuals of the FEM estimation in (5) lagged one period, that is,

u_{it-1}. The output in Table 4 is obtained by estimating the ECM, via the GLS procedure with cross-section weights, according to the following equation:

$$\Delta lnC_{it} = \delta_1 \Delta lnP_{it} + \delta_2 \Delta lnHDD_{it} + \delta_3 \Delta lnY_{it} + \delta_4 \Delta lnC_{it-1} + u_{it-1} + \varepsilon_{it} \quad (6)$$

Note that disposable income, Y, and Heating degree days, HDD, are not significant – suggesting that these variables might not be relevant drivers of demand in the short-run, in contrast to the short-run case. Price elasticity is significant and carries the expected sign, revealing a short-run rebound effect estimate with a magnitude of 31%. The ECM's R-squared is not as high as in the previous estimation, but is in-line with similar models in the literature. Nonetheless, the error correction mechanism's high statistical significance provides further evidence of a long-run relationship in levels between all the variables and supports the choice of an ECM to deal with short-run effects.

According to these results, the elasticity of electricity demand by households is larger in the short-run than in the long-run, which runs counter to economic theory. However, a reasonable explanation for this lies in the regulatory framework in Portugal, where prices are not freely decided in the marketplace. The political intervention in the electricity market introduces rigidity which may explain the results obtained.

However, these figures are still indicative of the magnitude of the direct rebound effect's in Portugal for households' consumption of electricity (heating, cooling and cooking), 21% in the long-run and 30% in the short-run. Furthermore, these results can be considered in-line with similar estimations in other developed nations, as is the case of the USA, with results ranging from 32% to 38% (Guertin et al., 2003), and Catalonia, Spain, with a short-run effect of 35% and 49% for the long-run (Gonzaléz, 2010). Further research, to improve on these results, might require gathering less aggregate data, e.g. at the municipal level. Unfortunately, these data are not yet available for all variables.

9. Concluding Remarks

Even when implementing relatively mild and conservative policy instruments as is the case of those included in the PNEEAP, relative to other EU member states, it has been established in this work that policymakers ought to take concurrent events into account carefully, as the project to advance the liberalization of the electricity market will generally lead to higher energy pricing. With this in mind and under the rationale of energy conservation, actively promoting energy efficiency when prices are high may increase energy consumption due to the presence of a direct rebound effect which implies that energy efficiency should not be further encouraged by policy intervention. .In fact, our direct rebound effect estimates for electricity consumption in Portuguese households imply that an increase in energy efficiency leading to savings in electricity consumption of 10 would only materialize in savings of 7.9 in the long-run and 7.0 in the short-run.

Finally, we conclude that behavioral aspects are also extremely important when attempting to promote energy efficiency and accelerate the rate of technology diffusion.

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<u>Annex A</u>
Unit Root tests

Series	Unit Root Test	ADF	Result (Critical values, 1%*; 5%** and 10%***)	Integration order
LnC	Levels	-1.29916	Reject Ho***	I(0)
LnY	Levels	1.52197	Don't Reject Ho*	
	1st differences	-3.30925	Reject Ho*	I(1)
LnP	Levels	6.26959	Don't Reject Ho*	
	1st differences	-4.86600	Reject Ho*	I(1)
LnHDD	Levels	-4.20539	Reject Ho*	I(0)
LnC(-1)	Levels	-1.52234	Reject Ho***	I(0)
Ho: Individual unit root process When AD > Z–Choi Chi-Squared critical value			Individual intercept Lag length based on AIC	

Cointegration test

Pedroni Residual Cointegration Test	Series: lnc lny lnhdd lnc	Series: lnc lny lnhdd lnc lnc(-1)	Result (5%*, 10%**)
Panel ADF-Statistic	-1.565809	-7.632896	Reject Ho**/*
Panel PP-Statistic	-1.930246	-9.507280	Reject Ho*/*
Ho: No Cointegration		Individual intercept Lag length based on AIC	