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1 **TITLE:**

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3 2010.

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# 1 Energy efficiency policies for space heating in EU countries: 2 A panel data analysis for the period 1990 to 2010.

## 3 ABSTRACT

4 We present an empirical analysis of the more than 250 space heating-focused energy efficiency policies  
5 that have been in force at the EU and national levels in the period 1990–2010. This analysis covers the  
6 EU-14 residential sector (Pre-2004 EU-15, excluding Luxembourg) using a panel data regression analysis  
7 on unit consumption of energy for space heating (kWh/m<sup>2</sup>/year). The policies are represented as a  
8 regression variable using a semi-quantitative impact estimation obtained from the MURE policy database.  
9 The impacts of the policies as a whole, and subdivided into financial, regulatory, and informative policies,  
10 are examined. The correlation between the actual reductions in demand and the estimated impact of  
11 *regulatory policies* is found to be stronger than the corresponding correlations with the respective impacts  
12 of *financial policies* and *informative policies*. Together with the well-known market barriers to energy  
13 efficiency that exist in the residential sector, these findings suggest that regulatory policy measures be  
14 given a high priority in the design of an effective pathway towards the EU-wide goals for space heating  
15 energy.

## 16 Keywords

17 Residential; Econometrics; Efficiency; Policy; Space heat; Regulations

## 18 1 INTRODUCTION

19 Lowering the absolute energy demand of buildings is a key policy goal of the EU. This is to be achieved  
20 mainly through improvements in end-use efficiency [1]. The indicative goal for Year 2020 is to lower  
21 primary energy demand within the EU by 20% relative to a business-as-usual scenario. This goal is part of  
22 the EU Climate and Energy Packet (known colloquially as the EU 2020 goal), and also includes the  
23 mandatory goals that by Year 2020 there should be a 20% share for renewables in the energy supply and a  
24 20% reduction in greenhouse gas emissions (relative to the levels in Year 1990) [2]. For the residential  
25 sector, the energy savings target has been set at the higher level of 27% given the well-documented  
26 savings opportunities that exist in this sector [3]. The multifaceted motivations behind the overall energy  
27 savings goal include reducing dependence on fossil fuels imported from outside the EU, mitigating the  
28 volatility associated with oil prices, increasing competitiveness by reducing energy costs, stimulating  
29 employment in the construction sector, improving both the indoor and outdoor air quality *via* improved  
30 ventilation and decreased emissions of combustion gasses, reducing noise pollution, and mitigating  
31 climate change. However, studies have shown that the EU is on target to meet only half of its Year 2020  
32 overall energy savings goal [4]. In addition, the negotiations surrounding the Energy Efficiency Directive  
33 [5] have highlighted that it is not possible to lower EU Primary Energy Demand by more than 17% using  
34 the measures agreed in the directive, meaning that a *de facto* 3% watering down of the savings through  
35 efficiency target has occurred.

## Nomenclature

|  |   |
|--|---|
| <i>CH</i>  | Percentage of dwellings with Central Heating installed.   |
| <i>Delay1 Model</i>  | A model used in this work in which the implementation of policies has been delayed by 1 year, to determine if there is a time lag in the impacts of efficiency policies that have been introduced.  |
| <i>EEW</i>   | Energy Efficiency Watch Project   |
| <i>EP</i>  | Efficiency Policies. A time series variable constructed for the purpose of the present work to represent all ( <i>EP</i> ), just the financial ( <i>Fin</i> ), just the regulatory ( <i>Reg</i> ) or just the informative ( <i>Info</i> ) residential sector heating-focused efficiency policies that are in place.   |
| <i>EPBD</i>  | EU Energy Performance of Buildings Directive  |
| <i>ESD</i>   | EU Energy Services Directive  |
| <i>HAC</i>   | Heteroskedasticity and Autocorrelation Consistent Standard Errors.  |
| <i>HDD</i>   | Heating Degree Days.  |
| <i>Laspeyres Decomposition</i>   | A method of index decomposition in which model variables are each in turn changed to their final year (Year 2010) values, while the other model variables are kept at their base year (Year 1990) values. This allows the individual impact of a variable-on-demand to be estimated.  |
| <i>LSDV</i>  | Least-Squares Dummy Variable-fixed effects panel data model.  |
| <i>MURE Policy Database</i>  | An online database of all national and EU-wide sector-level efficiency policies that have been introduced in the EU-28 countries and Norway since the 1970's.   |
| <i>NEEAP</i>   | National Energy Efficiency Action Plan  |
| <i>SQI</i>   | Semi-quantitative impact. The name given to the <i>ex post</i> or <i>ex ante</i> evaluations of each of the policies in the MURE database. Policies are ranked as having a low, medium or high impact on the demand reduction in which they are found to or expected to result. These rankings are used in the present work to construct the EP, Fin, Reg, and Info policy variables.                               |
| <i>Unit consumption of energy for space heating (kWh/m<sup>2</sup>/year)</i> | A time series variable constructed for the purpose of this work that represents the sum of each energy carrier used for heating divided by total floor area. The unit is the square metre. Unit consumption is an established indicator of energy efficiency progress, as it tracks changes in energy use related to efficiency improvement and is not influenced by changes in either population or dwelling size. |
| <i>WAP</i>   | Weighted Average Price. A time series variable constructed for the purpose of the present work that aggregates the prices of different energy carriers for heating into a single price weighted according to the proportion of each energy carrier in the heating mix.  |
| <i>Wald (F)Test</i>  | A mathematical test to examine the combined significance of a number of explanatory variables.  |
| <i>VIF</i>   | A mathematical test that detects the multicollinearity of a number of explanatory variables.  |

1 Over the last decade, the European Commission has introduced a package of measures aimed at achieving  
2 the Year 2020 goal of a 20% reduction in primary energy demand. These measures include the Energy  
3 Performance of Buildings Directive (EPBD) [6], the Energy Services Directive [7], the Eco Design  
4 Directive [8], and the Energy Labelling of Products Directive [9]. These are policy measures that seek to  
5 drive technical innovation, the diffusion of efficient technologies, and the creation of a market for  
6 efficiency. More recently, additional policies that aim to improve or enhance the aforementioned factors  
7 have been introduced or debated, namely, the recast of the EPBD [10], the Energy Efficiency Directive  
8 [11], and the proposed Energy Taxation Directive [12]. These EU directives are transposed into national  
9 policy legislation by the respective countries and complement the energy savings measures that individual  
10 countries have introduced to varying degrees since the 1970's [13, 14].

11 A study that looked at 30 years of experience in OECD countries with policies for increasing energy  
12 efficiency [15] revealed that most Western European countries have undergone substantial energy  
13 intensity reductions, distinct from structural changes, since 1973. These authors report that many policies  
14 and programs have been adopted to increase energy efficiency, and some have clearly “made a  
15 difference”. The most influential policies have been energy codes, industrial voluntary agreements,  
16 pricing initiatives, and financial incentives adopted at the national level, while EU-wide appliance  
17 labelling and standards, and the new vehicle CO<sub>2</sub> emissions intensity agreement also have had impacts.  
18 However, they conclude that it is very difficult to estimate what fraction of the overall energy efficiency  
19 improvement can be attributed to specific policy initiatives and what fraction is linked to other factors,  
20 such as market forces and on-going technological change.

21 Although thorough descriptions of the efficiency policy options in existence and their theoretical bases in  
22 terms of dealing with the well-known market barriers to efficiency are available in the literature [14, 16-  
23 23], most of these studies do not quantify *ex post* the effects of individual or portfolios of efficiency  
24 policies. Gillingham and colleagues [18] have commented that most of the policy evaluation studies have  
25 been *ex ante*, and while they are useful for understanding future policies, they do not demonstrate that a  
26 policy has been effective.

27 Some *ex post* analyses, e.g., [24], have compared a projected baseline energy demand to the actual  
28 demand outfall and postulated that the difference is due to policy-driven energy efficiency improvements  
29 and the use of less-energy-intensive products. This approach is similar to the findings of indicator-based  
30 efficiency evaluations [25]. Vine and co-workers [26] reported that the combination of mandatory  
31 labelling which was introduced in the EU in 1992 and other efficiency policies improved the efficiency of  
32 refrigeration appliances by 10% from 1992 to 1996. Hoicka et al. [27] showed that financial rewards can  
33 increase both the levels of participation and outcomes in efficiency programmes. As part of the IPCC 4<sup>th</sup>  
34 assessment (AR4) chapter on mitigation options for residential/commercial buildings, a qualitative  
35 evaluation of 60 *ex post* efficiency case studies was carried out [28]. Appliance standards, building codes,  
36 tax exemptions, and voluntary labelling were found to be the most effective policy instruments for  
37 reducing demand. Using a panel of 48 of the states in the USA, Horowitz [29] examined empirically  
38 whether states with strong commitments to energy efficiency have lower levels of energy intensity than  
39 those with weak commitments, and found that this was indeed the case. He also found that energy  
40 efficiency programmes have a transformative effect on other macroeconomic variables, such as electricity

1 price, income per capita, and technological change, and that there are spill-over efficiency effects  
2 from states with strong commitments to efficiency towards states with weaker commitments. Using panel  
3 data methodologies, Filippini and colleagues [30] examined empirically the impact of energy policy  
4 instruments on the estimated level of underlying energy efficiency in the EU residential sector, while  
5 Saussay et al. [31] did the same for seven EU countries and Bigano et al. [32] did the same for all sectors.  
6 The two latter studies [31 and 32] found that energy efficiency in the residential sector had been improved  
7 by the application of, in particular, mandatory standards for buildings. Filippini et al. [30] found that  
8 financial measures had the greatest impact, mandatory standards for appliances or buildings less of an  
9 impact; they found no improvement in efficiency from informative policies.

10 From a policymakers perspective and considering the well-known market barriers to energy efficiency, it  
11 is of interest to know how well the existing and previous efficiency policy frameworks have succeeded in  
12 reducing energy demand, i.e., what level of causality there exists between the efficiency improvements  
13 highlighted by indicators and the portfolio of efficiency-focused policies in place. In this paper, the extent  
14 to which the energy efficiency-focused policies introduced at the EU and national levels have succeeded  
15 in reducing energy demand is examined empirically. This has been examined to some extent by various  
16 groups [15, 24-36] and explicitly by Filippini et al. [30] and Bigano et al. [32] for the same or other  
17 regions. Where the present work differs from the aforementioned studies is that it: 1) covers all the  
18 efficiency policies in place in the region under examination; 2) looks at different categories of efficiency  
19 policies, as compared with a previous study [29]; and 3) examines the ways in which efficiency policies in  
20 place are modelled, as compared with the previous works [30, 32].

21 For the empirical analysis, panel data regression is used. Various groups [37-39] have presented  
22 comprehensive reviews of how panel data analysis can be used for energy demand studies. In the present  
23 work, the analysis is performed for energy demand for space heating. As the focus of the present study is  
24 energy efficiency, the dependent variable used is unit consumption (kWh/m<sup>2</sup>/year), as its temporal  
25 dynamic is an established indicator of energy efficiency [25]. The period examined is 1990 to 2010. This  
26 is motivated primarily by the availability of the relevant data, but it is also the historical period that has the  
27 most relevance for policymakers who are designing contemporary efficiency policies.

28 This paper is divided into four sections. Following the *Introduction*, Section 2 presents the approach used  
29 and then describes the model parameters and the data used as inputs. This includes a description of the  
30 quantitative method used in this work to represent energy efficiency policies applied to the residential  
31 sector. Section 3 presents results for the various models and a detailed discussion on the implications and  
32 interpretations of the findings. Section 4 presents the conclusions drawn from the study.

## 33 **2 METHODOLOGY**

34 This paper uses a panel data regression approach to estimate the energy savings conferred by the policy  
35 portfolio in place across the EU. In modelling terms, the core determinants of energy demand are defined  
36 for the purposes of this paper as: energy price; personal income; the outdoor climate; the penetration of  
37 central heating in the building stock; and a time trend, which is a linear approximation of other effects that

1 have occurred over the studied period. The latter include autonomous technical progress, fuel switching,  
2 and structural changes. These explanatory variables are similar to those used by others [16, 40], except  
3 that no alternative fuel price options, such as a response to an increase in the gas price, are employed. This  
4 is because the dependent variable used in this study (space heating) is not substitutable.

5 To achieve the goal set out in this paper, an additional explanatory variable is included that represents  
6 policies aimed at reducing energy demand *via* efficiency. The new variable is an aggregation of relevant  
7 policies and measures introduced at the EU and national levels since the 1970's and is termed *EP* (Energy  
8 Policies) for the purposes of modelling. By introducing this variable, the component of the time trend that  
9 otherwise would have represented efficiency policy is removed. As a development, *EP* in the model is  
10 replaced by separate variables that represent different categories of efficiency policies, to determine which  
11 particular policy categories have had the greatest impacts on demand.

12 In considering whether to employ a fixed or random effects panel data model to account for the  
13 unobserved heterogeneity across a panel of countries, it has been argued [41] that a fixed effects model  
14 should be used. Their argument is that the selection of countries for studies such as the one described in  
15 this paper is not random, since the countries chosen are not exchangeable with other countries. Dougherty  
16 [42] has explained that if a panel is designed with OECD countries only, the countries are inherently not  
17 chosen randomly. Dougherty [42] has also presented a model choice scheme, which for the purposes of  
18 this paper would suggest the use of a fixed effects model.

## 19 2.1 Model description

20 The linear regression model of unit consumption for space heating,  $I_{it}$ , takes the form:

$$21 \ln(I_{it}) = \beta_0 + \beta_1 \ln(P_{it}) + \beta_2 \ln(Y_{it}) + \beta_3 \ln(CH_{it}) + \beta_4 (HDD_{it}) + \beta_5 (t) + \beta_6 (EP_{it}) + \varepsilon_{it} \quad (1)$$

22 where  $P_{it}$  is a weighted average (by heating energy carrier for each individual country) real price of  
23 energy,  $Y_{it}$  is income per capita,  $CH_{it}$  is the percentage of dwellings with central heating installed,  $HDD_{it}$   
24 are heating degree days which are a proxy variable for the outdoor climate,  $t$  is a time trend,  $EP_{it}$  is a  
25 numerical representation of the energy efficiency policies in place, and  $\varepsilon_{it}$  is the residual term. The  $i$  and  $t$   
26 subscripts in Eq. (1) give the spatial and temporal parameters of the panel, respectively. Initially, other  
27 choices of dependent variables for heating were tested, including the total heating demand (space heating  
28 plus water heating plus heat for cooking), total per capita, and total per square metre. However, it was  
29 decided to perform the work only for unit consumption for space heating for the EU-14 after taking into  
30 consideration the following issues: (i) data availability; (ii) the need to have a balanced panel to facilitate  
31 some statistical tests; (iii) structural differences between the newer and older Member States of the EU  
32 due to the former having had price controls in their energy markets; (iv) the research question to be  
33 answered; and (v) the preliminary results obtained.

34 In estimating a fixed effects model, Eq. (1) is transformed to a Least-Squares Dummy Variable fixed  
35 effects (LSDV) regression model, so that the constant ( $\beta_0$ ) absorbs the individual country fixed (time

1 invariant) effects. A unique feature of the model compared to similar residential sector models in the  
2 literature [16, 43] is the inclusion of the variable  $EP$ , which explicitly accounts for policies that have been  
3 introduced with the aim of reducing energy demand or, as compared with other studies [30, 32], the way  
4 in which such a variable is included. For the purposes of the present work, the remaining determinants of  
5 energy demand, e.g., price,  $HDD$  etc., are control variables, the coefficients of which are expected to  
6 concur with those reported in the literature in terms of magnitude and polarity.

## 7 2.2 Quantitative representation of Efficiency Policies

8 Data for the construction of the  $EP$  variable in Eq. (1) were obtained from the MURE Policy Database  
9 [13]. This database includes more than 500 policies focused on energy efficiency that have been  
10 introduced since the 1970's across the 28 EU countries and Norway. The policies include the following  
11 types: (i) Financial; (ii) Fiscal/Tariffs; (iii) Informational/Educational; (iv) Legislative/Informative; (v)  
12 Legislative/Normative; (vi) Co-operative; and (vii) Unknown (as designated in the MURE database).  
13 Table 2 lists examples of some of these policy categories for the case of Austria. The database also  
14 provides a semi-quantitative impact (SQI) ranking of each policy carried out by energy agencies from  
15 each country and based on an estimation of the energy savings achievable or achieved by that policy.  
16 These SQI's are grouped into three bands, high, medium and low, depending on whether they describe  
17 policies that are expected or that have been found to reduce energy demand in their sector of focus by  
18  $>0.5\%$ ,  $0.1\%–0.5\%$ , and  $<0.1\%$ , respectively. However, the descriptions of specific policies rated as low  
19 impact reveal that they are usually associated with very low expected savings in comparison to the  
20 medium-impact and high-impact policies. Therefore, for the purposes of the present work, these three  
21 bands are assigned values of 20, 10, and 1, respectively. This is done for each year that a policy is in force  
22 and creates a quantitative time series [ $EP$  in Eq. (1)], which represents policies in place and their expected  
23 impacts on demand. This solution is similar to that adopted by Berry [34], who used the American Council  
24 for an Energy-Efficient Economy's (ACEEE's) 2006 efficiency scorecard for US states as a variable in a  
25 regression function for electricity sales. As the  $EP$  time series in Eq. (1) is an aggregation of the high-,  
26 medium-, and low-impact policies, the  $\beta 6$  term in Eq. (1) represents the actual demand reduction achieved  
27 from a certain level of expected policy impact (SQI in the database). Previous studies [30, 32] have also  
28 used the MURE Policy database to model the effects of efficiency policies. Both investigations introduce  
29 dummy variables in their models for the years during which subcategories of policies, e.g., building  
30 regulations, are in force. The study of Filippini et al. [30] represents an advance on the work of Bigano et  
31 al. [32], since the former distinguishes between the number of policies implemented, i.e., it uses separate  
32 dummy variables for cases of 1–2 or  $\geq 3$  policies in a particular subcategory that are in force. The work  
33 presented in this paper is an advance on both these studies [30 and 32] because it goes beyond binary  
34 representations of policies in place to represent them as a time series, which increases as more policies are  
35 introduced and decreases as policies become obsolete (Figure 1).

36 For the 14 countries that are in focus in the present work, the database contains 329 residential sector  
37 policies. Of these, six are defined as cross-cutting, and therefore are excluded from the work because they  
38 represent energy and carbon taxes of various types that would already be represented in the energy price  
39 time series ( $P_{it}$ ) in Eq. (1). Similarly, 15 regionally focused policies in Belgium, e.g., Flanders or Wallonia,  
40 were not included, whereas federal policies for the same country were included. In addition, 48 policies

1 that focus exclusively on electricity demand for appliances and lighting were also ignored. Of the  
 2 remaining 260 policies, 202 are focused on heat and 58 are focused on both heat and electricity (See  
 3 Table 1). An example of the latter is a policy named “Energy advice for households”, which obviously  
 4 applies to both heating and other household uses of energy.

5 As mentioned earlier, the database of policies and the variable *EP* are divided into different categories of  
 6 efficiency policy, to evaluate their respective impacts. The policy categorisation used previously [14] is  
 7 adopted for the purposes of the present work. Thus, EU policies that are aimed at dealing with the energy  
 8 performances of buildings are divided into: (i) Financial; (ii) Regulatory framework and standardisation;  
 9 and (iii) Information, capacity building and market transformation. This system of categorisation is similar  
 10 to that put forward by others [44]. Several assumptions were needed to apply this categorisation to the  
 11 policies in the MURE Policy Database. Although policies that are labelled Legislative/Informative are  
 12 regulatory, in that they mandate the display of information, these policies have been categorised as  
 13 informative, since market transformation *via* information is their main goal. Most of the policies in this  
 14 category refer to the EU EPBD and the Energy Labelling of Products directives [6, 9]. While the EU  
 15 EPBD directive contains regulatory components, such as the mandatory inspection of boilers, the main  
 16 focus of both directives is the energy labelling of buildings and appliances, respectively. Policies in the  
 17 database categorised as ‘Co-operative’ or ‘Unknown’ were each examined in turn to define their  
 18 placements. Although the Co-operative policy shown in the example for Austria (Table 2) is ostensibly  
 19 information-driven, its main contribution with respect to the residential sector is in relation to minimum  
 20 standards for standby, which makes it a regulatory policy for the classification applied in this work. For  
 21 some countries, notably, the Netherlands, many of the policies listed are labelled as Co-operative. This is  
 22 because in the Netherlands, there is strong representation of housing organisations, which make voluntary  
 23 agreements with the authorities to reduce energy demand. Each of these policies have been categorised on  
 24 an *ad hoc* basis to determine if they are more regulatory or informative in nature. Policies labelled  
 25 Financial, i.e., grants for renewables, were included. Many of these refer to grants or subsidies for the  
 26 installation of heat pumps and solar photovoltaic (PV) or collector panels, all of which would reduce the  
 27 final energy demand, as listed in the energy statistics. Table 1 shows the numbers of policies for each  
 28 category based on the categorisation carried out for the present work. Most of these policies were  
 29 implemented in the period 1990–2010, while others were already in force in 1990.

30 **Table 1 : Numbers of policies from the MURE Policy Database analysed for the purpose of the present work<sup>a</sup>**

| Policy type        | Heat | Electricity and heat | Total |
|--------------------|------|----------------------|-------|
| <b>Financial</b>   | 67   | 12                   | 79    |
| <b>Informative</b> | 54   | 14                   | 68    |
| <b>Regulatory</b>  | 81   | 32                   | 113   |
| <b>Total</b>       | 202  | 58                   | 260   |

31 <sup>a</sup>Categorisation carried out as described in the text.

32 As an example, for Austria, the database includes nine heat-focused energy efficiency measures, four  
 33 electricity efficiency-focused measures, and one measure that covers both heat and electricity. These  
 34 fourteen policies were introduced between 1989 and 2009 and are all still in force (Table 2). Six of the

1 Austrian measures have received a high SQI, three have received a medium score, one a low score, and  
 2 four have had their SQI graded as “Unknown”. The policies without an SQI ranking are assumed to have a  
 3 low impact on demand. The fourteen policies are divided into the Financial (Fin), Regulatory (Reg), and  
 4 Informative (Info) categories in line with the categorisation used in the present work, although those that  
 5 focus exclusively on electricity are not included in the subsequent analysis. Columns 1 and 2 of Table 2  
 6 show the categorisation of the policy measures applied by the authors of this paper, while the remaining  
 7 columns are based on data from the MURE Policy Database [13]. Thus Policy Type and SQI are MURE  
 8 categorisations for each measure. As all the measures are still in force, the column Duration gives the  
 9 starting year of the policy measure. The column that follows Duration indicates whether the measures  
 10 were the result of an EU directive or not, while the last column lists the MURE Policy Database codes for  
 11 Households.

12 **Table 2 : Residential sector energy efficiency policies for Austria from the MURE Policy Database [13] analysed in**  
 13 **the present work.<sup>a</sup>**

| Designation <sup>b</sup> | Focus <sup>b</sup>   | Policy Title <sup>c</sup>                                | Policy Type <sup>c</sup> | SQI <sup>c</sup> | Duration <sup>c</sup> | EU <sup>c</sup> | Code <sup>c</sup> |
|--------------------------|----------------------|--|--------------------------|------------------|-----------------------|-----------------|-------------------|
| Fin                      | Heat                 | Residential building subsidy                             | Financial                | High             | 1989–                 | No              | AU13              |
|                          | Heat                 | Grants for renewable energy (heat pumps, biomass etc.)   | Financial                | High             | 1992–                 | No              | AU10              |
|                          | Heat                 | National recovery plan / renovation voucher              | Financial                | Unknown          | 2009–                 | No              | AU26              |
| Reg                      | Heat                 | Heating system design standards                          | Legislative/Normative    | High             | 1989–                 | No              | AU6*              |
|                          | Heat                 | Minimum thermal standards for buildings                  | Legislative/Normative    | High             | 1991–                 | No              | AU5               |
|                          | Heat                 | Heating cost settlement for common thermal facilities    | Legislative/Normative    | Medium           | 1992–                 | No              | AU8               |
|                          | Elec                 | EU-related: Energy Labelling (Energy Star)               | Co-operative Measures    | Unknown          | Unknown               | Yes             | AU22*             |
| Info                     | Heat                 | EU-related: EPBD – Building Energy Certificates          | Legislative/Informative  | High             | 2008–                 | Yes             | AU21              |
|                          | Heat                 | Klima:Aktiv Building - new standards for buildings       | Information/Education    | High             | 2005–                 | No              | AU18              |
|                          | Heat                 | “Wohnmodern“ support for large apartment renovation      | Information/Education    | Medium           | 2006–                 | No              | AU19*             |
|                          | Heat and Electricity | Energy advice for households                             | Information/Education    | Unknown          | 1990–                 | No              | AU27              |
|                          | Elec                 | topprodukte.at, Platform for energy-efficient appliances | Information/Education    | Low              | 2005–                 | No              | AU17*             |
|                          | Elec                 | Smart Metering and Informative Billing                   | Information/Education    | Unknown          | 2008–                 | No              | AU28              |
|                          | Elec                 | EU-related: Energy Labelling of Household Appliances     | Legislative/Informative  | Medium           | 1994–                 | Yes             | AU1               |

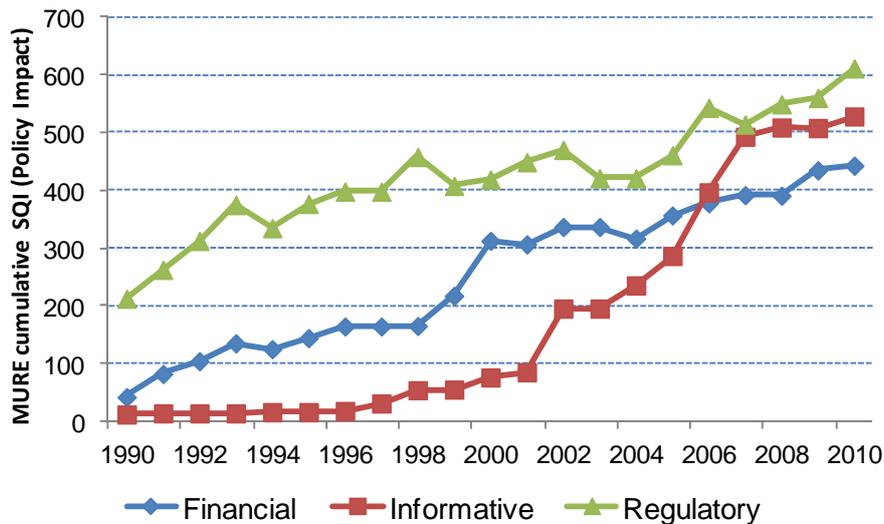
14 <sup>a</sup>Since the completion of the work described in this paper, the MURE Policy Database has been reorganised. For the example of Austria given in  
 15 this table, the reorganisation has resulted in the removal of the policies marked with an asterisk and the relabeling of all household-focused  
 16 policies with the prefix HOU, e.g., HOU-AU13 for the first policy listed in the table. See: <http://www.measures-odyssee-mure.eu/>

17 <sup>b</sup>These designations (categories) are assigned as part of the present work.

18 <sup>c</sup>These items are derived from the MURE Policy Database.

19 Figure 1 shows the cumulative SQI ranking of the 260 policies analysed in this work. The difference  
 20 between the numbers shown in Table 1 and those shown in Figure 1 is that rather than show the number of  
 21 policies in force for the EU-14, the latter takes into account the different rankings assigned to each policy  
 22 in the MURE policy database (high-, medium-, and low-impact policies) and also the years in which each  
 23 policy was in force. Thus the y-axis of Figure 1 represents the cumulative value of the SQI of the policies  
 24 in force in each of the three categories for the 14 countries analysed in this work (*cf* a high-impact policy  
 25 in force is assigned a value of 20, a medium-impact policy gets a 10, and a low- or unknown-impact  
 26 policy gets a value of 1). It is clear that informative policies have the lowest expected impact until Year  
 27 2006 when they catch up with the regulatory policies. A pattern of decreasing impact, e.g., from 1998 to  
 28 1999 for regulatory policies, reflects the fact that some policies in this category became obsolete in 1998.

1 As it may take several years for the impacts of policies introduced to be realised in terms of energy  
 2 demand reductions, the *EP* variable is tested with delays of up to 7 years. Taking the example of Austria  
 3 (Table 2), the two pieces of legislation introduced in 1989 would in the Delay7 scenario not kick-in until  
 4 Year 1996, while the six pieces of legislation introduced after Year 2005 would not be included in the  
 5 regression. Note also that in the case of Austria, the flagship EU legislation on energy efficiency in  
 6 buildings, the EPBD, was only incorporated into policy legislation in Year 2008, which means that its  
 7 effect, as defined in the empirical examination carried out in this work, is limited.



8

9 **Figure 1 : Estimated level of impact of each policy category on space heating in the residential sector for the 14**  
 10 **EU countries analysed in this work.**

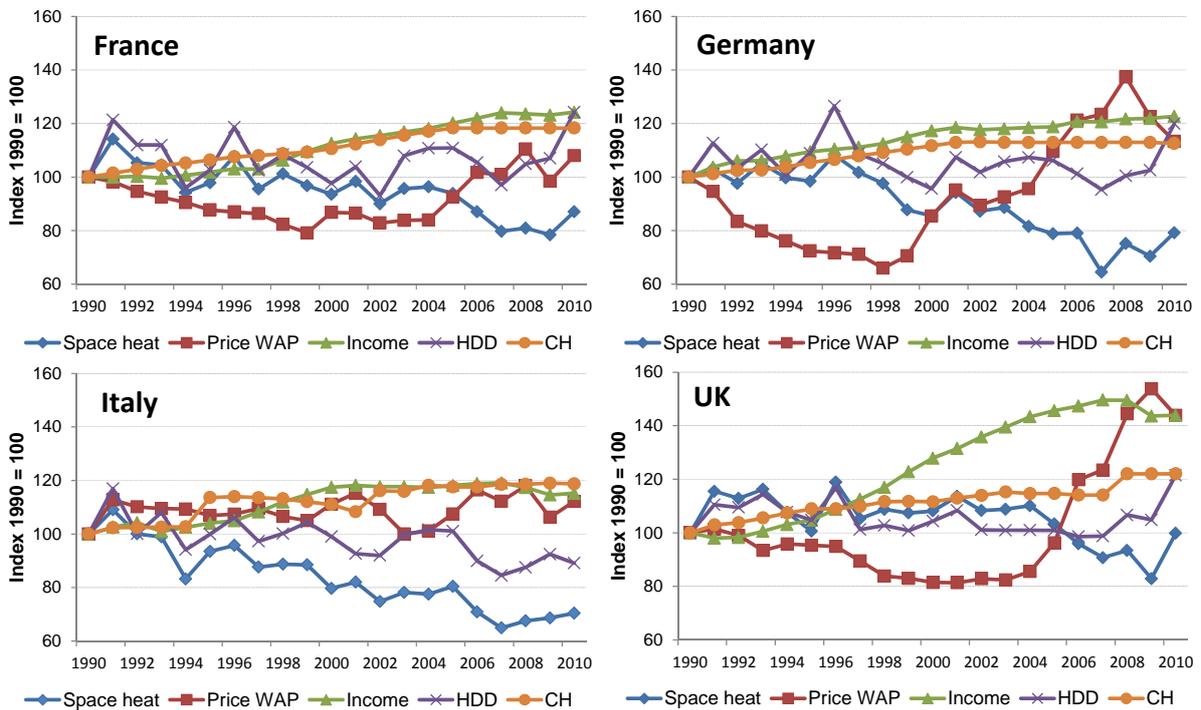
### 11 2.3 Data sources for other determinants

12 The data for Eq. (1) for the core determinants of space heating energy demand were obtained from the  
 13 following sources: income [national private consumption in Euro]; population; average floor area per  
 14 dwelling; number of permanently occupied dwellings; *HDD*; energy demand for six energy carriers [coal,  
 15 oil, gas, district heating, biomass, electricity] for space heating [25]; consumer price indices [private final  
 16 consumption expenditure deflator] [5]; Harmonized Indices of Consumer Prices (HICP) [46]; and district  
 17 heating prices [47]. Income was divided by population to derive the per capita values. The heating demand  
 18 data were divided by the total floor area (average floor area per dwelling times the number of permanently  
 19 occupied dwellings) to derive the heating demand per square metre (unit consumption).

20 IEA [44] provides a time series of prices for the residential sector for coal, oil, gas, and electricity  
 21 normalised to Year 2005 prices ( $\text{€}_{2005}/\text{toe}$ ), while Werner [47] supplies the time series of prices for district  
 22 heating. These latter prices were normalised to Year 2005 prices using price indices from the OECD [45]  
 23 and Eurostat [46]. Combining the time series of prices for these five energy carriers with the  
 24 corresponding time series of their usage for space heating, from the Odyssee database [25], allowed a

1 Weighted Average Price (WAP) of energy for space heating to be constructed. As a ton of oil equivalent  
 2 (toe) of oil does not produce the same amount of heat as a toe of natural gas or coal (given their different  
 3 conversion efficiencies when used in household boilers), the IEA prices for oil, natural gas, and coal were  
 4 divided by a factor of 0.78, 0.85, and 0.64 [49], respectively, to obtain the prices of heat from these  
 5 respective energy carriers prior to their inclusion in the WAP. Prices for biomass for the respective  
 6 countries are not available in national statistics due to the nature of the trade in this commodity. Thus, the  
 7 options were to include biomass in the energy demand time series ( $I_{it}$ ) but not in the weighted average  
 8 energy price time series or to omit biomass from the energy demand time series; best-fit modelling  
 9 indicated that the latter option was best.

10 For Finland (1990–1994) and Portugal (1990–1999), no data were available on the demand for electricity  
 11 and space heating. In these two cases, a time series of total energy demand respectively electricity demand  
 12 for the residential sector obtained from a previous study [48] covering these periods was used to  
 13 extrapolate the missing data. Prices for district heating were not available for most countries for 2009 and  
 14 2010. To obtain a complete time series, the district heating prices for each country for Year 2008 were  
 15 increased by a factor that corresponded to the change in price of the main heating fuel of the specific  
 16 country for the period 2008–2010. The justification for this approach is that although district heating can  
 17 be cheaper than alternative heating fuels, its price is usually maintained just below that of its main  
 18 competitor.



19  
 20 **Figure 2 : Index of space heating demand and determinants of its dynamics (including *HDD* and penetration of**  
 21 **central heating) for four large EU countries.**

1 Figure 2 shows the index of unit consumption for space heating demand and for four determinants of  
 2 energy demand from Eq. (1) for France, Germany, Italy, and the UK, i.e., four of the largest countries of  
 3 the EU (by demand and population). The dynamics of the variables over the period (Figure 2) shows that  
 4 unit consumption has been falling since 1990 and that it tracks *HDD*, with spikes for colder years. Year  
 5 2010 would appear to have been a very cold year in France, Germany, and the UK. Income per capita and  
 6 the penetration of central heating have been rising steadily, with the exception of the UK where there was  
 7 an increase of >50% in income per capita between 1993 and 2008 followed by a fall after the recession. In  
 8 France, Germany, and the UK, energy prices fell in the 1990's and rose in the 2000's, although prices in  
 9 Italy remained fairly stable for the entire period. In the four countries shown in Figure 2, the penetration of  
 10 central heating increased by approximately 20% between 1990 and 2010. By Year 2010, the penetration of  
 11 central heating in the residential sector was >90% in all of the countries examined in the present study,  
 12 with the exceptions of Greece, Portugal, and Spain [25].

### 13 3 RESULTS AND DISCUSSION

14 This section presents the results of the linear regression of Eq. (1) and discusses the findings in relation to  
 15 similar studies in the literature. The impacts on demand of the individual variables of Eq. (1) are also  
 16 described.

#### 17 3.1 Space heating demand per square metre in the period 1990– 2010

18 Table 3 presents the coefficients and test statistics, calculated for the model of space heating demand per  
 19 square metre using Eq. (1), for the 14 EU countries examined in the present work.

20 **Table 3 : Elasticity coefficients calculated in models of space heating demand per square metre. The basic model**  
 21 **is fitted without any variable for *EP*. The other models include an *EP* variable without delay (0) and with delays of**  
 22 **1, 3, 5, and 7 years respectively<sup>a</sup>.**

| Unit Consumption       | Basic Model   | Delay0          | Delay1         | Delay3         | Delay5         | Delay7         |
|------------------------|---------------|-----------------|----------------|----------------|----------------|----------------|
| $\beta_1$ (Price)      | -0.16 (1.99)  | -0.17 (2.18)    | -0.18 (2.27)   | -0.17 (2.15)   | -0.15 (1.93)   | -0.15 (2.08)   |
| $\beta_2$ (Income)     | 0.31 (1.10)   | 0.32 (1.15)     | 0.30 (1.12)    | 0.27 (1.08)    | 0.27 (1.08)    | 0.23 (0.91)    |
| $\beta_3$ (HDD)        | 0.56 (2.87)   | 0.59 (3.63)     | 0.60 (3.67)    | 0.59 (3.33)    | 0.54 (3.14)    | 0.53 (3.45)    |
| $\beta_4$ (CH)         | 0.29 (1.04)   | 0.27 (1.05)     | 0.25 (1.03)    | 0.23 (1.03)    | 0.26 (1.14)    | 0.27 (1.19)    |
| $\beta_5$ (Trend)      | -0.018 (3.27) | -0.015 (2.56)   | -0.013 (2.12)  | -0.011 (2.23)  | -0.013 (2.58)  | -0.012 (2.20)  |
| $\beta_6$ (EP)         |               | -0.00071 (0.79) | -0.0011 (1.25) | -0.0017 (2.16) | -0.0021 (2.88) | -0.0025 (3.32) |
| $\beta_0$ Constant     | 31.76         | 24.44           | 20.52          | 18.37          | 21.48          | 20.12          |
| R <sup>2</sup> Overall | 0.73          | 0.73            | 0.72           | 0.70           | 0.70           | 0.69           |
| F-test statistic       | 12.81         | 19.46           | 16.44          | 13.44          | 21.77          | 30.47          |

23 <sup>a</sup>Values shown in parentheses denote absolute t-statistics.

24 The difference between the six models presented in Table 3 relates to how the time series representing  
 25 policies focused on energy efficiency (*EP*)<sup>1</sup> are included in the models. In the basic model, *EP* are not  
 26 included at all. In the Delay0 model, they are included for the year in which they were published. For the

<sup>1</sup> See the nomenclature and Section 2.2 for descriptions of the *EP* and other policy-related variables.

1 remaining four models, they are included with delays of 1, 3, 5, and 7 years, respectively, after  
 2 publication. This means that, for example, policies introduced in Year 2000 do not have an effect until  
 3 Year 2007 in the Delay7 model. The reason for presenting the different models is to compare the effects of  
 4 the introduction of the *EP* variable with different time delays. If the values shown in Table 3 for *EP* are  
 5 instead calculated as percentages then they represent the percentage reductions in demand for the  
 6 introduction of one new low-impact policy (e.g., -0.0017 expressed as a percentage is -0.17%). The  
 7 values shown in parentheses are t-statistics calculated from the HAC standard errors.

8 The variable coefficients presented in Table 3 have the expected polarities, in the sense that e.g. when  
 9 price goes up demand is expected to fall. The absolute values of variable coefficients are also in line with  
 10 those previously published [16, 36, 43, 50], with low price elasticities and slightly higher income  
 11 elasticities, and with a time trend that represents an annual reduction in demand of >1% per annum. The  
 12 introduction of central heating is found to have a strong effect on demand, i.e., a 1% increase in the  
 13 penetration of *CH* leads to a >0.25% increase in demand. A key finding is that as time passes the impacts  
 14 of the policies, as represented by the *EP*, increase, while at the same time the impacts of price and income  
 15 decrease slightly. During its year of introduction, a low-impact policy reduces demand by 0.071%. This  
 16 makes sense given that low-impact policies are ranked as those that reduce demand by <0.1% (see Section  
 17 2.2). After 5 years, the policy impact has tripled to -0.21% and become statistically significant.

18 In Table 4, the same models as in Table 3 are presented except that the variable *EP* is divided into the  
 19 three policy categories of financial, informative, and regulatory. The polarities and absolute values for the  
 20 price, income, *HDD*, *CH*, and trend coefficients in the models shown in Table 4 are similar to those shown  
 21 in Table 3.

22 **Table 4 : Elasticity coefficients calculated in models of space heating demand per square metre. Compared to**  
 23 **Table 3, the Efficiency Policies variable (*EP*) has been divided into three separate types of policy measures<sup>a,b</sup>. The**  
 24 **basic model is fitted without any variable for *EP*. The other models include an *EP* variables without delay (0) and**  
 25 **with delays of 1, 3, 5, and 7 years respectively.**

| Unit Consumption       | Basic Model   | Delay0         | Delay1         | Delay3          | Delay5          | Delay7         |
|------------------------|---------------|----------------|----------------|-----------------|-----------------|----------------|
| $\beta_1$ (Price)      | -0.16 (1.99)  | -0.17 (2.80)   | -0.18 (3.53)   | -0.17 (3.41)    | -0.14 (2.22)    | -0.15 (2.55)   |
| $\beta_2$ (Income)     | 0.31 (1.10)   | 0.42 (1.69)    | 0.42 (1.73)    | 0.35 (1.45)     | 0.32 (1.32)     | 0.27 (1.07)    |
| $\beta_3$ (HDD)        | 0.56 (2.87)   | 0.62 (4.21)    | 0.63 (4.33)    | 0.57 (3.56)     | 0.54 (3.45)     | 0.53 (3.78)    |
| $\beta_4$ (CH)         | 0.29 (1.04)   | 0.26 (1.04)    | 0.23 (1.02)    | 0.22 (1.03)     | 0.25 (1.13)     | 0.28 (1.23)    |
| $\beta_5$ (Trend)      | -0.018 (3.27) | -0.016 (2.83)  | -0.014 (2.37)  | -0.013 (2.69)   | -0.014 (2.87)   | -0.013 (2.43)  |
| Financial Policy       |               | 0.00069 (0.62) | 0.00062 (0.59) | -0.00029 (0.34) | -0.00071 (0.90) | -0.0015 (2.29) |
| Informative Policy     |               | -0.0012 (0.96) | -0.0017 (1.46) | -0.0018 (1.14)  | -0.0027 (1.22)  | -0.0021 (0.76) |
| Regulatory Policy      |               | -0.0025 (1.73) | -0.0034 (2.27) | -0.0031 (3.08)  | -0.0030 (3.28)  | -0.0033 (3.21) |
| $\beta_0$ Constant     | 31.76         | 25.55          | 21.64          | 21.53           | 23.67           | 22.30          |
| R <sup>2</sup> Overall | 0.73          | 0.76           | 0.76           | 0.74            | 0.73            | 0.72           |
| F-test statistic       | 12.81         | 27.93          | 27.41          | 34.57           | 40.38           | 116.84         |

26 <sup>a</sup>Since the OLS regressions technique treats each variable independently, the absolute values of some of the coefficients shown in Table 4 are  
 27 slightly different from those shown in Table 3.

28 <sup>b</sup>The values in parentheses denote absolute t-statistics.

1 Regulatory policies seem to be the most effective type of energy efficiency policies when the expected  
2 impacts, as provided by the MURE database, are evaluated. The regression coefficients in Table 4 can be  
3 interpreted to mean that the introduction of one unit of regulatory policy (i.e., one ‘low-impact’ policy)  
4 has reduced the energy demand by an average of 0.25% in the year of introduction. As this is greater than  
5 the <0.1% impact expected for low-impact policies, it can be concluded that regulatory policies have on  
6 average performed better than expected. The results also point to different profiles over time for the three  
7 policy types:

- 8 • Regulatory policies have a strong impact already in the year of introduction, and this impact is  
9 consistent over the years that follow. This is what would be expected from policies of this type,  
10 e.g., building codes with minimum requirements.
- 11 • Financial policies show a low impact in the year of introduction, and require a number of years  
12 before they reduce demand by >0.1% and reach statistical significance. This might be expected  
13 from, for example, subsidies for new technologies whereby more and more house owners adopt  
14 the new technology, resulting in a cumulative increase in impact.
- 15 • Information policies show the opposite effect, with an increasing coefficient but falling statistical  
16 significance after being in force for 1 year. This may be explained by people getting used to  
17 information and returning to previous habits and routines after an initial change of behaviour.

18 A sensitivity analysis was carried out by removing each country in turn from the panel and re-running the  
19 Delay0 model shown in Table 3. It was found that removing Ireland and Portugal resulted in the income  
20 elasticity increasing to >0.6 and becoming significant at the 5% level. These two countries have had very  
21 large increases in per capita income over the period 1990–2010 that were not coupled to any large  
22 increases in the use of space heating. It seems that in the absence of economic booms, as experienced in  
23 Ireland and Portugal in recent years, the income elasticity for the EU-14 would be higher.

24 Given that the installation of *CH* in homes is influenced by *inter alia* rising household income, it was  
25 investigated whether removing *CH* from the model resulted in an increase in the calculated income  
26 elasticity. It did not. The F-form of the Wald test was also used to examine the effect on the model of  
27 omitting the *CH* variable, and it was found that the model was not improved by this omission. Despite its  
28 relationship to income, the inclusion of *CH* in the model may be justified because the installation of *CH*  
29 has a non-linear impact on heat demand, i.e., the installation of *CH* is said to double the heat demand of an  
30 average dwelling.

31 Given the disparities in the sizes of the 14 countries included in the panel, e.g., Germany and Ireland, a  
32 weighted least-squares regression using the same model variables was used to investigate the size effect.  
33 For this, the data for each country were weighted by the square root of its population. This weighting was  
34 applied to all the variables, with the exceptions of the time trend and the policy variables. The results  
35 obtained were very similar to those shown for the non-weighted models in Tables 3 and 4, suggesting that  
36 in this case size does not matter.

1 VIF tests carried out for multicollinearity did not show a VIF value  $>6$  for any variable, indicating that  
2 multicollinearity is not a problem for the data and model used. Driscoll-Kraay standard errors [51] were  
3 calculated to correct for the possible presence of inter-country spatial correlation in the data set. The  
4 calculated Driscoll-Kraay standard errors were smaller than the HAC standard errors. Although Driscoll-  
5 Kraay standard errors can be biased downwards in small panels, the one used in the present work is in the  
6 range suggested by the authors ( $T > 20$  and  $N$  not important), which suggests that for this dataset, spatial  
7 correlation is not a problem.

8 In a static fixed effects panel of electricity demand in the residential sector of 48 US states for the period  
9 1997–2008, Alberini and Filippini [16] deduced price and income elasticities of  $-0.22$  and  $0.28$ ,  
10 respectively. The values are similar to the results obtained in the present study given the differences in  
11 explanatory and dependent variables used. Using a dataset that contains 255 observations in the period  
12 1978–1999, Liu [52] found short-term and long-term price elasticities for total energy demand of  $-0.025$   
13 and  $-0.140$ , respectively, for OECD Europe, and short-term and long-term income elasticities for energy  
14 of  $0.052$  and  $0.291$ , respectively. These results for long-term elasticities are similar to those found in the  
15 present work. Azevedo et al. [40] calculated price elasticities for electricity for the EU of  $-0.2$ , which is  
16 similar to the value obtained in the present work. EEW [36] reported that autonomous technical progress  
17 brings about a 1% per annum reduction in demand across the EU, which corresponds with the coefficients  
18 calculated for the time trend in Table 3 and Table 4. Overall, in the present study, the price and income, as  
19 well as other calculated elasticities seem to conform to what has been reported in the literature.

20 Table 4 shows that the correlation between the estimated impact of informative policies from the MURE  
21 database and the savings that actually occurred is low and statistically insignificant. This is similar to  
22 previous studies [30, 35], which found that only a small proportion of total annual savings from efficiency  
23 at the EU level originated from the effects of information campaigns. In the context of promoting  
24 household energy conservation, Steg [53] has reported that information campaigns result in only modest  
25 behavioural changes, and von Borgstede et al. [54] has shown that informational policies only give the  
26 desired outcomes when households are willing to change wasteful behaviour patterns related to energy  
27 use. Yohanis [55] in a survey carried out in Northern Ireland found that although 88% of surveyed homes  
28 had purchased a major appliance in the previous 2 years, only 16% of the respondents had any idea about  
29 the energy ratings of their new appliances. In contrast to these findings, Ek and Söderholm [56] tested the  
30 hypothesis that information about available saving measures that is presented in a more concrete and  
31 specific way is more likely to affect (stated) behaviour than is more general information. The data they  
32 collected from a questionnaire sent to 1200 households in Sweden supported this notion. Lindén et al. [57]  
33 reported that following repeated information campaigns, households in Sweden filled washing and  
34 dishwashing machines before using them and households in detached houses were more likely to adopt a  
35 lower indoor temperature than households in apartments. The findings of various groups [56–59] suggest  
36 that there is room for improving the design of information policies, although it should be borne in mind  
37 that the willingness to switch to pro-environmental behaviours depends on the levels of the perceived  
38 thresholds that have to be overcome [49].

39 The results of interviews with experts and NEEAP screenings [36] revealed enormous disparity across  
40 Member States in terms of the levels of ambition of their energy efficiency policies and that in the less-

1 progressive countries many experts consider the first EPBD [6] to be a milestone that catalyses a new  
2 legal framework for energy use in buildings. Of the portfolio of policy measures in place across the EU,  
3 the IEA [58] reported that up to now the EPBD (categorised as an information policy in this work) has  
4 been the policy instrument with the greatest potential impact on energy efficiency in existing residential  
5 buildings in the short-term ( 5–10-year period) or even in the medium-term up to Year 2020. As the EPBD  
6 [6] was, for example, only proscribed in Austria in 2008, it is too early to state definitively what its effect  
7 on demand will be and whether it will be a transformative agent, given that it seems to have brought  
8 energy efficiency in buildings into the political agenda.

9 With regard to financial policies, Boonekamp et al. [35] reported that across the EU a substantial number  
10 of new measures for funding (40%) were introduced after the Energy Services Directive [7] came into  
11 force (post-2006). This suggests that it may be also too early to say what the effects of such policies are.  
12 However, Filippini et al. [30] found financial policies to be the policy type with the greatest impact in  
13 terms of reducing demand. Their study covered total energy demand in the residential sector, i.e.,  
14 including electricity for appliances and lighting, for 27 EU countries in the period 1996–2009. The  
15 difference between their results and the present results is that we show that the financial policies have an  
16 impact a number of years after they are introduced. Tietenberg et al. [21] reported that the literature makes  
17 it quite clear that any second-best policy mix in the face of bounded rationality non-optimising behaviour  
18 and volatile prices must recognize a role for more prescriptive strategies, such as targeted subsidies,  
19 efficiency standards, and/or tradable white certificates. The prescriptive nature of regulatory policy may  
20 be the reason why this policy type shows the greatest effect in the present work. The findings of several  
21 groups [15, 26, 28, 31–33] reinforce the results of the present paper in demonstrating that regulations are  
22 most effective.

### 23 3.2 Implication of calculated coefficients

24 For the EU-14 overall, the average percentage increase in energy prices between 1990 and 2010 has been  
25 1% per year (this value encompasses the increases and decreases in prices over the period, as shown in  
26 Figure 2). The average percentage increase in income for the same period has been 2%. If the coefficients  
27 calculated in the present work (Table 3 and Table 4) were to persist after 2010 one could expect that a 1%  
28 rise in the price of energy would result in a 0.15% fall in demand *ceteris paribus*. If at the same time,  
29 income would increase by only 1% per annum (half the rate seen in the previous decades), this would  
30 offset the energy savings resultant from higher prices. The penetration of central heating has been steady  
31 at 1% per year for the period 1990–2010, although as this is approaching saturation, i.e., >90% penetration  
32 in most countries, the same rate of growth cannot be expected in the future. Regardless of price and  
33 income dynamics or the impact of policy, demand can be expected to fall by a compounded 1% per year,  
34 due to factors represented by the time trend (autonomous technical progress, fuel switching, and structural  
35 effects). While autonomous technical progress and fuel switching from direct electric heating, oil heating  
36 and solid fuels heating to district heating, renewables<sup>2</sup> and natural gas heating can be expected to continue

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<sup>2</sup> As noted earlier, while the use of renewables in dwellings may not reduce heating demand *per se*, it reduces final energy demand, as represented in national statistics.

1 in the coming decades, future structural effects are less clear. During the period 1990–2010, increasing  
2 indoor temperatures would have diluted the effects of efficiency as represented by the time trend. Going  
3 forward, this effect should be diminished as homes converge on a standard indoor temperature of around  
4 21°C. However, the effects of people spending more time at home, e.g., more retirees and more people  
5 working from home, could have a similar diluting effect<sup>3</sup>. Nonetheless, two of the aforementioned factors  
6 represented by the time trend (autonomous technical progress and fuel switching) should continue to  
7 reduce demand apace.

8 The results of the present work also show that regulatory policies reduced demand for space heating by  
9 around 0.3% for each low-impact policy introduced. Given that medium-rank and high-rank policies are  
10 assumed to have ten and twenty times, respectively, the impact of low-impact policies, this suggests that  
11 the introduction of such regulatory policies would reduce demand by 3% and 6%, respectively<sup>4</sup>. It should  
12 be borne in mind that such large impacts reflect the fact that such policies are not introduced very often  
13 (e.g., for Austria, there was only one high-impact and one medium-impact regulatory policy introduced  
14 between 1990 and 2010; Table 2 ) and they represent the averages for a wide variety of regulatory policy  
15 impacts across the 14 countries studied. Therefore, it may be the case that the data representing the  
16 policies are too disparate for a strong emphasis to be placed on the calculated values. Thus, the differences  
17 in magnitudes of the three policy categories may be of more interest than the numbers themselves. EEW  
18 [36] advocates a savings target of 2% per annum, composed of a combination of efficiency policies and  
19 autonomous technical progress, based on the idea that savings of 1% per annum are already being made  
20 and that this should be doubled. The numerical results from the present work suggest that this can be  
21 achieved through the introduction of more or stronger regulatory policies (e.g., the introduction of an  
22 additional medium-rank policy every 3 years or an additional high-rank policy every 6 years). However,  
23 given the uncertainty related to the exact impact of policies on savings, the message from this paper for  
24 policymakers is to increase either the ambition level or the number of regulatory policies in force.

25 A Laspeyres decomposition [60,61 and Nomenclature] was carried out to examine the effects of individual  
26 model variables on energy demand (kWh/m<sup>2</sup>/year). For this, the model coefficients of the Delay3 model  
27 shown in Table 4 (chosen as a representative model) were multiplied by the respective time series data for  
28 1990 used in their calculation, except that each variable was in turn changed to its 2010 value (while  
29 keeping the other time series data at 1990 values), to isolate their effects on demand relative to those of  
30 the other variables. The time series variables used for the decomposition for 1990 and 2010 were the  
31 averages for each variable for the 14 EU countries. Table 5 shows the magnitude that each model variable  
32 increased or decreased demand in 2010 relative to 1990. The impact on demand of the time trend, which  
33 represents autonomous technical progress, fuel switching, and structural effects, stands out as it accounts

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<sup>3</sup> The structural effects of trends in larger dwellings are not considered because the dependent variable examined is unit consumption, while the structural effects of longer daily and annual heating duration and increased indoor temperature are included in the unit consumption variable. These latter effects cannot however be examined explicitly due to the scarcity of relevant time series of data.

<sup>4</sup> Note that because of the way in which the analysis in the present work has been carried out, this would mean individual regulatory policies across the 14 countries would collectively give these percentages.

1 for >20% of the change. Energy efficiency policies resulted in an approximately 11% reduction most of  
 2 which was as a result of regulatory and informative policies. Energy price increases were modest during  
 3 this period and decreased energy demand by less than 3%. At the same time, income dynamics increased  
 4 demand by over 10%. This corresponds to the pre-financial crisis period of economic growth in the EU.  
 5 The introduction of *CH* increased demand by approximately 4%, while a number of colder-than-average  
 6 winters increased demand by over 10%.

7 **Table 5 : Examination of impacts of model variables on demand between 1990 and 2010.**

| Variable                         | Impact 1990 – 2010 |
|----------------------------------|--------------------|
| Price                            | Decrease by 2.8%   |
| Income                           | Increase by 11.9%  |
| Climate (HDD)                    | Increase by 10.6%  |
| Central Heating                  | Increase by 4.4%   |
| Time Trend                       | Decrease by 22.9%  |
| Financial Policies               | Decrease by 0.5%   |
| Information Policies             | Decrease by 5.0%   |
| Regulatory Policies              | Decrease by 5.8%   |
| Total Change (sum of above)      | Decrease by 10.1%  |
| Total Change (measured)          | Decrease by 13.8%  |
| Laspeyres Decomposition Residual | Decrease by 3.7%   |

## 8 **4 CONCLUSIONS**

9 The effects of energy efficiency policies on space heating in the EU residential sector were analysed using  
 10 a fixed effects static panel data model for the period 1990–2010. This analysis was performed using unit  
 11 consumption of energy for space heating (kWh/m<sup>2</sup>/year), which is an established indicator of efficiency.  
 12 The impacts of three specific categories of efficiency-focused policy, namely financial, regulatory, and  
 13 informative, were also examined. The results show that in relation to the *ex-ante* evaluations of impacts,  
 14 the regulatory policies have been more effective at reducing demand than have the informative and  
 15 financial policies. In addition, regulatory policies are found to have a consistent demand-reducing impact  
 16 over time, as compared with informative and financial policies. Informative policies are found to have a  
 17 short-term impact, whereas financial policies require a number of years to have an effect. Although the  
 18 EU EPBD and ESD policy packages may improve the effects of information and financial policies, the  
 19 indications to date, which are supported by the findings of the present work, are that regulatory policies  
 20 reduce demand in the year in which they are introduced and for at least 7 years thereafter. These findings  
 21 suggest that regulatory policy measures should be assigned a high priority if EU-wide energy goals are to  
 22 be met expeditiously and build on similar work carried out recently by others [30, 32]. This conclusion is  
 23 supported by the well-known market barriers to efficiency that exist in the residential sector, which, in  
 24 contrast to information- or financial efficiency-focused policies, necessitate regulation to be overcome.

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## 6 REFERENCES

- [1] EC. A Roadmap for moving to a competitive low carbon economy in 2050. COM(2011)112.: European Commission.; 2011.
- [2] EC. Energy efficiency: delivering the 20% target. COM(2008)772.: European Commission; 2008.
- [3] EC. Action plan for energy efficiency: realising the potential. COM(2006)545. European Commission; 2006.
- [4] ECF. Energy savings 2020. How to triple the impact of energy saving policies in Europe. European Climate Foundation; 2011.
- [5] Euraktiv. Lidegaard: 'We fought like lions for the Energy Efficiency Directive'. 2012.
- [6] EC. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Official Journal of the European Communities: European Commission; 2002. p. L1.
- [7] EC. Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC. EEC: European Commission; 2006.
- [8] EC. Directive 2009/125/EC of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for energy-related products.: European Commission; 2009.
- [9] EC. Directive 2010/30/EU of the European parliament and of the council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (recast). COM(2010): European Commission; 2010.
- [10] EC. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, L153 of: European Commission; 2010. p. 13-35.
- [11] EC. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending directives 2009/125/EC and 2010/30/EC and repealing directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union L: European Commission; 2012. p. 1-56.
- [12] EC. Energy taxation: Commission promotes energy efficiency and more environmental friendly products. IP(11)468: European Commission; 2011.
- [13] ISIS. MURE II Database on energy efficiency policies and measures. 2012.
- [14] Uihlein A, Eder P. Policy options towards an energy efficient residential building stock in the EU-27. Energy and Buildings. 2010;42:791-8.
- [15] Geller H, Harrington P, Rosenfeld AH, Tanishima S, Unander F. Polices for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy. 2006;34:556-73.
- [16] Alberini A, Filippini M. Response of residential electricity demand to price: The effect of measurement error. Energy Economics. 2011;33:889-95.
- [17] Convery FJ. Reflections–Energy Efficiency Literature for Those in the Policy Process. Review of Environmental Economics and Policy. 2011;5:172-91.
- [18] Gillingham K, Newell RG, Palmer K. Energy Efficiency Economics and Policy. Annual Review of Resource Economics. 2009;1:597-620.

- 1 [19] Neij L. Barriärer och styrmedel för en effektivare energianvändning. Lunds Universitet.  
2 2007.
- 3 [20] Ryan L, Moarif S, Levina E, Baron R. Energy efficiency policy and carbon pricing. IEA.  
4 2011.
- 5 [21] Tietenberg T. Reflections—Energy Efficiency Policy: Pipe Dream or Pipeline to the Future?  
6 Review of Environmental Economics and Policy. 2009;3:304-20.
- 7 [22] IEA/UNDP. Modernising Building Energy Codes to Secure our Global Energy Future. 2013.
- 8 [23] de T'Serclaes P, Jollands N. Mind the gap: quantifying principal-agent problems in energy  
9 efficiency. Paris, International Energy Agency and the Organization for Economic Cooperation  
10 and Development. 2007.
- 11 [24] Joskow PL. Energy Policies and their consequences after 25 years. The Energy Journal  
12 2003;24.
- 13 [25] Enerdata. Odyssee Database. 2013.
- 14 [26] Vine E, du Pont P, Waide P. Evaluating the impact of appliance efficiency labeling  
15 programs and standards: process, impact, and market transformation evaluations. Energy.  
16 2001;26:1041-59.
- 17 [27] Hoicka, C.E., Parker, P., Andrey, J. Residential energy efficiency retrofits: How program  
18 design affects participation and outcomes. Energy Policy 2014; 65:5 94–607
- 19 [28] Ürge-Vorsatz D, Koeppl S, Mirasgedis S. Appraisal of policy instruments for reducing  
20 buildings' CO<sub>2</sub> emissions. Building Research & Information. 2007;35:458-77.
- 21 [29] Horowitz M. Changes in electricity demand in the United States from the  
22 1970s to 2003. The Energy Journal. 2007; 28.
- 23 [30] Filippini, M., Hunt, L., Zorić, J., 2014. Impact of energy policy instruments on the estimated  
24 level of underlying energy efficiency in the EU residential sector. Energy Policy 2014; 69:73-81.
- 25 [31] Saussay, A., Saheb, Y., Quirion, P., 2012. The impact of building energy codes on the energy  
26 efficiency of residential space heating in European countries—a stochastic frontier approach. In:  
27 International Energy Program Evaluation Conference, 12–14 June 2012, Rome.
- 28 [32] Bigano et al., 2011 A. Bigano, R. Arigoni Ortiz, A. Markandya, E. Menichetti, R.  
29 Pierfederici. The linkages between energy efficiency and security of energy supply in Europe. I.  
30 Galarraga, M. González-Eguino, A. Markandya (Eds.), Handbook of Sustainable Energy, Edward  
31 Elgar Publishing Ltd., Northampton (2011), pp. 60–83.
- 32 [33] Ademe. Energy Efficiency Monitoring in the EU. Paris: Ademe Editions; 2005.
- 33 [34] Berry D. The impact of energy efficiency programs on the growth of electricity sales.  
34 Energy Policy. 2008;36:3620-5.
- 35 [35] Boonekamp P, Vethman P, Gerdes J, Sipma J, Feenstra Y, Pollitt H, et al. Background study  
36 for horizontal issues concerning energy savings in the EU. Request for Services, TREN/A2/143-  
37 2007. Energy Research Centre of the Netherlands, Cambridge Econometrics. 2011.
- 38 [36] EEW. Improving and implementing national energy efficiency strategies in the EU  
39 framework. Energy Efficiency Watch; 2013.
- 40 [37] Espey JA, Espey M. Turning on the Lights: A Meta-Analysis of Residential Electricity  
41 Demand Elasticities. Journal of Agricultural and Applied Economics. 2004;36:17.
- 42 [38] Lee C, Lee J. A Panel Data Analysis of the Demand for Total Energy and Electricity in  
43 OECD Countries. The Energy Journal. 2010;31.
- 44 [39] Narayan PK, Smyth R, Prasad A. Electricity consumption in G7 countries: A panel  
45 cointegration analysis of residential demand elasticities. Energy Policy. 2007;35:4485-94.
- 46 [40] Azevedo IML, Morgan MG, Lave L. Residential and Regional Electricity Consumption in  
47 the U.S. and EU: How Much Will Higher Prices Reduce CO<sub>2</sub> Emissions? The Electricity Journal.  
48 2011;24:21-9.
- 49 [41] Nerlove M, Sevestre P, Balestra P. Introduction. In: Mátyás L, Sevestre, P., editor. The  
50 Econometrics of Panel Data - Fundamentals and Recent Developments in Theory and Practice.  
51 Third Edition ed. Berlin Heidelberg: Springer-Verlag 2008.

- 1 [42] Dougherty C. Introduction to Panel Data Models. Introduction to Econometrics Fourth  
2 Edition ed. UK: Oxford University Press; 2011.
- 3 [43] Haas R, Schipper L. Residential energy demand in OECD-countries and the role of  
4 irreversible efficiency improvements. *Energy Economics*. 1998;20:421-42.
- 5 [44] Yearwood Travezan J, Harmsen R, van Toledo G. Policy analysis for energy efficiency in  
6 the built environment in Spain. *Energy Policy*. 2013;61:317-26.
- 7 [45] OECD. Economic Outlook No 84: Annual and Quarterly data. Paris: OECD; 2008.
- 8 [46] Eurostat. Eurostat Statistics Database, European Commission. Luxembourg 2013.
- 9 [47] Werner S. European DH Prices 1980-2009. 2009.
- 10 [48] IEA. IEA Energy Prices and Taxes Statistics, OECD iLibrary. Paris 2012.
- 11 [49] Werner S. Ecoheatcool 2005–2006, Work package 1 (The European heat market) and 4  
12 (Possibilities with more district heating in Europe). Brussels, Belgium: Euroheat and Power.  
13 2006.
- 14 [50] Nässén J, Sprei F, Holmberg J. Stagnating energy efficiency in the Swedish building  
15 sector—Economic and organisational explanations. *Energy Policy*. 2008;36:3814-22.
- 16 [51] Driscoll, J and Kraay, A. Spatial Correlations, A correction for spatial correlation in panel  
17 data. Policy research working paper 1553. The World Bank Policy Research Department, 1995.
- 18 [52] Liu G. Estimating energy demand elasticities for OECD countries: a dynamic panel data  
19 approach: Statistisk Sentralbyrå; 2004.
- 20 [53] Steg L. Promoting household energy conservation. *Energy Policy*. 2008;36:4449-53.
- 21 [54] von Borgstede C, Andersson M, Johnsson F. Public attitudes to climate change and carbon  
22 mitigation—Implications for energy-associated behaviours. *Energy Policy*. 2013;57:182-93.
- 23 [55] Yohanis YG. Domestic energy use and householders' energy behaviour. *Energy Policy*.  
24 2012;41:654-65.
- 25 [56] Ek K, Söderholm P. The devil is in the details: Household electricity saving behavior and the  
26 role of information. *Energy Policy*. 2010;38:1578-87.
- 27 [57] Lindén A-L, Carlsson-Kanyama A, Eriksson B. Efficient and inefficient aspects of  
28 residential energy behaviour: What are the policy instruments for change? *Energy Policy*.  
29 2006;34:1918-27.
- 30 [58] Kristom, B. Residential Energy Demand. Volume 1: ENERGY - Reference Module in Earth  
31 Systems and Environmental Sciences. Encyclopedia of Energy, Natural Resource, and  
32 Environmental Economics. 2013, Pages 218–224.
- 33 [59] IEA. Promoting Energy Efficiency Investments – Case Studies in the Residential Sector.  
34 Paris: OECD/IEA; 2008.
- 35 [60] IEA, 1997. Indicators Manual. IEA, Paris.
- 36 [61] Ó Broin, E., 2007. Energy Demands of European Buildings: A Mapping of Available Data,  
37 Indicators and Models, Department of Energy and Environment. Chalmers University of  
38 Technology, Göteborg, Sweden.