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The adoption of energy efficiency measures in households: Effective for all and for ever?

ABSTRACT

Improving energy efficiency is crucial for creating a sustainable, affordable, and secure energy system. Buildings are responsible for one-third of global total final energy consumption, with residential buildings accounting for 73% of that total. This brief summarizes the conclusions reached by a study on the impact of energy efficiency measures on residential gas consumption in households in England and Wales. The study looked at changes in consumption five years before and after the installation of heating-related insulation equipment specifically loft insulation and cavity walls. It found that the adoption of energy efficiency measures led to significant reductions in household residential gas consumption after implementation. Yet, long lasting effects were not observed and, in the long run, there was a reduction in the energy savings achieved. These results indicate that energy savings from efficiency measures for heating might be influenced by other factors. This shows the potential of energy efficiency measures to prevent energy poverty and highlights the need for additional policy implementation to decarbonise the residential building sector.

RÉSUMÉ

L'amélioration de l'efficacité énergétique est essentielle pour créer un système énergétique durable, abordable et sûr. Les bâtiments sont responsables d'un tiers de la consommation d'énergie dans le monde, les bâtiments résidentiels représentant 73 % de ce total. Ce Policy Brief résume les conclusions d'une étude sur l'impact de mesures d'efficacité énergétique sur la consommation de gaz de ménages en Angleterre et au Pays de Galles. L'étude a examiné l'évolution de leur consommation cinq ans avant et après l'installation d'équipements d'isolation liés au chauffage. On constate que l'adoption de mesures d'efficacité énergétique entraînait des réductions significatives de la consommation de gaz résidentielle des ménages après leur mise en œuvre. Cependant l'adoption de ces mesures n'a pas d'effet sur le long terme et sur la durée, on observe une réduction des économies d'énergies réalisées. Ces résultats indiquent que les économies d'énergie réalisées grâce aux mesures d'efficacité énergétique pour le chauffage peuvent être influencées par d'autres facteurs. Cela montre le potentiel des mesures d'efficacité énergétique pour prévenir la pauvreté énergétique et souligne la nécessité d'une mise en œuvre politique supplémentaire pour décarboner le secteur des bâtiments résidentiels.

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Introduction

Improving energy efficiency (EE) in the residential sector is key to address multiple energy-related challenges. In 2018, residential buildings in the United Kingdom (UK) were responsible for about 29.5% of the country's final energy consumption, with 37,991 Ktoe [1], making the sector the second largest in terms of energy consumption after the transportation sector (IEA, 2020a). Some analysis indicates that energy efficiency has already contributed to reducing UK energy consumption but much more work on energy efficiency (as well as in other areas) is needed to meet the UK's climate and EE targets, reduce energy bills, and fight fuel poverty (ICL, 2019).

Yet, recent estimates suggest that 12 million dwellings will need to be retrofitted with energy efficiency technical improvements like insulation in the next 30 years, if the UK wants to meet its net zero target by 2050 (IPPR, 2020).

While the UK government has put in place several policies to promote the adoption of EE technical measures, e.g., the Energy Efficiency Commitment (EEC, 2002-2008), the Carbon Emission Reduction Target (CERT) and the Community Energy Saving Programme (CESP, 2008-2012), the Energy Company Obligation and the Green Deal (2013-cancelled) and the Green Home Grants (2020-cancelled), research has been inconclusive regarding the effectiveness of such policies in terms of their impact on the adoption of retrofitting measures and/or on achieving significant energy savings. A tentative reason for this potential lack of effectiveness is the rebound effects associated to the behaviour of occupants (Aydin et al, 2018; Galassi and Madlener, 2018; Sorrell et al., 2018). Research about the size and drivers of rebound effects, — increases in energy consumption due to behavioural changes induced by the lower energy costs—, either indirect or direct, resulting from different EE measures in the residential sector is vast. However, ex-post studies estimating the direct rebound effects for heating are rare and, in most cases, they only use a relatively short-term before and after comparison without a control group and/or without controlling for confounding variables (see Sorrell, 2007 for a review). In a recent publication (Peñasco and Anadon, 2023), we focus on improving our understanding of the impact of the installation of two specific energy efficiency measures on residential gas energy consumption in the long run, and on the heterogeneous effects in different types of households.

Understanding ex-post energy consumption responses to EE technical improvements in different types of households (vulnerable vs. high

income, for instance) is important for policy making as most of the energy efficiency programmes have focused on vulnerable households and it is those households that may experience the largest rebound effects (Milne and Boardman, 2000). We focus on loft insulation and cavity walls as they have been consistently the centre of all energy efficiency schemes in the UK over the past two decades. This work analyses the dynamic effect of the installation of such efficiency measures to determine whether such measures resulted in changes in gas consumption in the long run, i.e., up to five years after the adoption of an energy efficiency measure and if effects are different depending on the type of consumer.

Overall, the results obtained have important implications for the design of policies to help improve EE in residential buildings and thus help the UK deliver its net zero targets.

1. Data and methodology

1.1. Data

The analysis relies on the database put together in Peñasco and Anadon (2023) with microdata from the National Energy Efficiency Data-Framework (NEED). This takes the form of a panel of households and includes annual information from 2005 to 2017. The NEED collects annual information about energy consumption, i.e., gas and electricity, together with information on energy efficiency measures installed in dwellings and some property and household attributes and characteristics to deliver a representative sample of the housing stock in the England and Wales. The EE measures installed were (at least partly) supported by National EE support schemes, i.e., EEC, CERT, CESP, and the Green Deal Communities. The technical measures covered in a panel form in this paper are loft insulation and cavity wall installation. We focus on gas consumption as 85% of the dwellings in the UK as of 2018 relied on central gas heating systems (Ministry of Housing, Communities and Local Government, 2019).

The dataset is complemented with a measure of weather conditions, approximated by the heating degree days variable coming from Eurostat, and the average annual domestic unitary cost of gas by region provided by the Office for National Statistics and the UK Department of Business, Energy and Industrial Strategy (DBEIS). In order to analyse the impact of the installation of EE improvements in the energy consumption of households, we include the size of the household in squared-meters (sqm), the index of multiple deprivation, the property type and the age of the dwelling to control for confounding variables that may have an effect on the outcome.

[1] Kilotonnes of oil equivalent. Last available data.

1.2. Methods

The main goal of Peñasco and Anadon (2023) is to study the impact, if any, of the installation of EE technical improvements to reduce gas consumption in households. For that, we use a differences-in-differences (DiD) approach that is a statistical technique used in observational studies to estimate the causal effect of an intervention by comparing changes in outcomes between two or more groups over time. Given that the installation of EE measures differs in the time in which different households carried out the EE improvements, the authors identify and estimate the effect of the treatment, i.e., the installation of the corresponding energy efficiency measure, using a generalization of the DiD approach with multiple time periods. This allows to account for variations in the treatment timing and for the parallel trends assumption after controlling for possible confounding covariates.

To start with, we consider the installation of an EE measure whether loft insulation or cavity wall (a binary treatment indicator) for household i at time t :

$$EEM_{it} = \begin{cases} 1 & \text{if household } i \text{ is treated at time } t \\ 0 & \text{otherwise} \end{cases}$$

We use an extension of the DiD estimator by including five leads and lags of the treatment as regressors to estimate the average dynamic effect. This quasi-experimental exercise allows us to analyse the extent and duration of the effectiveness of the implementation of EE measures in reducing energy consumption in the residential sector. With the approach developed by Cerulli and Ventura's (2019) we can analyse simultaneously the average treatment effect (ATE) together with the pre- and post-treatment effects by estimating the following equation:

$$\ln(Y_{it}) = \alpha + \sum_{j=1}^J \beta_{pre,j} EEM_{i,t+j} + \sum_{k=0}^K \beta_k EEM_{i,t-k} + \gamma X_{it} + \theta_i + \mu_t + \varepsilon_{it}$$

where $EEM_{i,t-k}$ are year-specific indicators that denote whether a specific household i in year $t-k$ has installed one EE improvement; and $t+j$ will indicate if a household i will have EE improvements implemented in j years in future periods. With this approach, we cannot only analyse the effect of the EE improvements but also if there are anticipatory or delay effects in gas consumption. We aim to capture a pre-installation period and a post-installation period of 5 years allowing us to detect whether the impact of the treatment

changed over time [2].

We test therefore whether households introducing a technical energy efficiency measure differ from the non-treated households by checking that the coefficients of $EEM_{i,t-k}$ are not significant and how long the effect lasts.

2. Findings

2.1. Is energy efficiency lasting forever?

Results confirm that energy efficiency technical improvements in households reduce energy consumption on those households undertaking such measures in the short/medium term. While we cannot translate this result into an estimate of the rebound effect, given that we do not have an assessment of the ex-ante expected energy savings of the improvements for each household, we see that the rebound effect does not completely erase the gains of the technical improvement, at least one to two years after the introduction of the energy efficiency measure (See Fig. 1).

However, a new, challenging and policy relevant result emerges in our ex-post analysis: **energy efficiency effects resulting from the installation of technical measures were not as long-lasting as expected** and energy efficiency gains recede on average after four years after the treatment.

The results [3] indicate that cavity wall retrofits are more effective at reducing gas consumption than loft insulations after the installation of the EE measure. Cavity wall insulation (Fig. 1 right) generates an observed reduction on gas in the range of approximately a 6.9% in comparison with the pre-treatment period. The effect shows a decreasing pattern and the effective reduction in consumption lasts up to four more years. For the second period after treatment, the observed gas reduction oscillates around 2.7%. After four periods, when the reduction of gas consumption is only of 0.9%, the gas consumption recedes to the levels prior to the installation, **suggesting that behavioural interventions are as needed as technical ones if the goal is to get long-lasting energy efficiency gains**. Loft insulation (Fig. 1 left) seems to be half as effective as cavity wall installation, leading to reductions on gas consumption around 4%. Unlike cavity wall reforms, loft insulation effects on gas reduction last for up to two years after the installation of the technical energy efficiency measure with a

[2] In order to infer a causal interpretation we need to test that: i) the conditional parallel trends are valid, which is needed to be able to assume that, in the absence of treatment, similar households would follow similar energy consumption trends; ii) there has not been an anticipation of the treatment, implying that households have not adjusted their gas consumption proactively prior to the installation of the measure; and iii) there has not been selective treatment timing (no causal effect on the outcome, with respect to an early versus a later adoption) (Goodman-Bacon, 2018). The violation of these assumptions would imply that caution must be exercised while interpreting the results.

[3] See Peñasco and Anadon (2023) for detailed results and estimation tables

reduction of 1.8% and 0.9% respectively. In terms of the effectiveness of the different measures, results are aligned with Alan and Fuerst (2016), who concluded that one year after the treatment, cavity walls are the most effective technical measures in reducing gas and energy consumption.

These results support the hypothesis that the installation of **EE technical improvements in households generate significant reductions in the amount of gas consumed by dwellings when compared to those that have not adopted them.** However, we find that the reduction in household gas consumption in the UK after the installation of an EE technical improvement does not last beyond 3-5 years after the installation. Interestingly, the period by which the EE installations generate gas consumption reductions (2 to 4 years depending on the type of EE technical measure) approximately coincides with the payback time for those types of installations. On average, the payback time for a cavity wall installation may oscillate between 3 to 4 years after the installation. For loft insulation, the payback period tends to be slightly lower at around 1.5-3 years. **This result suggests the value of exploring aspects related to behavioural economics and consumer psychology.**

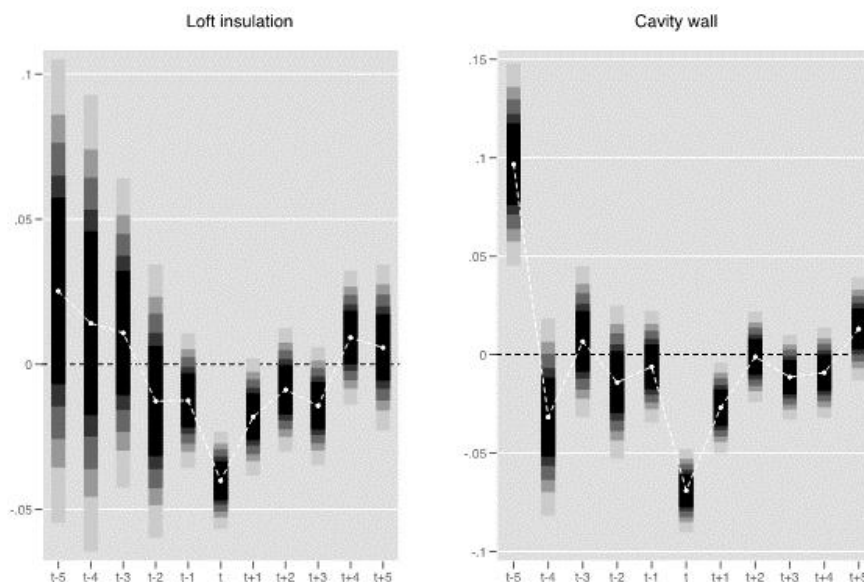
2.2. Is energy efficiency working for all?

Energy efficiency policy instruments in the UK have traditionally focused on improving energy efficiency in all households but especially in low-income households (EEC1, EEC2 programmes and CERT) and in households in deprived areas in Britain (CESP).

A segmentation of the sample by deprivation index [4] confirms that in those areas in which the deprivation is the highest, the installation of such measures generates the lowest reduction in gas consumption. Our results suggests that those households in more deprived areas experience half of the gas consumption reductions in percentage terms of their peers in the richer areas of the country (Fig. 2). This is probably because those households already consume little energy and display a higher energy price elasticity than their wealthier peers.

Controlling by gas prices, weather conditions and household characteristics, those households installing EE measures in more deprived areas will experience statistically significant gas consumption reductions of around 3% during the first and second year after installation of the technical measure. Similar households in less deprived areas can expect reductions in gas consumption of

Figure 1. Pre- and post-treatment pattern for the relation between household adoption on an EE measure and gas consumption (%)



Outcome variable: Ln gas consumption / Treatment variable: Loft insulation or Cavity wall / X variables: Lhdd, Lgasprice / Time-invariant controls: floorsq, IMD_band: property type, age.

Note: This graph represents the dynamic treatment effects for the OLS model with covariates. The vertical axis shows the variation in gas consumption (percentage change). The grey/black bars represent the confidence intervals. The horizontal axis measures the effect five years before and after the adoption (installation in t). There is no anticipatory significant effects except for the exceptionally high consumption in t-5. The parallel trend assumption tests were passed.

[4] The indices of multiple deprivation (IMD) are used within the UK to classify the relative deprivation of different areas in the country. Multiple components of deprivation are weighted with different strengths and compiled into a single score of deprivation.

around 5.6%. Results are consistent across energy efficiency technical measures adopted.

An important finding is that the most deprived households can expect statistically significant increases in the energy consumption four and five years after the EE installation. These increases would offset the initial consumption reductions during the year of installation reaching increases in gas consumption of around 3.6% and **represent a positive outcome in the fight against fuel poverty.**

These results confirm that, generally, the demand of those households in more deprived areas mostly covers basic needs, and therefore the installation of new energy efficiency improvements does not generate, on average, a decrease in the energy consumption. It may however result in a **higher flexibility to adjust to prices and therefore it makes it possible for people to not just meet their basic needs but to also reduce fuel poverty.** For households on less deprived areas, the installation of energy efficiency measures represents a way to reduce consumption, at least during the first year, which makes them less sensitive to changes in gas prices. This result is very interesting because it suggests that the adoption of EE technologies in households makes gas demand more flexible in deprived areas.

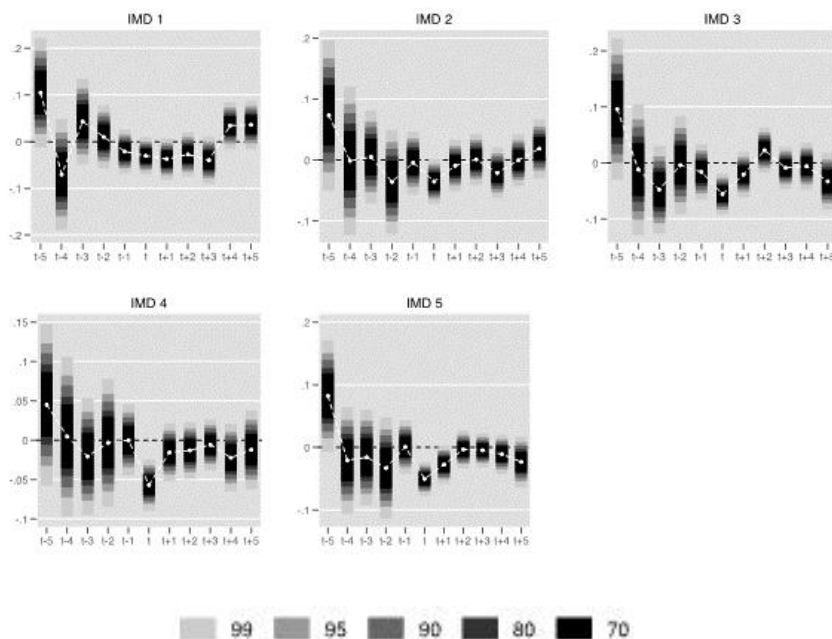
Figure 2 shows the pre- and post-treatment pattern of the relationship between household adoption of any type of EE measure and gas consumption in households belonging to different

deprivation areas. We find that for the higher deprivation areas (IMD1 and IMD2) after 4 or 5 years the energy savings have most likely receded and they increase their gas consumption.

We found therefore, that the impact of the adoption of the two EE technical measures under consideration **varies considerably depending on the level of deprivation of the areas in which households are located.** The smaller reduction on energy consumption seen on the poorest segments of the population, proxied by the quintiles level of the index of multiple deprivations by area, may provide a rationale to focus the attention on the barriers that may prevent those households to get potential energy savings derived from the adoption of EE measures.

Further, to explore these results we analyse the gas consumption distribution using percentile shares. We present estimates of the distribution of gas consumption for those household installing a technical energy efficiency measure vs. those who have not, and we analyse the outcomes for ten consumption distribution groups (deciles) in absolute and relative terms. The assessment of percentile shares allows us, in this case, to separate households into groups according of gas consumption and quantify the proportion of total gas consumption from 2005 to 2017 that will go to our defined groups in terms of their absolute and relative rank. We use the analysis developed by Jann (2016) to estimate the differences in the gas consumption distribution between households that

Figure 2. Pre- and post-treatment patterns of the relationship between household adoption of any type of EE measure and gas consumption in households belonging to different deprivation



Outcome variable: \ln gas consumption / Treatment variable: Loft insulation or Cavity wall / X variables: L_{hdd} , $L_{gasprice}$ / Time-invariant controls: $floorsq$, property type, age

Note: IMD1 is the category with the highest deprivation and IMD5 with the lowest. The vertical axis shows the variation in gas consumption (percentage change). The grey/black bars represent the confidence intervals. The horizontal axis measures the effect five years before and after the adoption (installation in t). There is no anticipatory significant effects except for the exceptionally high consumption in $t-5$. The parallel trend assumption tests were passed.

Figure 3. Percentile histogram (average absolute annual differences in gas consumption in KWh)

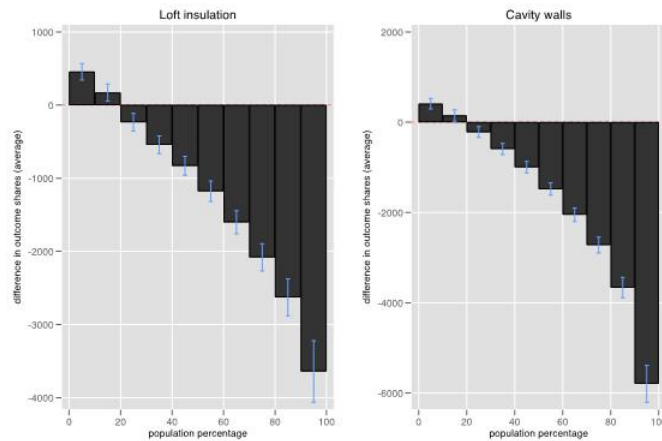
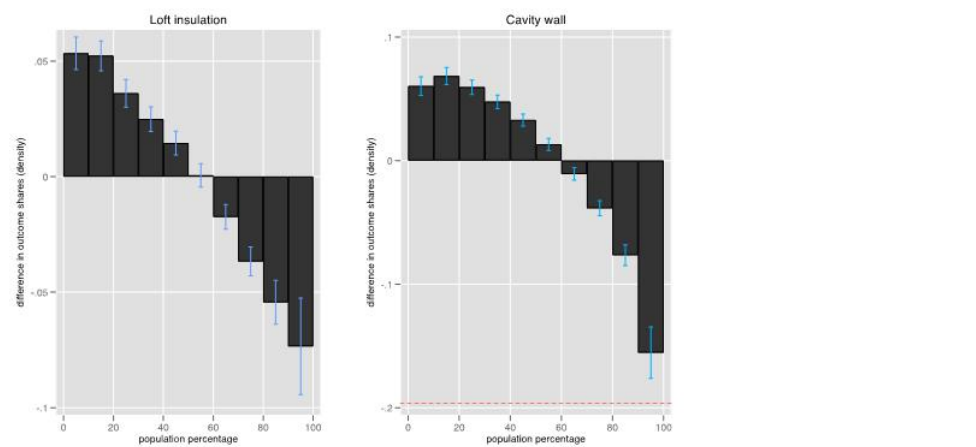


Figure 4. Percentile density histogram (relative differences)



have adopted an EE measure when compared to those that have not adopted such measures. The percentile shares represent on average how much of the total gas consumption each member in the percentile group gets in relation to the overall average.

Expressing the results in average levels of gas consumptions, the bottom two deciles, i.e., the bottom 20%, of the gas consumption distribution increase their gas consumption after the installation of an EE technical measure. Only from the 3rd decile we start seeing significant gas consumption reductions in absolute terms. Results are consistent across technical measures (Fig. 3). This result is important as it highlights that for those decile groups, the EE technical measures are not being effective in terms of reducing consumption. As previously mentioned, most UK EE policy instruments have targeted vulnerable households. However, those dwellings do not reduce their consumption but instead increase their energy use. This is not necessarily a bad outcome if the policy schemes are aimed at reducing fuel poverty in low-income households. Notwithstanding, to the extent that reducing energy consumption and consequently greenhouse gas emissions is at least one of several goals, those policies are not effective at delivering on all their missions. **From a policy perspective, this result calls for mission-oriented energy policy measures distinguishing between groups.**

The differences in Figure 3 reflect the overall variation in the gas consumption by percentile group. However, an interesting result to explore is if those differences affect the distributional shape of gas consumption in relative terms. Results suggest that the top 60% reduce their gas consumption when they adopt an energy efficiency measure, however, the bottom 50% increase their energy consumption after adopting an energy efficiency measure in relative terms towards the total gas consumption. **From a welfare perspective and in order to fight fuel poverty, we can conclude that the installation of EE measures reduces the inequalities in energy consumptions between percentile groups. The installation of EE measures, at least in the short term, reduces differences between groups to access to energy services, e.g., gas in this specific case.** This is a positive result in terms of policy goals as it seems EE measures may act as a mean to change the unequal distribution of energy consumption within a country. This is considered essential in order to get a fair and equitable transition to low carbon economies.

All in all, results confirm that for the two EE measures investigated, vulnerable households do not reduce their gas consumption after installing an EE technical measure. This result indicates that the main goal pursued by governments with the promotion and subsidization of the installation of this type of

energy measures is not achieved in vulnerable households, i.e., the policies have not been effective from an environmental point of view in vulnerable households. However, considering other outcomes like the distributional effects of the policy instruments, **subsidizing EE measures may improve inequality indicators by reducing the energy consumption differences between different types of households and pushing people in deprived areas out of the dangers of fuel poverty.**

3. Take aways for policy makers

This brief summarizes the responsiveness of household energy demand, specifically gas consumption, in the UK to the adoption of EE technical improvements during the period 2005-2017.

Understanding the patterns of energy consumption in residential buildings and if energy efficiency technical measures generate the expected energy savings modelled before the adoption of such measures, is a prerequisite for the formulation of accurate, effective and cost-effective energy policies. Given that around 85% of dwellings in the UK use gas as the main source of heating, **policies to reduce gas consumption in households and improve efficiency are important complements to other key efforts, most notably heating electrification.**

The results from Peñasco and Anadon (2023) show that the adoption of EE measures in households leads to a decrease in the demand of gas consumption right after the adoption. However, the energy savings generated from the installation of those technical measures, i.e., loft insulation and cavity walls, do not long-last in the very long term. Attention must be paid to the fact that the impact of the adoption of these measures varies considerably depending on the level of deprivation of the areas in which households are located.

The particular lack of reductions in gas consumption on the poorest segments of the population, proxied by the quintiles level of the index of multiple deprivations by area, shows the importance of considering the heterogeneous impacts of policies and further investigating the mechanisms that prevent those households from realizing energy savings. Dwellings in deprived areas are more likely to receive full support for the costs of the energy efficiency improvement. Romero et al. (2016) suggest that public policy should not inhibit price signals but instead provide rent transfer-oriented policies, such as annual payments or grants to vulnerable households. However, the policies that have been put in place in the UK during the last years reflect this and our analysis suggest that the reduction on energy consumption have not

materialized in low-income households.

We found, however, that the introduction of EE technical improvements measures makes households on deprived areas more responsive to changes in energy prices. This represents a positive outcome as EE measures may be acting as tools for the flexibility of the energy demand in the residential sector. They also reduce inequalities between groups of consumers allowing households at the bottom of the gas consumption distribution to increase their gas consumption in absolute and relative terms regarding their peers at the top of the distribution. This result implies positive impacts of EE measures in reducing fuel poverty in deprived areas of the UK geography.

Given the results, we suggest that the implementation of energy efficiency schemes consisting of a mix of regulatory instruments (tighter standards for newly constructed dwellings and for renovations), financial incentives (grants, loans or subsidies), and soft instruments influencing behaviour is more likely to result in longer term reductions in gas consumption. Also, given that energy efficiency gains vary widely among households located in areas with different levels of deprivation. Considering the domains of the Index of Multiple Deprivation (IMD) of the UK Government, those households in the lowest quintiles of the IMD are likely to represent households with low-income levels, low education attainment and that are more likely to be hit by unemployment. Our results indicate that households in the first and second quintile of the IMD do not experience the same levels of energy efficiency gains after the installation of technical efficiency improvements as the other groups. This conclusion is reinforced by the result obtained with the analysis of percentile shares of the total gas consumption distribution where we see that the bottom 20% of the distribution increases their gas consumption after the installation of EE measures. While energy efficiency policies therefore may be having a positive impact on reducing fuel poverty, the energy efficiency schemes are not effective in this segment of the population in terms of delivering energy savings. **This result is relevant for the design of measures targeting different groups and policy goals**, e.g., reduction of fuel poverty vs. energy efficiency savings. These findings regarding the specific challenges by income group may also be important when thinking about designing new policies focusing on household heat electrification. Cultural and behavioural aspects need to be considered in the design of the policy schemes if the UK wants to get a net zero carbon economy by 2050.

Our results call for the urgent need to fully incorporate human behaviour into ex-ante



modelling of energy use; and to complement financial and regulatory energy efficiency policy instruments with soft instruments to promote the behavioural changes needed to realize the full saving potential of the adoption of EE improvements. From a policy perspective, this result underlines **the need to establish more tailored energy policies adapted to a wider set of household characteristics.**

In order to achieve long lasting energy savings, it may be necessary to implement additional measures beyond technical energy efficiency improvements.

One potential solution is to establish energy reduction targets for households rather than energy companies. Households that meet their targets could receive waivers on their energy bills in the long term, similar to the *No stamp duty on zero carbon homes policy in the UK*. However, households in deprived areas may require assistance to overcome barriers to achieving their targets. Local governments can play an essential role in understanding the needs and barriers faced by local communities. Successful examples of this approach can be found in schemes like Pay-as-you-save (PAYS), which provides users with immediate and sustained economic savings by using a tariff to put a fixed charge on the customer's monthly bill that is smaller than the estimated savings from adopting energy efficiency measures (Lin, 2018). These policies would also be relevant for electrification of heating in residential buildings, such as adoption or substitution of gas boilers with electric heat pumps. Further research is needed to fully understand the lack of long-lasting effects, which may be related to social challenges, behavioural challenges, or both.

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