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1 **TITLE:**
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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 looks at 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/m²/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>	A time series variable constructed for the purpose of the present work to represent the residential sector heating-focused Efficiency Policies that are in place. <i>EP</i> is also subdivided into financial, informative and regulatory policies in this work.
<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>High-, Medium- or Low-impact Policy</i>	A policy listed in the MURE Policy Database that is estimated to reduce demand by >0.5%, 0.1%–0.5% or <0.1%, respectively.
<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 regression 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 <i>EP</i> , Financial, Informative and Regulatory policy variables.
<i>Unit consumption of energy for space heating (kWh/m²/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>VIF</i>	Variance inflation factor. A statistical tool to detect the multicollinearity of a number of explanatory variables.
<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 parametric statistical test used to examine the combined significance of a number of explanatory variables.
<i>Wu-Hausman test</i>	A statistical hypothesis test used to examine a model for endogeneity.

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 CO₂ 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. From a policymaker's perspective and considering the well-known market
27 barriers to energy efficiency, it is of interest to know how well the existing and previous efficiency policy
28 frameworks have succeeded in reducing energy demand. Previous studies of this issue, which included
29 some *ex post* analyses, e.g., [24], have compared a projected baseline energy demand to the actual demand
30 outfall and postulated that the difference is due to policy-driven energy efficiency improvements and the
31 use of less-energy-intensive products. This approach is similar to the findings of indicator-based
32 efficiency evaluations [25]. Vine and co-workers [26] reported that the combination of mandatory
33 labelling which was introduced in the EU in 1992 and other efficiency policies improved the efficiency of
34 refrigeration appliances by 10% from 1992 to 1996. Hoicka et al. [27] showed that financial rewards can
35 increase both the levels of participation and outcomes in efficiency programmes. As part of the IPCC 4th
36 assessment (AR4) chapter on mitigation options for residential/commercial buildings, a qualitative
37 evaluation of 60 *ex post* efficiency case studies was carried out [28]. Appliance standards, building codes,
38 tax exemptions, and voluntary labelling were found to be the most effective policy instruments for
39 reducing demand.

1 Using a panel of 48 of the states in the USA, Horowitz [29] examined empirically whether states with
2 strong commitments to energy efficiency have lower levels of energy intensity than those with weak
3 commitments, and found that this was indeed the case. He also found that energy efficiency programmes
4 have a transformative effect on other macroeconomic variables, such as electricity price, income per
5 capita, and technological change, and that there are spill-over efficiency effects from states with
6 strong commitments to efficiency towards states with weaker commitments. Filippini and colleagues [30]
7 also used panel data methodologies to examine empirically the impacts of energy policy instruments on
8 the estimated level of underlying energy efficiency in the EU residential sector, while Saussay et al. [31]
9 did the same for seven EU countries and Bigano et al. [32] did the same for all sectors. The two latter
10 studies [31 and 32] found that energy efficiency in the residential sector had been improved by the
11 application of, in particular, mandatory standards for buildings. Filippini et al. [30] found that financial
12 measures had the greatest impact, mandatory standards for appliances or buildings less of an impact; they
13 found no improvement in efficiency from informative policies.

14 These last three cited papers [30-32] represent a discourse initiated by Bigano et al. [32] in which panel
15 data econometric methods are used to examine the extents to which the energy efficiency-focused policies
16 introduced across the EU have succeeded in reducing energy demand. The three papers differ from more
17 common residential sector models in the literature, e.g. [16, 33], in that they explicitly include variables
18 that account for the introduction of energy efficiency policies. While all three papers provide valuable
19 insights into modelling methods and the impact of efficiency policies, the method that they use for
20 quantifying the actual efficiency policies in place is somewhat rudimentary. Bigano et al. [32] state in
21 their conclusions that: ‘It would be more interesting to use continuous instead of binary policy variables’,
22 while Saussay et al. [31] write that: ‘Finally, the parameterization we chose for the building energy codes
23 is admittedly fairly simple, and would call for further improvements’. Therefore, the present study
24 develops the aspect regarding the modelling of efficiency policy and as such presents a further
25 contribution to the discourse. Our focus is on the case of space heating energy demand in the EU-15
26 residential sector from 1990 to 2010. In addition, this paper describes other methodological developments,
27 which are outlined in the *Methodology* section and expands the literature review to place the work in a
28 broader perspective. In light of the methodological developments, the results obtained in the present work
29 reinforce the general findings of the previous studies [30-32] regarding the paramount importance of
30 regulatory policies as well as adding new results with regard to the impact of policy over time. This paper
31 is divided into four sections. Following the *Introduction*, Section 2 presents the approach used and then
32 describes the model parameters and the data used as inputs. This includes a description of the quantitative
33 method used in this work to represent energy efficiency policies applied to the residential sector. Section 3
34 presents results for the various models and a detailed discussion on the implications and interpretations of
35 the findings. Section 4 presents the conclusions drawn from the study.

2 METHODOLOGY

This paper uses a panel data regression approach to estimate the energy savings conferred by the policy portfolio in place across the EU¹. In modelling terms, the core determinants of energy demand are defined for the purposes of this paper as: energy price; personal income; the outdoor climate; the penetration of central heating in the building stock; and a time trend, which is a linear approximation of other effects that have occurred over the studied period. The latter include autonomous technical progress, fuel switching, and structural changes. These explanatory variables are similar to those used by others [16, 37], except that no alternative fuel price options, such as a response to an increase in the gas price, are employed. This is because the dependent variable used in this study (space heating) is not substitutable. In considering whether to employ a fixed or random effects panel data model to account for the unobserved heterogeneity across a panel of countries, it has been argued [38] that a fixed effects model should be used. Their argument is that the selection of countries for studies such as the one described in this paper is not random, since the countries chosen are not exchangeable with other countries. Bigano et al [32] chose a fixed effects rather than a random effects panel using the same justification. Dougherty [39] has explained that if a panel is designed with OECD countries only, the countries are inherently not chosen randomly. Dougherty [39] has also presented a model choice scheme, which for the purposes of this paper would suggest the use of a fixed effects model.

In keeping with the previous studies [30-32], the present study incorporates an additional explanatory variable that represents policies aimed at reducing energy demand *via* efficiency. The new variable is an aggregation of relevant policies and measures introduced at the EU and national levels since the 1970's and is termed *EP* (Energy Policies) for the purposes of modelling. By introducing this variable, the component of the time trend that otherwise would have represented efficiency policy is removed. As a development, *EP* in the model is replaced by separate variables that represent different categories of efficiency policies, to determine which particular policy categories have had the greatest impacts on demand. For the purposes of the present work, the remaining determinants of energy demand, e.g., price, income etc., are control variables, the coefficients of which are expected to concur with those reported in the literature in terms of magnitude and polarity.

In the present work, the analysis is performed for energy demand for space heating in the residential sector. The dependent variable used in this study is unit consumption (kWh/m²/year), as its temporal dynamic is an established indicator of energy efficiency [25]. The period examined is 1990–2010. While this interval is motivated primarily by the availability of the relevant data, it is also a historical period that is of high relevance for policymakers who are designing contemporary efficiency policies. The work carried out in [32] also used Unit Consumption as a dependant variable, while [30] looked at all energy demand and [31] examined total space heating energy demand.

¹ Various groups [34-36] have presented comprehensive reviews of how panel data analysis can be used for energy demand studies.

1 Table 1 : Comparisons of the methodologies used in the present study and the previous studies [30-32].

	This paper	Filippini et al. [30]	Saussay et al.[31]	Bigano et al. [32]
Temporal Scope	1990 – 2010	1996 – 2009	1990 – 2008	1980 - 2006
Spatial Scope	EU-15 except Luxembourg	EU-27 except Malta	Seven EU countries: Austria, Denmark, Finland, France, Germany, Poland and the United Kingdom	EU-15 plus Norway
Panel Structure	Balanced	Unbalanced	Unbalanced	Unbalanced
Panel approach	Fixed Effects	Fixed and Random Effects separately	Random Effects	Fixed Effects
Dependent variable	Unit Consumption (kWh/m ² /year) of residential sector space heating energy demand from five energy carriers: electricity, natural gas, oil, coal and district heating.	Total energy demand in residential sector	Sum of residential sector space heating energy demand from three energy carriers: electricity, natural gas and oil	Unit Consumption for total energy demand in residential sector
Price variable	WAP for heat from five energy carriers coal, district heating, electricity natural gas and oil.	Index of household energy prices	WAP of market prices for three energy carriers: electricity, natural gas and oil.	Electricity prices
Policy Data Source	MURE Policy Database	MURE Policy Database	IEA BEEP Database	MURE Policy Database
Policy parameterization	Index that increases by 20, 10 or 1 every time a High-, Medium-, or Low-impact policy is introduced respectively.	Separate dummy variables for cases of 1–2 or ≥3 policies in a particular category that are in force.	Index that increases by 1 for every year a policy is in force.	Dummy variable for each year at least one policy in a particular category is in force.
Inclusion of policy variables in model	Variable in panel OLS	Stochastic Frontier Approach	Stochastic Frontier Approach	Variable in panel OLS
Lagged effects of policy variables	Up to 7 years	None	Implicit <i>via</i> annually increasing policy index	Up to 2 years
Policy Categories Modelled	Four: (i) All; (ii) Financial; (iii) Informative; and (iv) Regulatory	Six: (i,ii) building standards; (iii,iv) financial; (v) appliances; and (vi) information	One: Building Standards	Twelve: (i)Mandatory Standards for Buildings; (ii) Regulation for Heating Systems and hot water systems; (iii) Other Regulation in the Field of Buildings; (iv) Mandatory Standards for Electrical Appliances; (v) Legislative/Informative; (vi) Grants/subsidies; (vii) Loans/Others, (viii), Tax Exemption/Reduction; (ix) Tariffs; (x) Information/Education; (xi) Co-operative Measures; (xii) Cross-cutting with sector-specific characteristics

1 Table 1 presents a comparison of the methodologies employed in the work presented in this paper and that
2 used in the previous studies [30-32]. In summary, the present paper encompasses methodological
3 advances that implement changes to: 1) the way that the policy data are interpreted (see Section 2.2); 2)
4 the time period used for the analysis; 3) how the time series of energy prices is calculated (see Section
5 2.3); 4) the process by which the econometric testing of model results is carried out (See Section 3.1); and
6 5) the dependant variable used (Unit Consumption for Space Heating).

7 2.1 Model description

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

$$9 \ln(I_{it}) = \beta_0 + \beta_1 \ln(P_{it}) + \beta_2 \ln(Y_{it}) + \beta_3 \ln(CH_{it}) + \beta_4 \ln(HDD_{it}) + \beta_5(t) + \beta_6(EP_{it}) + \varepsilon_{it} \quad (1)$$

10 where P_{it} is a weighted average (by heating energy carrier for each individual country) real price of
11 energy, Y_{it} is income per capita, CH_{it} is the percentage of dwellings with central heating installed, HDD_{it}
12 are heating degree days which are a proxy variable for the outdoor climate, t is a time trend, EP_{it} is a
13 numerical representation of the energy efficiency policies in place, and ε_{it} is the residual term. The i and t
14 subscripts in Eq. (1) give the spatial and temporal parameters of the panel, respectively. Initially, other
15 choices of dependent variables for heating were tested, including the total heating demand (space heating
16 plus water heating plus heat for cooking), total per capita, and total per square metre. However, it was
17 decided to perform the work only for unit consumption for space heating for the EU-14 after taking into
18 consideration the following issues: (i) data availability; (ii) the need to have a balanced panel to facilitate
19 some statistical tests; (iii) structural differences between the newer and older Member States of the EU
20 due to the former having had price controls in their energy markets; (iv) the research question to be
21 answered; and (v) the preliminary results obtained. In estimating a fixed effects model, Eq. (1) is
22 transformed to a Least-Squares Dummy Variable fixed effects (LSDV) regression model, so that the
23 constant (β_0) absorbs the individual country fixed (time invariant) effects. In addition, statistical tests are
24 applied to the results of the (LSDV) regression model to check for: multicollinearity of the explanatory
25 variables; the presence of inter-country spatial correlation in the dataset; and endogeneity between the EP
26 and the dependant variable.

27 2.2 Quantitative representation of Efficiency Policies

28 Data for the construction of the EP variable in Eq. (1) were obtained from the MURE Policy Database
29 [13]. This database includes more than 500 policies focused on energy efficiency that have been
30 introduced since the 1970's across the 28 EU countries and Norway. The policies include the following
31 types: (i) Financial; (ii) Fiscal/Tariffs; (iii) Informational/Educational; (iv) Legislative/Informative; (v)
32 Legislative/Normative; (vi) Co-operative; and (vii) Unknown (as designated in the MURE Policy
33 Database). Table 3 lists examples of some of these policy categories for the case of Austria. Previous
34 studies [30, 32] have also used the MURE Policy Database to model the effects of efficiency policies.
35 Both investigations introduce dummy variables in their models for the years during which subcategories
36 of policies, e.g., building regulations, are in force (See Table 1). Filippini et al. [30] represents an advance

1 on the work of Bigano et al. [32] in this regard, since the former distinguishes between the number of
2 policies implemented, i.e., it uses separate dummy variables respectively for cases of 1–2 or ≥ 3 policies in
3 a particular subcategory that are in force. The work presented in this paper is an advance on both these
4 studies [30 and 32] because it goes beyond binary representations of policies in place to represent them as
5 a time series, which increases as more policies are introduced and decreases as policies become obsolete
6 (Figure 1).

7 The MURE Policy Database also provides a semi-quantitative impact (SQI) ranking of each policy
8 contained therein. These SQI rankings have been carried out by the respective energy agencies in each
9 country that are responsible for the policy content of the database and are based on an estimation of the
10 energy savings achievable or achieved by each policy. These SQI's are grouped into three bands, high,
11 medium and low, depending on whether they describe policies that are expected or that have been found
12 to reduce energy demand in their sector of focus by $>0.5\%$, $0.1\%–0.5\%$, and $<0.1\%$, respectively. For
13 example, a low impact policy as designated in the MURE Policy Database is one that has been found to
14 lower or is expected to lower demand by less than 0.1% . It is these SQI's that are used to construct the
15 policy time series [EP in Eq. (1)] used in this paper. This solution is similar to that adopted by Berry [40],
16 who used the American Council for an Energy-Efficient Economy's (ACEEE's) 2006 efficiency scorecard
17 for US States as a variable in a regression function for electricity sales.

18 In order to construct a time-series variable that represented efficiency policy in place, it was initially
19 thought that each policy could in turn be assigned values of 5, 2.5, and 1 for each year that they were in
20 force, corresponding to the three SQI impact bands described above. However, an examination of the
21 qualitative descriptions of specific policies that accompany each SQI revealed that policies rated as low
22 impact are usually associated with very low expected savings in comparison to medium-impact and high-
23 impact policies. Therefore, for the purposes of the present work, the three bands are assigned values of 20,
24 10, and 1, respectively. In other words a policy classed as a medium impact policy in the MURE Policy
25 Database is assumed to lead to a ten times higher demand reduction than a low impact policy. This
26 grading scheme is applied to all categories of policy and all countries. Thus, for the example of Austria
27 shown in Table 3, the first named policy, a Residential building subsidy, is assigned a value of 20 for
28 every year from 1990 to 2010, as its SQI from the database ranks it as a High Impact Policy. Similarly, the
29 second policy listed is assigned a value of 20 for each year from 1992 to 2010, while the third policy listed
30 is assigned a value of 1 for the years 2009 and 2010.

31 Taking the case of France, two low impact policies (FRA6 and FRA28) have SQI's that estimate
32 reductions in demand of 0.01% and 0.02% , respectively. Four medium-impact policies (FRA9, FRA16,
33 FRA18, FRA44) have SQI's that estimate reductions in demand of 0.35% , 0.36% , 0.46% , and 0.14% ,
34 respectively. Three high-impact policies (FRA5, FRA7, and FRA8) have SQI's that estimate reductions in
35 demand of 2.25% , 0.55% , and 1.40% , respectively. Thus, for France, the medium-impact policies are in
36 general estimated to have a ten-fold greater impact on demand than the low-impact policies, while the
37 high-impact policies are estimated to have 1–16-fold greater impacts than the medium-impact policies. An
38 examination of Finland and Germany revealed differences in the SQI's of the medium- and high-impact
39 policies at the higher end of the 1–16-fold range highlighted for France. Italy, Greece, and the UK were
40 closer to the lower end of the range for France. Following calibration tests using the averages of the

1 differences between the SQI's of high-, medium-, and low-impact policies, the aforementioned values of
2 20, 10, and 1, respectively, were chosen.

3 No distinction is made between say a medium-impact financial policy in Austria and one in another
4 country, despite the fact that for Austria this could amount to a Heating cost settlement for common
5 thermal facilities (see Table 3), whereas for say France, a medium-impact financial policy could amount to
6 a zero-rated eco-loan (FRA 31). Distinguishing between policy types at a national level would increase
7 significantly the level of disaggregation in the model and would represent a deviation from the focus on
8 improving the representation of policies heretofore implemented in previous studies [30-32]. Nevertheless,
9 this is an area that warrants further research. As the *EP* time series in Eq. (1) is an aggregation of the high-
10 , medium-, and low-impact policies, the β_6 term in Eq. (1) represents the actual demand reduction
11 achieved from the expected (SQI) impact of a low-impact policy.

12 For the 14 countries that are in focus in the present work, the database contains 329 residential sector
13 policies. Of these, six are defined as cross-cutting, and therefore are excluded from the work because they
14 represent energy and carbon taxes of various types that would already be represented in the energy price
15 time series (P_{it}) in Eq. (1). Similarly, 15 regionally focused polices in Belgium, e.g., Flanders or Wallonia,
16 were not included, whereas federal policies for the same country were included. In addition, 48 policies
17 that focus exclusively on electricity demand for appliances and lighting were also ignored. Of the
18 remaining 260 policies, 202 are focused on heat and 58 are focused on both heat and electricity (See Table
19 2). An example of the latter is a policy named “Energy advice for households”, which obviously applies to
20 both heating and other household uses of energy.

21 **Table 2 : Numbers of policies from the MURE Policy Database analysed for the purpose of the present work^a**

Policy type	Heat	Electricity and heat	Total
Financial	67	12	79
Informative	54	14	68
Regulatory	81	32	113
Total	202	58	260

22 ^aCategorisation carried out as described in the text.

23 As mentioned earlier, the database of policies and the variable *EP* are divided into different categories of
24 efficiency policy, to evaluate their respective impacts. The categories chosen are: regulatory, economic,
25 and information policy instruments [41]. According to [42], this classification is based on the degree of
26 authoritative force. Regulations imply commanding particular behaviours; economic instruments aim at
27 altering the benefits and/or costs in order to encourage energy efficiency investments; and, finally,
28 information aims at shifting priorities by building awareness. Several assumptions were needed to apply
29 this categorisation to the policies in the MURE Policy Database. Although policies that are labelled
30 ‘Legislative/Informative’ are regulatory, in that they mandate the display of information, these policies
31 have been categorised as informative, since market transformation via information is their main goal.
32 Most of the policies in this category refer to the EU EPBD and the Energy Labelling of Products
33 directives [6, 9]. While the EU EPBD directive contains regulatory components, such as the mandatory

1 inspection of boilers, the main focus of both directives is the energy labelling of buildings and appliances,
2 respectively. Policies in the database categorised as ‘Co-operative’ or ‘Unknown’ were each examined in
3 turn to define their placements. Although the Co-operative policy shown in the example for Austria (Table
4 2) is ostensibly information-driven, its main contribution with respect to the residential sector is in
5 relation to minimum standards for standby, which makes it a regulatory policy for the classification
6 applied in this work. For some countries, notably, the Netherlands, many of the policies listed are labelled
7 as ‘Co-operative’. This is because in the Netherlands, there is strong representation of housing
8 organisations, which make voluntary agreements with the authorities to reduce energy demand. Each of
9 these polices have been categorised on an ad hoc basis to determine if they are more regulatory or
10 informative in nature. Policies labelled Financial, i.e., grants for renewables, were included. Many of these
11 refer to grants or subsidies for the installation of heat pumps and solar photovoltaic (PV) or collector
12 panels, all of which would reduce the final energy demand, as listed in the energy statistics. Table 2 shows
13 the numbers of policies for each category based on the categorisation carried out for the present work.
14 Most of these policies were implemented in the period 1990–2010, while others were already in force in
15 1990.

16 **Table 3 : Residential sector energy efficiency policies for Austria from the MURE Policy Database [13] analysed in**
17 **the present work.^a**

Designation ^b	Focus ^b	Weight ^b	Policy Title ^c	Policy Type ^c	SQI ^c	Duration ^c	EU ^c	Code ^c
Financial	Heat	20	Residential building subsidy	Financial	High	1989–	No	AU13
	Heat	20	Grants for renewable energy (heat pumps, biomass etc.)	Financial	High	1992–	No	AU10
	Heat	1	National recovery plan / renovation voucher	Financial	Unknown	2009–	No	AU26
Regulatory	Heat	20	Heating system design standards	Legislative/Normative	High	1989–	No	AU6*
	Heat	20	Minimum thermal standards for buildings	Legislative/Normative	High	1991–	No	AU5
	Heat	10	Heating cost settlement for common thermal facilities	Legislative/Normative	Medium	1992–	No	AU8
	Elec	1	EU-related: Energy Labelling (Energy Star)	Co-operative Measures	Unknown	Unknown	Yes	AU22*
Informative	Heat	20	EU-related: EPBD – Building Energy Certificates	Legislative/Informative	High	2008–	Yes	AU21
	Heat	20	Klima:Aktiv Building - new standards for buildings	Information/Education	High	2005–	No	AU18
	Heat	10	"Wohnmodern" support for large apartment renovation	Information/Education	Medium	2006–	No	AU19*
	Heat and Electricity	1	Energy advice for households	Information/Education	Unknown	1990–	No	AU27
	Elec	1	topprodukte.at, Platform for energy-efficient appliances	Information/Education	Low	2005–	No	AU17*
	Elec	1	Smart Metering and Informative Billing	Information/Education	Unknown	2008–	No	AU28
	Elec	10	EU-related: Energy Labelling of Household Appliances	Legislative/Informative	Medium	1994–	Yes	AU1

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

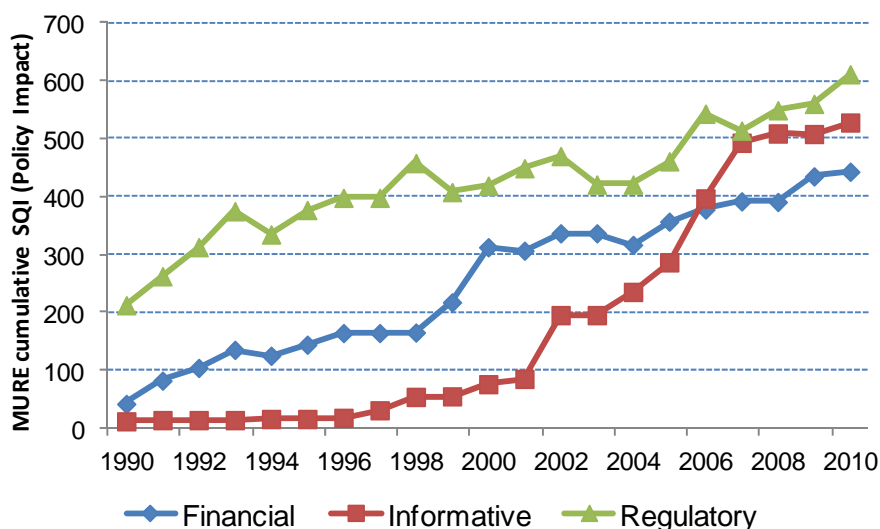
21 ^bThese designations (categories) are assigned as part of the present work.

22 ^cThese items are derived from the MURE Policy Database.

23 As an example, for Austria, the database includes nine heat-focused energy efficiency measures, four
24 electricity efficiency-focused measures, and one measure that covers both heat and electricity. These
25 fourteen policies were introduced between 1989 and 2009 and are all still in force (Table 3). Six of the
26 Austrian measures have received a high SQI, three have received a medium score, one a low score, and
27 four have had their SQI graded as “Unknown”. The policies without an SQI ranking are assumed to have a
28 low impact on demand. The fourteen policies are divided into the Financial (Fin), Regulatory (Reg), and

1 Informative (Info) categories in line with the categorisation used in the present work, although those that
 2 focus exclusively on electricity are not included in the subsequent analysis. Columns 1 and 2 of Table 3
 3 show the categorisation of the policy measures applied by the authors of this paper, while the remaining
 4 columns are based on data from the MURE Policy Database [13]. Thus, Policy Type and SQI are MURE
 5 categorisations for each measure. As all the measures are still in force, the column Duration gives the
 6 starting year of the policy measure. The column that follows Duration indicates whether the measures
 7 were the result of an EU directive or not, while the last column lists the MURE Policy Database codes for
 8 Households.

9 Figure 1 shows the cumulative SQI ranking of the 260 policies analysed in this work. The difference
 10 between the numbers shown in Table 2 and those shown in Figure 1 is that rather than show the number of
 11 policies in force for the EU-14, the latter takes into account the different rankings assigned to each policy
 12 in the MURE Policy Database (high-, medium-, and low-impact policies) and also the years in which each
 13 policy was in force. Thus the y-axis of Figure 1 represents the cumulative value of the SQI of the policies
 14 in force in each of the three categories for the 14 countries analysed in this work (cf a high-impact policy
 15 in force is assigned a value of 20, a medium-impact policy gets a 10, and a low- or unknown-impact
 16 policy gets a values of 1). It is clear that informative polices have the lowest expected impact until Year
 17 2006 when they catch up with the regulatory policies. A pattern of decreasing impact, e.g., from 1998 to
 18 1999 for regulatory policies, reflects the fact that some policies in this category became obsolete in 1998.



19

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

22 As it may take several years for the impacts of policies introduced to be realised in terms of energy
 23 demand reductions, the *EP* variable is tested with delays of up to 7 years. This approach of effectively
 24 lagging the *EP* variable also removes the possibility of endogeneity between *EP* and *I* for the lagged cases.
 25 Bigano et al. [32] and Saussay et al. [31] also incorporated delayed impacts of policies (See Table 1).

1 Taking the example of Austria (Table 3), the two pieces of legislation introduced in 1989 would not kick-
2 in in the Delay7 scenario until Year 1996, while the six pieces of legislation introduced after Year 2005
3 would not be included in the regression. Note also that in the case of Austria, the flagship EU legislation
4 on energy efficiency in buildings, the EPBD, was only incorporated into policy legislation in Year 2008,
5 which means that its effect, as defined in the empirical examination carried out in this work, is limited.

6 2.3 Data sources for other determinants

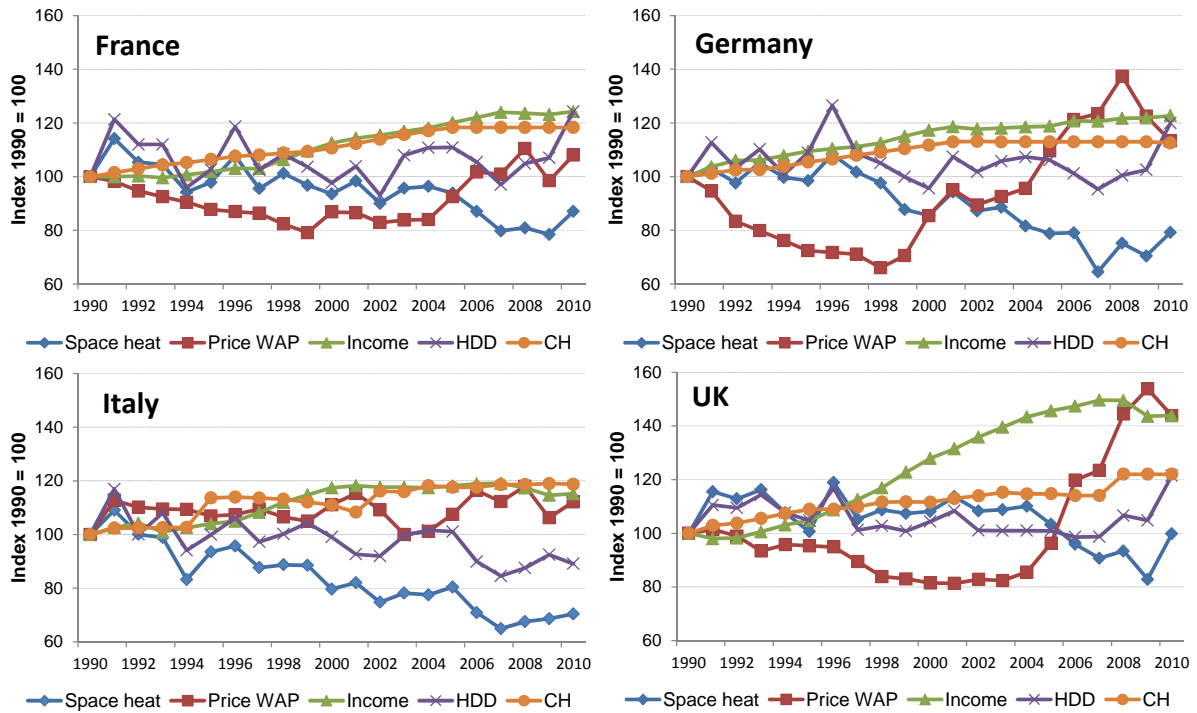
7 The data for Eq. (1) for the core determinants of space heating energy demand were obtained from the
8 following sources: income [national private consumption in Euro]; population; average floor area per
9 dwelling; number of permanently occupied dwellings; *HDD*; energy demand for six energy carriers [coal,
10 oil, gas, district heating, biomass, electricity] for space heating [43]; consumer price indices [private final
11 consumption expenditure deflator] [44]; Harmonized Indices of Consumer Prices (HICP) [45]. Income
12 was divided by population to derive the per capita values. The heating demand data were divided by the
13 total floor area (average floor area per dwelling times the number of permanently occupied dwellings) to
14 derive the heating demand per square metre (unit consumption). IEA [46] provides a time series of prices
15 for the residential sector for coal, oil, gas, and electricity normalised to Year 2005 prices (€₂₀₀₅/toe), while
16 Werner [47] supplies the time series of prices for district heating. These latter prices were normalised to
17 Year 2005 prices using price indices from the OECD [44] and Eurostat [45].

18 Combining the time series of prices for these five energy carriers with the corresponding time series of
19 their usage for space heating, from the Odyssee database [43], allowed a Weighted Average Price (WAP)
20 of energy for space heating to be constructed. As a ton of oil equivalent (toe) of oil does not produce the
21 same amount of heat as a toe of natural gas or coal (given their different conversion efficiencies when
22 used in household boilers), the IEA prices for oil, natural gas, and coal were divided by a factor of 0.78,
23 0.85, and 0.64 [48], respectively, to obtain the prices of heat from these respective energy carriers prior to
24 their inclusion in the WAP². Prices for biomass for the respective countries are not available in national
25 statistics due to the nature of the trade in this commodity. Thus, the options were to include biomass in the
26 energy demand time series (I_{it}) but not in the weighted average energy price time series or to omit biomass
27 from the energy demand time series; best-fit modelling indicated that the latter option was best. This price
28 time-series thus provides a more accurate estimation of the actual price paid by households for residential
29 sector energy demand than those used in [30-32] (See Table 1).

30 For Finland (1990–1994) and Portugal (1990–1999), no data were available from [43] on the demand for
31 residential sector electricity and space heating respectively. In these two cases, time series for residential
32 sector electricity and total energy demand obtained from [46] and [43] respectively were used to
33 extrapolate the missing data. Prices for district heating were not available for most countries for 2009 and
34 2010. To obtain a complete time series, the district heating prices for each country for Year 2008 were

² These three conversion efficiencies were kept constant for the period of the study. This is due to the assumption that improvements in boiler efficiency over the period were marginal in terms of their impact on overall space heating demand [49].

1 increased by a factor that corresponded to the change in price of the main heating fuel of the specific
 2 country for the period 2008–2010. The justification for this approach is that although district heating can
 3 be cheaper than alternative heating fuels, its price is usually maintained just below that of its main
 4 competitor.



5
 6 **Figure 2 : Index of space heating demand and determinants of its dynamics (including *HDD* and penetration of**
 7 **central heating) for four large EU countries.**

8 Figure 2 shows the index of unit consumption for space heating demand and for four determinants of
 9 energy demand from Eq. (1) for France, Germany, Italy, and the UK, i.e., four of the largest countries of
 10 the EU (by demand and population). The dynamics of the variables over the period (Figure 2) shows that
 11 unit consumption has been falling since 1990 and that it tracks *HDD*, with spikes for colder years. Year
 12 2010 would appear to have been a very cold year in France, Germany, and the UK. Income per capita and
 13 the penetration of central heating have been rising steadily, with the exception of the UK where there was
 14 an increase of >50% in income per capita between 1993 and 2008 followed by a fall after the recession. In
 15 France, Germany, and the UK, energy prices fell in the 1990's and rose in the 2000's, although prices in
 16 Italy remained fairly stable for the entire period. In the four countries shown in Figure 2, the penetration of
 17 central heating increased by approximately 20% between 1990 and 2010. By Year 2010, the penetration of
 18 central heating in the residential sector was >90% in all of the countries examined in the present study,
 19 with the exceptions of Greece, Portugal, and Spain [43].

3 RESULTS AND DISCUSSION

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

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

Table 4 presents the coefficients and test statistics, calculated for the model of space heating demand per square metre using Eq. (1), for the 14 EU countries examined in the present work.

Table 4 : Elasticity coefficients calculated in models of space heating demand per square metre. The basic model is fitted without any variable for EP. The other models include an EP variable without delay (0) and with delays of 1, 3, 5, and 7 years respectively^a.

Parameter	Basic Model	Delay0	Delay1	Delay3	Delay5	Delay7
β_1 (Price)	-0.16** (0.077)	-0.17** (0.076)	-0.18** (0.076)	-0.17** (0.076)	-0.15** (0.074)	-0.15** (0.068)
β_2 (Income)	0.31 (0.27)	0.32 (0.26)	0.30 (0.25)	0.27 (0.24)	0.27 (0.24)	0.23 (0.24)
β_3 (HDD)	0.56*** (0.19)	0.59*** (0.16)	0.60*** (0.16)	0.59*** (0.17)	0.54*** (0.16)	0.53*** (0.15)
β_4 (CH)	0.29 (0.27)	0.27 (0.25)	0.25 (0.24)	0.23 (0.21)	0.26 (0.22)	0.27 (0.22)
β_5 (Trend)	-0.018*** (0.0053)	-0.015*** (0.0054)	-0.013** (0.0056)	-0.011** (0.0048)	-0.013*** (0.0047)	-0.012** (0.0051)
β_6 (EP)	--	-0.00071 (0.00086)	-0.0011 (0.00085)	-0.0017** (0.00076)	-0.0021*** (0.00068)	-0.0025*** (0.00073)
β_0 Constant	31.76	24.44	20.52	18.37	21.48	20.12
LSDV R ²	0.99	0.99	0.99	0.99	0.99	0.99
Within R ²	0.45	0.46	0.47	0.49	0.50	0.52
Test stat F _(13,274)	211***	212***	217***	223***	227***	237***

^aValues shown in parentheses denote HAC standard errors. ***Significant at 1% level. **Significant at 5% level. *Significant at 10% level.

The difference between the six models presented in Table 4 relates to how the time series representing policies focused on energy efficiency (EP)³ are included in the models. In the basic model, EP are not included at all. In the Delay0 model, they are included for the year in which they were published. For the remaining four models, they are included with delays of 1, 3, 5, and 7 years, respectively, after publication. This means that, for example, policies introduced in Year 2000 do not have an effect until Year 2007 in the Delay7 model. The reason for presenting the different models is to compare the effects of the introduction of the EP variable with different time delays. If the values shown in Table 4 for EP are instead calculated as percentages then they represent the percentage reductions in demand for the introduction of one new low-impact policy (e.g., -0.0017 expressed as a percentage is -0.17%).

³ See the nomenclature and Section 2.2 for descriptions of the EP and other policy-related variables.

1 The variable coefficients presented in Table 4 have the expected polarities, in the sense that, for example,
2 when price goes up demand is expected to fall. The price (β_1), *HDD* (β_3) and Trend (β_5) coefficients are
3 found to be significant at the 5% level for all models. The income (β_2) and *CH* (β_4) coefficients are
4 insignificant in all models. Saussay et al. [31] also found the coefficient of income to be insignificant.
5 However, removing Ireland and Portugal from the panel used in the present work resulted in the income
6 elasticity (β_2) value increasing to >0.6 and becoming significant at the 5% level⁴. During the period 1990–
7 2010, these two countries enjoyed large increases in per capita income that were not coupled to any
8 similarly large increases in the use of space heating. It seems that in the absence of economic booms, as
9 experienced in Ireland and Portugal in recent years, the income elasticity for the EU-14 would be higher
10 and significant. Given the lack of statistical significance of the *CH* variable the F-form of the Wald test
11 was used to examine the effect on the model of omitting it. It was found that the model was not improved
12 by omitting the *CH* variable⁵. The F-test for the combined significance of variables was found to be
13 significant at the 1% level for all the models.

14 The absolute values of variable coefficients are also in line with those previously published [16, 31, 33,
15 50, 51], with low price elasticities and slightly higher income elasticities, and with a time trend that
16 represents an annual reduction in demand of $>1\%$ per annum. In a static fixed effects panel of electricity
17 demand in the residential sector of 48 US states for the period 1997–2008, Alberini and Filippini [16]
18 deduced price and income elasticities of -0.22 and 0.28, respectively. The values are similar to the results
19 obtained in the present study given the differences in explanatory and dependent variables used. Using a
20 dataset that contains 255 observations in the period 1978–1999, Liu [52] found short-term and long-term
21 price elasticities for total energy demand of -0.025 and -0.140, respectively, for OECD Europe, and short-
22 term and long-term income elasticities for energy of 0.052 and 0.291, respectively. These results for long-
23 term elasticities are similar to those found in the present work. Azevedo et al. [34] calculated price
24 elasticities for electricity for the EU of -0.2, which is similar to the value obtained in the present work.
25 EEW [50] reported that autonomous technical progress brings about a 1% per annum reduction in demand
26 across the EU, which corresponds with the coefficients calculated for the time trend in Table 4 and
27 Table 5. Overall, in the present study, the price and income, as well as other calculated elasticities seem to
28 conform to what has been reported in the literature.

29 Although the coefficient of the *EP* variable is not statistically significant in the Delay0 and Delay1
30 models, it is in the subsequent models. It is clear that as time passes the absolute value and statistical
31 significance of the coefficient of the *EP* variable increase, while those of the Price, Income, and Trend
32 variables decrease. This suggests that initially the impact of *EP* on demand is negligible compared to

⁴ Each country was removed in turn from the panel to investigate if there were any significant impacts on β_1 to β_6 . The above mentioned finding in relation to income elasticity (β_2) was the only major deviation from the results presented in Table 4 found.

⁵ The removal of *CH* from the model did not change the income elasticity (β_2) despite the obvious relationship between *CH* and income, i.e. as income rises more households install central heating. The inclusion of *CH* in the model can be justified because the installation of *CH* has a non-linear impact on heat demand, i.e., the installation of *CH* is said to double the heat demand of an average dwelling.

1 these three other variables but that after a number of years its relative impact increases. During its year of
2 introduction, a low-impact policy reduces demand by 0.071%. This makes sense given that low-impact
3 policies are ranked as those that reduce demand by <0.1% (see Section 2.2). After 5 years, the policy
4 impact has tripled to -0.21% and become statistically significant.

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

11 VIF tests carried out for multicollinearity did not show a VIF value >6 for any variable, indicating that
12 multicollinearity is not a problem for the data and model used. Driscoll-Kraay standard errors [53] were
13 calculated to correct for the possible presence of inter-country spatial correlation in the data set. The
14 calculated Driscoll-Kraay standard errors were smaller than the HAC standard errors. Although Driscoll-
15 Kraay standard errors can be biased downwards in small panels, the one used in the present work is in the
16 range suggested by the authors ($T > 20$ and N not important), which suggests that for this dataset, spatial
17 correlation is not a problem.

18 Five different instruments for the *EP* variable were tested separately to ascertain if the variable was
19 endogenous. The instruments were time series for each country from 1990 to 2010 regarding: 1) the years
20 in which a green political party was in power [54]; 2) the total CO₂ emissions [55]; 3) CO₂ emissions from
21 the residential sector [55]; 4) gasoline taxes [55]; and 5) average CO₂ emissions standards for vehicles⁶
22 [56]. These five instruments were chosen as possible explanatory variables for the *EP* variable that were
23 not correlated with energy demand in the residential sector. The idea behind the first three instruments
24 listed was that governments might increase the implementation of efficiency policies as a result of a green
25 party being in government or in reaction to increased CO₂ emissions. The idea behind the last two
26 instruments was that a regime change in another sector, e.g., transport, might indicate general energy
27 policy development in an unrelated sector, e.g., housing. To determine if *EP* was endogenous, it was
28 regressed in a model that included one of the five instruments and the other explanatory variables from
29 Eq. (1). The residuals from this auxiliary regression were then added to Eq. (1) as a new explanatory
30 variable that represents the endogenous part of *EP*. Eq. (1) was then re-run to establish if the endogenous
31 part of *EP* had statistical significance (Hausman test). This was not found to be the case for any of the five
32 instruments tested, suggesting that *EP* is not endogenous.

33

⁶ Data for CO₂ emissions standards for vehicles for the years 1990 to 1994 and 1996 to 1999 were not available and so were interpolated and estimated based on the data that was available for 1995 and 2000 to 2010.

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

Parameter	Basic Model	Delay0	Delay1	Delay3	Delay5	Delay7
β_1 (Price)	-0.16** (0.077)	-0.17*** (0.057)	-0.18*** (0.049)	-0.17*** (0.048)	-0.14** (0.061)	-0.15*** (0.057)
β_2 (Income)	0.31 (0.27)	0.42* (0.24)	0.42* (0.23)	0.35 (0.23)	0.32 (0.23)	0.27 (0.24)
β_3 (HDD)	0.56*** (0.19)	0.62*** (0.14)	0.63*** (0.14)	0.57 *** (0.15)	0.54*** (0.15)	0.53*** (0.13)
β_4 (CH)	0.29 (0.27)	0.26 (0.24)	0.23 (0.22)	0.22 (0.20)	0.25 (0.21)	0.28 (0.21)
β_5 (Trend)	-0.018*** (0.0053)	-0.016*** (0.0053)	-0.014** (0.0055)	-0.013*** (0.0047)	-0.014*** (0.0046)	-0.013 ** (0.0051)
Financial Policy	--	0.00069 (0.0010)	0.00062 (0.0010)	-0.00029 (0.00082)	-0.00071 (0.00075)	-0.0015** (0.00063)
Informative Policy	--	-0.0012 (0.0012)	-0.0017 (0.0011)	-0.0018 (0.0015)	-0.0027 (0.0021)	-0.0021 (0.0026)
Regulatory Policy	--	-0.0025* (0.0014)	-0.0034 ** (0.0015)	-0.0031*** (0.00095)	-0.0030*** (0.00086)	-0.0033 *** (0.00097)
β_0 Constant	31.76	25.55	21.64	21.53	23.67	22.30
LSDV R ²	0.99	0.99	0.99	0.99	0.99	0.99
Within R ²	0.45	0.49	0.52	0.51	0.51	0.52
Test stat F _(13,272)	211***	219***	234***	227***	225***	232***

5 ^aSince the OLS regressions technique treats each variable independently, the absolute values of some of the coefficients shown in Table 5 are
6 slightly different from those shown in Table 4.

7 ^b Values shown in parentheses denote HAC standard errors. ***Significant at 1% level. **Significant at 5% level. *Significant at 10% level.

8 In Table 5, the same models as in Table 4 are presented except that the variable *EP* is divided into the
9 three policy categories of financial, informative, and regulatory. The polarities and absolute values for the
10 price, income, *HDD*, *CH*, and trend coefficients in the models shown in Table 5 are similar to those shown
11 in Table 4. However, examining the statistical significance of the coefficients representing the financial,
12 informative, and regulatory policies shows that only the latter is significant in the Delay0 and Delay1
13 models. This suggests that the coefficient of the *EP* variable described in the previous paragraph is not
14 significant in the Delay0 and Delay1 models owing to the lack of significance of the impacts of the
15 financial and informative policies. Regulatory policies seem to be the most effective type of energy
16 efficiency policies when the expected impacts, as provided by the MURE Policy Database, are evaluated.
17 The regression coefficients in Table 5 can be interpreted to mean that the introduction of one unit of
18 regulatory policy (i.e., one ‘low-impact’ policy (See Nomenclature and Section 2.2)) has reduced the
19 energy demand by an average of 0.25% in the year of introduction. As this is greater than the <0.1%
20 impact expected for low-impact policies, it can be concluded that regulatory policies have on average
21 performed better than expected. The results also point to different profiles over time for the three policy
22 types:

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

11 The literature on the respective impacts of financial, informative, and regulatory efficiency policies in the
12 residential sector corroborates these findings. Table 5 shows that the correlation between the estimated
13 impact of informative policies from the MURE Policy Database and the savings that actually occurred is
14 low and statistically insignificant. This is similar to previous studies [30, 57], which found that only a
15 small proportion of total annual savings from efficiency at the EU level originated from the effects of
16 information campaigns. In the context of promoting household energy conservation, Steg [58] has
17 reported that information campaigns result in only modest behavioural changes, and von Borgstede et al.
18 [59] has shown that informational policies only give the desired outcomes when households are willing to
19 change wasteful behaviour patterns related to energy use. Yohanis [60] in a survey carried out in Northern
20 Ireland found that although 88% of surveyed homes had purchased a major appliance in the previous 2
21 years, only 16% of the respondents had any idea about the energy ratings of their new appliances. In
22 contrast to these findings, Ek and Söderholm[61] tested the hypothesis that information about available
23 saving measures that is presented in a more concrete and specific way is more likely to affect (stated)
24 behaviour than is more general information. The data they collected from a questionnaire sent to 1200
25 households in Sweden supported this notion. Lindén et al. [62] reported that following repeated
26 information campaigns, households in Sweden filled washing and dishwashing machines before using
27 them and households in detached houses were more likely to adopt a lower indoor temperature than
28 households in apartments. The findings of various groups [61–64] suggest that there is room for
29 improving the design of information policies, although it should be borne in mind that the willingness to
30 switch to pro-environmental behaviours depends on the levels of the perceived thresholds that have to be
31 overcome [59].

32 The results of interviews with experts and NEEAP screenings [50] revealed enormous disparity across
33 Member States in terms of the levels of ambition of their energy efficiency policies and that in the less-
34 progressive countries many experts consider the first EPBD [6] to be a milestone that catalyses a new
35 legal framework for energy use in buildings. Of the portfolio of policy measures in place across the EU,
36 the IEA [64] reported that up to now the EPBD (categorised as an information policy in this work) has
37 been the policy instrument with the greatest potential impact on energy efficiency in existing residential
38 buildings in the short-term (5–10-year period) or even in the medium-term up to Year 2020. As the EPBD

1 [6] was, for example, only proscribed in Austria in 2008, it is too early to state definitively what its effect
2 on demand will be and whether it will be a transformative agent, given that it seems to have brought
3 energy efficiency in buildings into the political agenda.

4 With regard to financial policies, Nauleau [65] used a panel of over 23,000 French households to analyze
5 the impact of the introduction of a tax credit in 2005; no significant impact was noted for the first 2 years
6 of the scheme, although this changed after 2007. Boonekamp et al. [57] reported that across the EU a
7 substantial number of new measures for funding (40%) were introduced after the Energy Services
8 Directive [7] came into force (post-2006). This suggests that it may be also too early to say what the
9 effects of such policies are. However, Filippini et al. [30] found financial policies to be the policy type
10 with the greatest impact in terms of reducing demand. Their study covered total energy demand in the
11 residential sector, i.e., including electricity for appliances and lighting, for 27 EU countries in the period
12 1996–2009. The main difference between their results and the present results is that we show that the
13 financial policies have an impact a number of years after they are introduced. Tietenberg et al. [21]
14 reported that the literature makes it quite clear that any second-best policy mix in the face of bounded
15 rationality non-optimising behaviour and volatile prices must recognize a role for more prescriptive
16 strategies, such as targeted subsidies, efficiency standards, and/or tradable white certificates. The
17 prescriptive nature of regulatory policy may be the reason why this policy type shows the greatest effect in
18 the present work. The findings of several groups [15, 25, 26, 28, 31,32] reinforce the results of the present
19 paper in demonstrating that regulations are most effective.

20 3.2 Implication of calculated coefficients

21 For the EU-14 overall, the average percentage increase in energy prices between 1990 and 2010 has been
22 1% per year (this value encompasses the increases and decreases in prices over the period, as shown in
23 Figure 2). The average percentage increase in income for the same period has been 2%. If the coefficients
24 calculated in the present work (Table 4 and Table 5) were to persist after 2010 one could expect that a 1%
25 rise in the price of energy would result in a 0.15% fall in demand *ceteris paribus*. If at the same time,
26 income would increase by only 1% per annum (half the rate seen in the previous decades), this would
27 offset the energy savings resultant from higher prices. The penetration of central heating has been steady
28 at 1% per year for the period 1990–2010, although as this is approaching saturation, i.e., >90% penetration
29 in most countries, the same rate of growth cannot be expected in the future. Regardless of price and
30 income dynamics or the impact of policy, demand can be expected to fall by a compounded 1% per year,
31 due to factors represented by the time trend (autonomous technical progress, fuel switching, and structural
32 effects). While autonomous technical progress and fuel switching from direct electric heating, oil heating
33 and solid fuels heating to district heating, renewables⁷ and natural gas heating can be expected to continue
34 in the coming decades, future structural effects are less clear. During the period 1990–2010, increasing
35 indoor temperatures would have diluted the effects of efficiency as represented by the time trend. Going
36 forward, this effect should be diminished as homes converge on a standard indoor temperature of around

⁷ 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 21°C. However, the effects of people spending more time at home, e.g., more retirees and more people
2 working from home, could have a similar diluting effect⁸. Nonetheless, two of the aforementioned factors
3 represented by the time trend (autonomous technical progress and fuel switching) should continue to
4 reduce demand apace.

5 The results of the present work also show that regulatory policies reduced demand for space heating by
6 around 0.3% for each low-impact policy introduced. Given that medium-impact and high-impact policies
7 are assumed to have ten and twenty times, respectively, the impact of low-impact policies (See Section 2.2
8), this suggests that the introduction of such regulatory policies would reduce demand by 3% and 6%,
9 respectively⁹. It should be borne in mind that such large impacts reflect the fact that such policies are not
10 introduced very often (e.g. for Austria. there was only one high-impact and one medium-impact regulatory
11 policy introduced between 1990 and 2010; Table 3) and they represent the averages for a wide variety of
12 regulatory policy impacts across the 14 countries studied. Therefore, it may be the case that the data
13 representing the policies are too disparate for a strong emphasis to be placed on the calculated values.
14 Thus, the differences in magnitudes of the three policy categories may be of more interest than the
15 numbers themselves. EEW [50] advocates a savings target of 2% per annum, composed of a combination
16 of efficiency policies and autonomous technical progress, based on the idea that savings of 1% per annum
17 are already being made and that this should be doubled. The numerical results from the present work
18 suggest that this can be achieved through the introduction of more or stronger regulatory policies (e.g., the
19 introduction of an additional medium-rank policy every 3 years or an additional high-rank policy every 6
20 years). However, given the uncertainty related to the exact impact of policies on savings, the message
21 from this paper for policymakers is to increase either the ambition level or the number of regulatory
22 policies in force.

23 A Laspeyres decomposition [66,67 and Nomenclature] was carried out to examine the effects of individual
24 model variables on energy demand (kWh/m²/year). For this, the model coefficients of the Delay3 model
25 shown in Table 6 (chosen as a representative model) were multiplied by the respective time series data for
26 1990 used in their calculation, except that each variable was in turn changed to its 2010 value (while
27 keeping the other time series data at 1990 values), to isolate their effects on demand relative to those of
28 the other variables. The time series variables used for the decomposition for 1990 and 2010 were the
29 averages for each variable for the 14 EU countries. Table 6 shows the magnitude that each model variable
30 increased or decreased demand in 2010 relative to 1990. The impact on demand of the time trend, which
31 represents autonomous technical progress, fuel switching, and structural effects, stands out as it accounts
32 for >20% of the change. Energy efficiency policies resulted in an approximately 11% reduction most of
33 which was as a result of regulatory and informative policies. Energy price increases were modest during

⁸ 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.

⁹ 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 this period and decreased energy demand by less than 3%. At the same time, income dynamics increased
 2 demand by over 10%. This corresponds to the pre-financial crisis period of economic growth in the EU.
 3 The introduction of *CH* increased demand by approximately 4%, while a number of colder-than-average
 4 winters increased demand by over 10%.

5 **Table 6 : Examination of impacts of model variables on demand between 1990 and 2010 made using a Laspeyres**
 6 **Decomposition.**

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%

7 **4 CONCLUSIONS**

8 The effects of energy efficiency policies on space heating in the EU residential sector were analysed using
 9 a fixed effects static panel data model for the period 1990–2010. This analysis was performed using unit
 10 consumption of energy for space heating (kWh/m²/year), which is an established indicator of efficiency.
 11 The impacts of three specific categories of efficiency-focused policy, namely financial, regulatory, and
 12 informative, were also examined. The results show that in relation to the *ex-ante* evaluations of impacts,
 13 the regulatory policies have been more effective at reducing demand than have the informative and
 14 financial policies. In addition, regulatory policies are found to have a consistent demand-reducing impact
 15 over time, as compared with informative and financial policies. Informative policies are found to have a
 16 more short-term impact, whereas financial policies require a number of years to have an effect. Although
 17 the EU EPBD and ESD policy packages may improve the effects of information and financial policies, the
 18 indications to date, which are supported by the findings of the present work, are that regulatory policies
 19 reduce demand in the year in which they are introduced and for at least 7 years thereafter. These findings
 20 suggest that regulatory policy measures should be assigned a high priority if EU-wide energy goals are to
 21 be met expeditiously. This conclusion is supported by the well-known market barriers to efficiency that
 22 exist in the residential sector, which, in contrast to information- or financial efficiency-focused policies,
 23 necessitate regulation to be overcome. It also reinforces the findings of the recent literature on the topic
 24 [30-32].

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