Grantham Research Institute on Climate Change and the Environment

The energy costs of historic preservation

Christian Hilber, Charles Palmer and Edward Pinchbeck

October 2017

Grantham Research Institute on Climate Change and the Environment
Working Paper No. 281

ISSN 2515-5717 (Online)

The Grantham Foundation for the Protection of the Environment

The London School of Economics and Political Science

The Grantham Research Institute on Climate Change and the Environment was established by the London School of Economics and Political Science in 2008 to bring together international expertise on economics, finance, geography, the environment, international development and political economy to create a world-leading centre for policy-relevant research and training. The Institute is funded by the Grantham Foundation for the Protection of the Environment and the Global Green Growth Institute. It has six research themes:

1. Sustainable development
2. Finance, investment and insurance
3. Changing behaviours
4. Growth and innovation
5. Policy design and evaluation
6. Governance and legislation

More information about the Grantham Research Institute on Climate Change and the Environment can be found at: www.lse.ac.uk/grantham

THE ENERGY COSTS OF HISTORIC PRESERVATION*

Christian A. L. Hilber

London School of Economics,

Centre for Economic Performance &

Spatial Economics Research Centre

Charles Palmer

London School of Economics &

Grantham Research Institute on Climate Change and the Environment

Edward W. Pinchbeck

London School of Economics &

Centre for Economic Performance &

Spatial Economics Research Centre

October 2017

* For helpful comments and suggestions, we thank Gabriel Ahlfeldt, Francois Cohen, Matt Cole, Simon Dietz, Steve Gibbons, Matt Kahn, Hans Koster, David Maddison, Henry Overman, Christopher Palmer, Olmo Silva, Wouter Vermeulen, and participants at the: SERC Work in Progress seminar; Grantham Workshop; research seminar series in the Economics Department at the University of Birmingham; annual meeting of the European Association of Environmental and Resource Economists held at the ETH Zürich; and, North American Regional Science Council (NARSC)-Urban Economics Association (UEA) Conference, held in Minneapolis. We also thank Adala Leeson at Historic England for kindly providing the Conservation Area shapefiles and the Energy Saving Trust for providing the HEED data. All errors are the sole responsibility of the authors. Address correspondence to: Christian Hilber, London School of Economics, Department of Geography and Environment, Houghton Street, London WC2A 2AE, United Kingdom. Phone: +44-20-7107-5016. E-mail: c.hilber@lse.ac.uk.

THE ENERGY COSTS OF HISTORIC PRESERVATION

Abstract

We explore the impact of historical preservation policies on domestic energy consumption. Using panel data for England from 2006 to 2013 and employing a fixed effects strategy, we document that (i) rising national energy prices induce an increase in home energy efficiency installations and a corresponding reduction in energy consumption and (ii) this energy saving effect is significantly less pronounced in Conservation Areas and in places with high concentrations of Listed Buildings, where the adoption of energy efficiency installations is typically more costly and sometimes legally prevented altogether. The energy costs of preservation are substantial.

JEL classification: Q48, Q54, R38, R52.

Keywords: Preservation policies, land use regulation, energy efficiency, energy consumption, climate change.

1. Introduction

Policies to preserve buildings for historical, cultural or architectural reasons are widespread across Europe and North America. They generate both benefits and costs. While the external benefits—as measured by higher house prices outside of designated areas—have recently been well documented (Ahlfeldt *et al.*, forthcoming; Been *et al.*, 2016), we know relatively little about the costs these policies may generate. In this paper we quantify the costs in the form of foregone energy efficiency savings and the social cost of carbon. We find that they are substantial.

The theoretical mechanism we have in mind is straightforward. In the absence of preservation policies, households can be expected to invest in energy efficiency improvements as long as the expected private benefits from potential energy savings exceed the additional upfront investment costs. Preservation policies drive a wedge into this decision process because they often mandate restrictions on the type and extent of changes—both internally and externally—that can be made to properties in designated areas. Restrictions on say the types of windows that can be installed may increase the cost of adopting energy efficiency technologies or, in fact, may legally prevent such installations altogether. Preservation policies may thus directly affect the energy efficiency of affected dwellings.

Our paper quantifies foregone energy efficiency savings by exploring the impact of historical preservation policies on domestic energy consumption in England. To do so, we focus on two well-established preservation policies: 'Conservation Areas' and 'Listed Buildings'. We collate a rich panel dataset at the Middle Layer Super Output Area (MSOA)-level (i.e., the neighbourhood-level) that spans the period from 2006 to 2013—a period during which energy prices, defined in our paper as a local weighted average of national gas and electricity prices per kilowatt hour, rose markedly and per capita energy consumption fell by around 20%.

Empirically, we exploit the fact that rising national energy prices shift the local demand for energy efficiency installations upwards, thereby reducing energy consumption, but less so in areas with widespread preservation. We first document that rising national energy prices induce a reduction in local energy consumption. Our findings indicate that energy consumption in England is fairly price elastic. Next we explore the sensitivity of the price elasticity of energy consumption with respect to the incidence of preservation. One difficulty in doing this is that the prevalence of buildings in Conservation Areas and Listed Buildings at the neighbourhood-level is likely to be correlated with income and other confounding factors. To condition out these factors and thus focus our analysis on identifying the causal impact of preservation policies on energy consumption, we control for location and year fixed effects, linear time-trends interacted with neighbourhood characteristics as well as flexible trends for each Travel to Work Area (TTWA), and the neighbourhood's distance from the centre of the TTWA. We also carefully control for the age and composition of the housing stock thereby helping us to disentangle the effects of preservation policies from vintage or heritage effects.

Doing this, we demonstrate that the energy saving effect is significantly less pronounced (i.e., the elasticity of energy consumption with respect to the energy price is significantly less negative) in Conservation Areas and in places with higher concentrations of Listed Buildings, consistent with the proposition that preservation policies prevent investments in new technologies that reduce energy consumption. Using a conservative but plausible energy price elasticity point estimate (-0.48) obtained from our data, our findings suggest that a one standard deviation increase in the share of dwellings in an MSOA located in Conservation Areas reduces the energy price elasticity at the MSOA-level by 3.5%, while a one standard deviation increase in the number of Listed Buildings per 100 dwellings in the MSOA reduces the elasticity by 4.4%. We provide evidence that the mechanism for this decline in energy price elasticity is the capacity of preservation policies to limit the uptake of home energy efficiency improvements.

Our findings are robust to a host of sensitivity checks. First, we employ an alternative estimation approach, a 'stacked regression', which allows us to control for all factors that commonly affect per capita domestic electricity and gas consumption in each MSOA-year cell. Second, we demonstrate that changes in the panel frequency or the lag structure of energy prices (which we use to examine households' expectations of future energy prices as drivers of investment decisions) do not materially affect our findings. We conduct further sensitivity checks and a placebo test exploring the effect of a preservation policy (Green Belt designation) that is not expected to affect energy efficiency investments, and all these tests—discussed in Appendix A—confirm our findings.

Our counterfactual simulations suggest that preservation policies in England impose additional private costs of energy consumption with a present value of around £16 billion and a social cost of carbon of around £5.1 billion. With approximately two million designated dwellings in England, this equates to £8,000 and £2,550 per designated dwelling, respectively. Limiting Conservation Areas and Listed Buildings to 1980 levels—a fairly moderate reversion that would bring back levels to a point in time when buildings with the highest heritage value were likely already designated—would have lowered total domestic energy consumption in England between 2006 and 2013 by 1.3 %. This amounts to a monetary saving over the 8-year period of around £1.7 billion and a carbon reduction of 8.9 million metric tons of carbon dioxide equivalent. It is important to note that while this decline accounts for a relatively small proportion of total domestic energy consumption, the energy saving per affected dwelling is substantial. This is because only one out of 10 dwellings in England is protected by preservation policies.

Our paper ties into a recent empirical literature that focuses on the house price effects of preservation policies. A study by Ahlfeldt *et al.* (forthcoming) is perhaps most relevant for our investigation because, like us, it focuses on designated Conservation Areas in England. Their findings indicate that property price effects inside newly-designated areas are not statistically different from zero, yet outside of these areas, the effects are positive and significant. In a similar vein, Been *et al.* (2016) explore preservation policies in New York City. They too find that properties just outside the boundaries of historic districts consistently increase in value after designation. The effect within these districts is more mixed; sometimes positive sometimes zero. Been *et al.* also document a modest reduction in new construction in districts after designation. Finally, Koster *et al.* (2016) focus on the impact of historic amenities on house prices and sorting of households within Dutch cities and document that high income households sort themselves into designated areas, suggesting that they have a higher willingness to pay for historic amenities.

While Ahlfeldt *et al.* (forthcoming) and Been *et al.* (2016) both suggest that preservation policies significantly increase prices of nearby dwellings, it is important to emphasize that this does not necessarily imply that they increase social welfare. First, as argued, for example by Glaeser (2011), excessive historic preservation on a wider scale may generate adverse impacts through supply restrictions that raise prices in an entire city or even nationwide. Second, there are factors other than supply constraints that can drive a wedge between house price capitalization effects and the public's willingness to pay (Kuminoff and Pope, 2014). Positive price effects also do not necessarily imply positive net benefits because even internal benefits and costs are not always fully capitalized into prices, for example, when the marginal house buyer is not well informed about particular benefits or costs associated with the location or dwelling (Hilber, 2017).

Third, and most crucially, research in this area has until now focused on external benefits that increase—or external costs that lower—property prices. However, externalities that are not capitalised in property prices may also exist. One example of a *positive* externality is the fact that some people's utility is positively affected by the existence of a historic building—such as London's St. Paul's Cathedral—even if they do not actually live close by. A *negative* externality may, for example, arise if historic preservation prevents or increases the cost of energy efficiency installations, with the resulting growth in energy consumption generating greenhouse gas (GHG) emissions—a global negative externality. Neither the existence value of a historic building nor GHG emissions will be capitalised into local property prices.

Our paper ties into a growing literature on the energy and climate impacts of land use regulations. This literature tends to focus more generally on land use restrictions, e.g. Glaeser and Kahn (2010), Larson *et al.* (2012), Larson and Yezer (2015). Glaeser and Kahn (2010) document a strong negative association between carbon dioxide emissions and land use regulations. They point out that restricting new development in the cleanest areas of the United States effectively pushes new development towards places with higher emissions. Larson *et al.* (2012) trace the energy footprint of transportation, housing and land use policies in a general equilibrium framework, allowing them to consider feedback or rebound effects that work through the urban land market. They find that such effects can lead to counterintuitive results. For example, minimum lot zoning may reduce energy consumption because it drives up the price of housing and this causes household densities in the unregulated inner parts of the city to rise significantly. Finally, Larson and Yezer (2015) employ simulations to demonstrate that density limits and greenbelts can positively or negatively affect both city welfare and energy use. Our main contribution to this literature is the focus on the careful empirical identification of energy consumption effects of historic preservation policies. To our knowledge, our paper is the first to evaluate and quantify the energy and climate costs of such policies.

With space heating accounting for around 70% of domestic energy consumption, buildings in the UK are responsible for 37% of the country's GHG emissions. Indeed, urban real estate is a major contributor of global GHG emissions (Kahn and Walsh, 2015). Our results suggest important implications for climate policy. In the UK, this is guided by the 2008 Climate Change Act, which legislates for an ambitious 80% reduction in the country's GHG emissions by 2050. To help meet this target, the Committee on Climate Change suggested in 2008 that the 'least-cost path' would entail a major contribution from energy efficiency improvements in buildings, including designated dwellings. Our findings indicate that the current extent of historic preservation in England signifies an important obstacle to achieving the ambitious targets set by the government. More generally, by demonstrating that historic preservation policies limit the uptake of home energy efficiency improvements, we contribute to a literature that seeks to understand the low apparent uptake of energy efficient durables (Allcott and Greenstone, 2012; Fowlie *et al*., 2015). Another measure by which the UK hopes to meet its target is via the Carbon Floor Price. Currently frozen at £18 per metric ton of carbon dioxide, this is projected to increase 'rapidly' after 2021.[1] Our results suggest that energy consumers living in designated dwellings are unlikely to respond to a rising CFP in the same manner as those living in non-designated dwellings.

The paper proceeds as follows. In Section 2, we discuss the institutional setting and provide some theoretical considerations. In the subsequent section we describe the data, discuss our baseline specifications and present our main empirical results along with robustness checks and evidence of a potential mechanism underlying our main results. Section 4 provides a quantitative interpretation of our findings by conducting a counterfactual analysis. In Section 5 we consider welfare implications. The final section concludes.

2. Institutional Setting and Theoretical Considerations

2.1. Preservation Policies: Listed Buildings and Conservation Areas

Listed Buildings and Conservation Areas were established to protect buildings of historical or architectural interest. These policies date back to 1953 for Listed Buildings (the Historic Buildings and Monuments Act) and 1967 for Conservation Areas (the Civic Amenities Act), although the current legislation in England and Wales dates from the Planning (Listed Buildings and Conservation Areas) Act 1990. According to Historic England (formerly English Heritage),[2] Grade I Listed Buildings are of "exceptional interest", Grade II* are of "particular importance" and Grade II are of "special interest". Less than 0.5% of all Listed Buildings were built after 1945; about a third was built in each of the 18th and 19th Centuries. Over 90% of all Listed Buildings have Grade II status. Conservation Areas protect whole neighbourhoods rather than individual dwellings, and Listed Buildings can be found in Conservation Areas.

Figure 1 shows the distribution of Conservation Areas in England from data collected by Historic England in 2008 and 2012, at the Local Planning Authority (LPA) scale. The time trend in the total number of Conservation Areas since the late-1960s is shown in Figure 2, based on the same data. There are currently just over 8,000 such areas, containing around two million dwellings, out of a total housing stock of some 23 million dwellings as of 2014. The 1970s and 1980s witnessed rapid growth in the designation of new Conservation Areas before tailing off in the 1990s. Similar to Conservation Areas, Listed Buildings, including dwellings and non-dwellings, are distributed all over England, particularly in the East and South-East

[1] The CPF works in conjunction with the European Union's Emissions Trading System. It imposes a minimum price for carbon permits and affects domestic energy consumption indirectly via impacts on energy providers and the Levy Control Framework.
[2] See: https://historicengland.org.uk/listing/what-is-designation/listed-buildings/.

(Figure 3). After rapid growth in the 1980s, the designation of new Listed Buildings also plateaued in the 1990s, remaining at around 0.3 to 0.4 million buildings (Figure 4) through to the 2010s.

2.2. The Role of Preservation Policies for Home Energy Efficiency Improvements and Implications for Energy Consumption

Preservation policies protect the heritage of the built environment by restricting the development or modernisation of specific dwellings. The policies' economic rationale centres on the external value of heritage, which is often enjoyed by individuals other than those owning or occupying designated dwellings. It may too solve coordination failure.[3] However, preservation policies may also impose costs, both private and social. Higher private costs of energy consumption materialise for example when households living in designated dwellings incur additional investment costs in order to comply with preservation policy standards. Households are also typically restricted in the extent to which they can reconfigure, redevelop, or alter the fabric of preserved buildings. One particular implication of preservation-induced restrictions—the focus of this paper—is that they may impede energy efficiency installations and thus increase the private costs of energy consumption and the social costs associated with negative externalities.

Table 1 illustrates the main restrictions on undertaking specific energy efficiency improvements for dwellings affected by each of the English preservation policies. In many Conservation Areas, planning consents are required for external improvement projects. For example, many Conservation Areas are subject to locally imposed so-called Article 4 Directions, which limit specific development rights such as making changes to windows or frontages. In contrast, outside Conservation Areas external improvement projects do not require planning permission (i.e., they are 'permitted developments'). For Listed Buildings, the requirements are much stricter and also cover internal upgrades, e.g. cavity wall insulation. The planning guidance even suggests that households living in a Listed Building should consult with planning authorities before installing a new heating system or boiler.

Some restrictions imposed by preservation policies may not prevent home energy efficiency improvements altogether but are likely to drive up homeowners' costs. For instance, a homeowner living in a Conservation Area wishing to install new, energy-efficient windows may need to ensure that they are consistent not only with the character of the owner's dwelling but also with the character of the surrounding buildings. In some cases, this could oblige owners to install expensive timber windows, rather than much less costly and more energy-efficient aluminium or uPVC windows.[4]

[3] As Holman and Ahlfeldt (2015) point out, even if heritage value is fully capitalised into property prices, coordination failure is likely. That is, individual homeowners may be tempted to inappropriately alter their property, thus free-riding on the historic character of nearby properties. Government intervention in the form of designating Conservation Areas may solve a sort of prisoner's dilemma, in which it may be rational for owners in historic districts to collectively restrict their own property rights without the possibility of compensation.

[4] Timber windows will usually be about twice as expensive as uPVC alternatives. In a public consultation about a Conservation Area in London, residents opposing the Conservation Area policy of timber replacement windows quoted replacement costs for a single timber window of £4,000 to £5,000, https://www.harrow.gov.uk/www2/documents/s61817/Revised%20PWPE_Appendix1.pdf.

We can illustrate the underlying theoretical mechanism we have in mind and the implications for the demand price elasticity and resulting energy consumption using a simple demand-supply framework. Figure 5 depicts two markets: A local energy market (Panel A) and a local market for energy efficiency installations (Panel B). Now consider an international or national shock to energy supply (e.g., a sudden decrease in oil and/or gas production) that raises the national energy price p_e. In Panel A of Figure 5 this equates to an upward shift of the energy supply curve and a corresponding increase in the price of energy. In the absence of preservation policies, local energy consumers will respond to this shock in two ways. First, the price increase will provide greater incentives to save more energy (e.g. by turning down the heating thermostat or by turning off electronic equipment when not in use). Second, the price increase provides greater incentives to invest in home energy efficiency installations as it makes such installations more beneficial. In the market for home energy efficiency installations—depicted in Panel B of Figure 5—this equates to an increase in the demand for such installations, resulting in greater energy efficiency (and consequently less energy consumption, all else equal).

Now consider an identical consumer (with identical utility function) who lives in an identical neighbourhood with identical housing stock. There is only one difference: for illustrative purposes we assume that this neighbourhood has a strict preservation policy that prevents new home energy efficiency installations altogether, implying a perfectly inelastic supply curve—illustrated in Panel B of Figure 5—in the market for such installations. Even though the energy price shock will also induce an increase in demand for installations, the strict preservation policy prevents more installations and consequently prevents an increase in energy efficiency. Energy consumers in the preserved neighbourhood will still reduce their energy consumption, but less so, all else equal, than consumers who live in the non-preserved location. In the energy market this results in consumers in the preserved location having a more price inelastic demand for energy (as illustrated in Panel A of Table 5). The supply price shock will induce additional energy savings—effect ① in the figure—but not an additional reduction of energy consumption as a consequence of additional energy efficiency installations—effect ② in the figure. The reduction in energy consumption (effects ①+②) will be greater for consumers in the non-preservation neighbourhood, by the amount of ②. In the next section we derive an identification strategy that takes advantage of a national energy price shock and spatial differences in the extent to which neighbourhoods in England are treated by preservation policies, allowing us to test the prediction that energy consumption of households living in neighbourhoods with stricter preservation policies will respond less strongly to given energy price shocks.

3. Empirical Analysis

After describing the data used in our analysis, we present our identification strategy to assess the extent to which preservation policies impact energy consumption and domestic investments in energy efficiency. Next we present our main result, i.e., preservation policies reduce energy price elasticities, and various robustness checks. Finally, we demonstrate that preservation policies limit the uptake of energy efficiency improvements, consistent with a decline in the energy price elasticity being driven by such policies.

3.1. Data

There is currently no dataset, at least not for England, that combines—or could combine—domestic energy consumption, the prevalence of preservation policies, and the uptake of home energy efficiency installations at the same geographic scale. Therefore, we focus our empirical analysis at two different spatial scales by constructing two panels for the period 2006-2013. The first combines measures of the prevalence of preservation policies with home energy consumption at MSOA-level, while the second combines the same policy measures, but with measures of the uptake of home energy efficiency installations at LPA-level. We briefly describe the data below and display summary statistics for the two panels in Tables 2a and 2b. Appendix B provides full details for the underlying datasets.

The first panel describes domestic energy consumption per person, prevalence of historical preservation policies, and various control variables at the MSOA-level. MSOAs are small area statistical units (i.e., neighbourhoods) introduced after the 2001 Census, each containing between 2,000 and 6,000 households. Domestic energy consumption per person is generated at the MSOA-spatial scale by linking sub-national consumption statistics data from the Department for Energy and Climate Change (DECC) to annual population data from the Office of National Statistic (ONS). Our dependent variable sums energy consumption across electricity and mains gas—the two fuel types available at the MSOA-level.[5]

The second panel is constructed at LPA-level by combining data on home energy efficiency installations from the Home Energy Efficiency Database (HEED) held by the Energy Saving Trust with our measures of preservation policies and control variables. Since counts of home energy efficiency installations are not available at a finer spatial scale, by necessity the spatial units in this panel are England's 354 pre-2009 LPAs.[6] This panel runs only from 2006 to 2010. The HEED data records a variety of installations including wall insulations, loft insulations, double glazing, new boilers, new heating systems, micro-generation and energy efficient lighting. We treat these installations as a stock-measure (because the upgrades we focus on are durable) and specify dependent variables based on installations in levels, controlling for household counts.

Since the HEED data do not contain domestic energy consumption, we utilise a third panel dataset to illustrate the impact of some of the most common types of home energy efficiency installations on domestic energy consumption. The National Energy Efficiency Database (NEED)—compiled by DECC between 2005 and 2012—does not contain geographical identifiers at the dwelling scale. This precludes it from further analysis with respect to preservation policies. NEED contains data for energy consumption and some household and

[5] A small number of MSOAs have energy consumption figures that imply infeasibly large year-to-year changes in energy consumption. These could plausibly result from measurement error or rare factors we are unable to fully capture e.g. new connections to the gas pipeline. To ensure these outliers do not drive our results, in our main regressions we drop MSOA-year cells where domestic energy consumption, gas, or electricity consumption are missing or change by more than 25% between years. Together these cells comprise around 2.5% of our original sample. As we show later, this strategy is conservative: estimates increase in magnitude when these outliers are retained.

[6] Given missing Conservation Areas data for some LPAs, we are only able to run regressions on 304 of the 354 LPAs.

dwelling characteristics, including measures of fuel poverty, for almost four million dwellings in England.[7]

Despite the differences in spatial scale, there are some commonalities across the first two panels and the corresponding empirical specifications we estimate. In both cases, the demand shifters we utilise are based on the national real price of domestic energy per kilowatt hour (kWh) provided in DECC Quarterly Energy Prices publications. We use these national prices in a number of ways, but in our main specifications we lag prices by a year because domestic energy consumers are arguably likely to take time to respond to changes in energy prices, for example, in order to select and install energy efficiency measures.[8]

National gas and electricity prices are weighted by the local share of each type of energy consumed in 2005. Using national energy prices as a shifter of the demand for energy efficiency installations has two advantages. First, national prices can be considered exogenous from the perspective of property owners and for the purpose of our empirical analysis. Second, there is no block energy pricing in the UK, which allows us to sidestep problems due to simultaneity between prices and consumption.[9] We also note that there is little apparent spatial variation in the cost of gas and electricity within the UK, presumably because consumers are able to switch between suppliers. National gas and electricity prices along with North Sea gas production are illustrated in Figure 6. Prices for electricity and mains gas remained relatively flat in real terms between 1990 and 2003 before rising rapidly until 2013. The rise in energy prices coincided with a dramatic decline in North Sea gas production as profitable reserves dwindled.

Our principal preservation policy variables are based on the estimated proportion of residential addresses in each MSOA or LPA that are covered by each of the policies. For both, the denominator is calculated from counts of residential addresses for each postcode in England from the Postcode Address File (PAF) contained in the 2010 National Statistics Postcode Directory. For Listed Buildings the numerator is the count of Grade II Listed Buildings in the MSOA or LPA.[10] For Conservation Areas the numerator is calculated by allocating postcodes to polygons using shapefiles provided by Historic England and the postcode centroid. Alternative measures used in the robustness checks are constructed in a similar way from the same underlying data (see Appendices A and B).

3.2. Identification Strategy

We aim to test empirically the extent to which historical preservation policies influence domestic energy consumption per capita and investments in home energy efficiency installations. Our focus is on dynamic effects because historical preservation policies may

---

[7] See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/437093/National_Energy_Efficiency_ Data-Framework__NEED__Main_Report.pdf.

[8] We justify the choice of a one-year lag in Section 3.3, and empirically test alternative lag assumptions when estimating elasticities in our robustness checks (Section 3.5).

[9] See Ito (2014) and Reiss and White (2005) for recent contributions that discuss how non-linear pricing schedules can cause problems in the estimation of energy demand elasticities and ways to resolve these issues.

[10] We use Grade II Listed Buildings only and not the higher grades (Grade II* and Grade I) because these are more likely to be buildings which are not in residential use e.g. churches. The resulting measure – Grade II Listed Buildings per 100 dwellings – proxies for the local prevalence of Listed *residential* Buildings which we are unable to observe directly.

restrict the ability of households to install energy efficiency measures or make such installations more expensive. Additionally, dynamic effects are arguably more policy relevant because: (i) the Climate Change Act focuses on reducing GHG emissions from current levels and new buildings comprise a tiny proportion of the overall housing stock, and; (ii) the strong growth in energy prices in our panel timeframe —shown in Figure 6— could potentially mimic the effects of a rising carbon tax, similar to the projected, incremental increases in the Carbon Floor Price described in the Introduction.[11]

The empirical set-up we adopt is consistent across the two (MSOA- and LPA-scale) panels to the extent feasible. We focus on describing the research design for the neighbourhood- level analysis of domestic energy consumption per capita, indicating any differences for the LPA home energy efficiency panel below. This neighbourhood level panel is composed of all MSOAs in England (indexed by subscript *i*) spanning the years 2006 to 2013 (indexed by subscript *t*).

We first estimate the following specification to obtain benchmark estimates of the energy price elasticity:

$$\mathrm{e}_{ijrt} = \beta_1 \mathrm{p}_{t-m} + \alpha_1 \mathrm{w}_{jt} + \alpha_2 \mathrm{hdd}_t + \gamma_i + \sum_{r=1}^{9} \delta_r \mathrm{D}_r\, \mathrm{t} + \varepsilon_{ijrt} \qquad (1)$$

This specification regresses the natural log of domestic energy consumption per capita e_{ijrt} on the log national weighted real energy price demand shifter lagged by *m* periods p_{t-m} and on MSOA fixed effects γ_i. Following the literature (e.g., Aroonruengsawat *et al.*, 2012) we also include a measure of logged local wages w_{jt} (measured at the LPA level (denoted *j)* since time-varying wage data are not available at the MSOA-level), and national atmospheric conditions measured by log heating degree days hdd_t to reflect that local income and weather conditions may influence domestic energy consumption. Since energy prices vary at the national level, we are unable to include year fixed effects in this regression. Instead, we allow for regional trends by interacting linear time trends with dummy indicators for the nine English regions, denoted D_r. Our theoretical priors are that, all else equal, consumers will respond to higher energy prices by reducing energy consumption so that the price elasticity will be negative ($\beta_1 < 0$).

In subsequent regressions we explore the effect of preservation policies on price elasticities by interacting the energy price demand shifter p_{t-m} with time invariant measures of local preservation policies, denoted $\overline{\mathrm{List}_i}$ and $\overline{\mathrm{CA}_i}$ and collected by Historic England between 2008 and 2012. Spatial differences in these measures provide the main source of variation from which we obtain results. For ease of interpretation, the planning variables are standardised by centring on the mean and dividing by the standard deviation throughout. Because our goal is to estimate the effect of preservation policies on energy price elasticities rather than the elasticities themselves, we henceforth include year fixed effects γ_t (which subsume national heating degree days as well as national energy prices) to control for previously unaccounted factors at the national level, e.g. macroeconomic conditions and national policy changes to subsidise energy efficiency, as follows:

[11] Note that carbon taxes may be more salient, i.e. may yield a larger change in demand, than equivalent movements in the market price of gasoline, at least in the short-run (see Rivers and Schaufele, 2015).

$$e_{ijrt} = \beta_2 p_{t-m} \times \overline{\text{List}_i} + \beta_3 p_{t-m} \times \overline{\text{CA}_i} + \alpha_1 w_{jt} + \gamma_t + \gamma_i + \sum_{r=1}^{9} \delta_r D_r t + \varepsilon_{ijrt} \quad (2)$$

This specification can be used to test whether the prevalence of preservation policies conditions local energy demand responses to price changes. The coefficient β_1 estimated in equation (1) above can be interpreted as the elasticity of domestic energy consumption with respect to real unit energy prices. Since we standardise the preservation policy measures, the coefficients β_2 and β_3 here can be interpreted as the extent to which this price elasticity is modified by a one standard deviation increase in the share of residential Listed Buildings and the share of dwellings within Conservation Areas, respectively. Our expectation is that all else equal historical preservation policies will make domestic energy consumption less elastic to exogenous national energy price changes ($\beta_2, \beta_3 > 0$).

Although we account for national factors through year fixed effects and regional trends, the interaction terms in these regressions could be picking up local trends in energy consumption that are correlated with our time invariant measures of preservation policies. There are a variety of channels through which this could operate. For example, Koster *et al.* (2016) find that richer households in the Netherlands have strong preferences for historical amenities and tend to sort into historic neighbourhoods. Such individuals are likely to have a relatively price inelastic demand for energy and may also be more likely to own their homes rather than rent. Hence, they may have greater incentives to make long-term investments in improving home energy efficiency, as found empirically by Davis (2011). Aside from the characteristics of households, Kahn and Walsh (2015) identify climatic factors and housing stock characteristics as drivers of domestic energy consumption, while Glaeser and Kahn (2010) show that patterns of energy consumption can vary with urban form.

To address these issues we progressively add a number of additional controls, fixed effects and trends to the specification in equation (2). We first include a set of variables in which linear time trends are interacted with a set of time-invariant demographic and socio-economic variables. These comprise MSOA median household income in 2004 as well as a number of variables drawn from the 2001 Census: share of residents with degree; share lone parents; share owner-occupiers; share ethnicity white; share age 45-59, share age 60+; share managers, professionals, or associate professionals; and share employed. The addition of these controls means we identify the impacts of preservation policies off of trends in energy consumption in places that are similar in terms of demographic and socio-economic characteristics, and should capture the heterogeneity in household energy demand elasticities documented by Reiss and White (2005).

It is also possible that localised factors, such as temperature and weather, could be driving energy consumption patterns, so we next include a full set of Travel to Work Area (TTWA) by year fixed effects. This strategy allows us to partial out unobserved patterns in energy consumption common to labour market areas—for example those that might be driven by localised changes in climate—and, with around 140 TTWAs in England, imply that we are making comparisons across neighbourhoods in close proximity to one another (e.g. within London).

The characteristics of the local housing stock are also likely to determine energy consumption and the scope for making energy efficiency improvements. To reflect this and to help us disentangle the effect of preservation policies from effects associated with the vintage of properties, we next introduce two further sets of trend variables, interacting linear trends with a vector of share variables for neighbourhood building types (share flat, share terrace, share semi-detached with omitted category share detached), and a vector of neighbourhood building vintage variables (share built pre-1945, share built between 1945 and 1965, share built between 1964 and 1982, share built 1983-1999 with omitted category share built after 2000). The former set of trends reflects that different house types could imply different home energy needs or efficiency requirements. For example, detached houses will usually, all else equal, have more external wall area than other dwelling types.[12] The latter set reflects well-documented relationships in the literature: between building vintage and energy consumption (Costa and Kahn, 2010; Brounen *et al*., 2012; Kahn *et al.*, 2014), and between building codes and energy consumption (Jacobsen and Kotchen, 2013, Aroonruengsawat *et al.*, 2012). These building vintage controls are likely to be important in our setting where the housing stock comprises dwellings built using a range of building technologies and under various energy efficiency standards.[13] In turn, localised variation in these features could be highly relevant in determining home energy consumption and the scope to improve home energy efficiency.

Two further sets of controls account for patterns in domestic energy consumption that may be associated with urban structure and form. Urban economic theory suggests that urban density may be highest in the centre of cities, and—to the extent that denser places are more tightly regulated—it is possible our estimates may capture correlates of urban density rather than the effect of preservation regulation. To address this concern, and to control for other possible confounding factors, we next introduce the interaction between the distance between the MSOA centroid and the population weighted centre of the TTWA ($\overline{S_i}$) with our energy price demand shifter as an additional control.

The final control strategy reflects that households in rural and urban areas tend to rely on a different mix of fuels to provide home heating. Over two million dwellings in England, or about 10% of the total, are not connected to the gas transmission network (DECC, 2014). The vast majority of these dwellings are in rural places, and are heated by alternative fuels, including electrical heating, heating oil, and Liquefied Petroleum Gas (LPG). Thus, households living in such dwellings are more likely, than those residing in towns and cities, to consume a different mix of fuels and be exposed to a different set of fuel prices, neither of which we observe in our data. Off-gas-grid homes are also considered to be "hard-to-treat" in terms of improving home energy efficiency (Beaumont, 2007). In recognition of this issue, we drop most rural MSOAs, which we define as MSOAs that have zero mains gas consumption and those places recorded as being in a "sparse" or "village" setting in the 2011 Census, and allow for a linear trend in each of the remaining rural-urban categories.

[12] A related issue is that leaseholders will usually have to get permission from the freeholder to make certain energy efficiency upgrades. The share of leasehold dwellings is very highly correlated with the share of flats.

[13] In general, the older the house, the less likely it is that it was built with energy efficiency measures already installed. For example, houses built prior to the introduction of national Building Regulations in 1965 were rarely insulated, and there was no requirement to insulate houses until the 1980s. Houses built after the 1920s were generally built with cavity walls whereas those built previously had solid walls and as such cannot benefit from cavity wall insulation techniques. Thus, while older homes may have greater scope for energy efficiency improvements, such homes are typically "hard-to-treat" with energy efficiency upgrades (Beaumont, 2007; Dowson et al., 2012).

Taking account of these strategies, our final estimated specification is as follows:

$$\mathrm{e}_{ijrt} = \beta_2 \mathrm{p}_{t-m} \times \overline{\mathrm{List}_i} + \beta_3 \mathrm{p}_{t-m} \times \overline{\mathrm{CA}_i} + \lambda_1 \mathrm{p}_{t-m} \times \overline{\mathrm{S}_i} + \alpha_1 \mathrm{w}_{jt} + \gamma_i + g(t) + \varepsilon_{ijrt} \quad (3)$$

where our time effects $g(t)$ are captured by TTWA-by-year fixed effects and linear time trends interacted with a host of geographical, housing market, and socio-economic variables (region indicators, Census 2001 variables, household income in 2004, building type and vintage share variables, and rural-urban indicators).

After presenting results based on the specification described above, we report several sets of additional regressions in which we: (i) use an alternative estimation approach that exploits the richness of our data (stacked regression); (ii) explore the robustness of our main approach to changing the panel frequency or the lag structure of prices (i.e. where we vary the lag *m*); (iii) explore the robustness of our findings to using alternative dependent variables, trends, preservation policy measures, and demand shifters; and (iv) use Green Belts, another type of preservation policy, as a placebo test.

The first set of these additional regressions exploits the depth of our data by treating each fuel type (indexed by *f*) separately, but stacking the observations so that each MSOA-year cell has two rows in the data. This permits us to adopt the following specification:

$$\mathrm{e}_{fijrt} = \beta_2 \mathrm{p}_{f(t-m)} \times \overline{\mathrm{List}_i} + \beta_3 \mathrm{p}_{f(t-m)} \times \overline{\mathrm{CA}_i} + \delta_1 \mathrm{p}_{f(t-m)} \times \overline{\mathrm{S}_i} + \alpha_1 \mathrm{w}_{jt} + \gamma_{fi} + g(f,t) + \varepsilon_{fijrt} \quad (4)$$

Here, the natural log of domestic energy consumption per capita for fuel type *f* is regressed on the policy variables interacted with the one-year lag (m=1) of the log national real price for fuel type *f*, fuel-specific MSOA fixed effects (γ_{fi}) and where $g(f,t)$ includes year by fuel type fixed effects, MSOA-year fixed effects, as well as the full set of trends from equation (3) interacted with fuel type *f*. One key benefit of this approach is that it allows us to control for MSOA-year fixed effects, which partial out any factors that have a common effect on per capita gas and electricity consumption in each MSOA-year cell. As such, this approach—in which we rely on divergences in electricity and gas prices for identification—provides a very powerful cross-check on our main specification, outlined in equation (3).

Robustness checks (ii), (iii), and (iv) return to the model specified in equation (3). All checks use domestic energy consumption and price variables that combine the two fuel types (gas and electricity). Our placebo test with Green Belts is conducted using both the approach documented in equation (3) and the stacked regression in equation (4).

3.3. Energy Price Elasticities

Before exploring the effects of preservation policies on home energy-related outcomes, Table 3 reports quantitative estimates of the elasticity of domestic energy consumption with respect to energy prices. We do not seek to make a causal interpretation of these estimates. Rather, the intention of this exercise is to provide benchmark elasticities against which we can interpret the effects of preservation policies estimated in subsequent tables.

Table 3 documents several specifications that regress log per capita energy consumption on our weighted energy price measures and the control variables in equation (1), i.e. log heating degree days, log LPA wages, MSOA fixed effects, and linear region trends. In this and all subsequent tables, except where indicated, standard errors are clustered at LPA level. The first three columns of Table 3 report estimates of the elasticity of domestic energy consumption with respect to different energy price lag structures. The specification in column (1) uses contemporaneous prices, column (2) uses a one-year lag, column (3) a two-year lag, and column (4) all these prices together. Although estimated elasticities are significant in all of the first three columns, the coefficients suggest that energy consumption responds most strongly to one-year lagged prices. The final column confirms this, and furthermore suggests the coefficient on the one-year lag (-0.479) is a good approximation for the aggregate effect across the all three price measures (which together sum to around -0.465). Based on these results, we use a one-year lag of prices as our demand shifter from this point forward, and adopt the coefficient from column (2) of Table 3 as a benchmark elasticity against which we interpret later results. The elasticity implies that for every 10% increase in the price of energy per unit, per capita domestic energy consumption falls by 4.8%. While relatively high, this is broadly comparable with estimates of short-term energy price elasticities from the literature.[14]

3.4 Baseline Specifications – Domestic Energy Consumption

Our analysis now turns to the extent to which preservation policies condition energy price elasticities. We first provide a visual illustration of the impact of preservation policies on energy price elasticities using MSOA-specific elasticities, which we obtain from estimating equation (1) but interacting the price variable with MSOA dummies. These estimated elasticities can be displayed visually using kernel density plots. To get a feel for the relationship between energy price elasticities and preservation policies we assign MSOAs to one of four quartiles based on the overall local extent of preservation policies, which we generate by adding up our main Conservation Area and Listed Buildings measures. The first and fourth quartiles, respectively, comprise the least and the most preserved MSOAs. Kernel density plots for MSOA-elasticities in each of these four groups are shown in Figure 7. Overall, these plots are consistent with the least preserved MSOAs having the most elastic response to energy prices and vice-versa.

In subsequent regressions we introduce preservation policies by including interaction terms between the one-year lagged weighted energy price demand shifter and our measures of historical preservation policies. Each column of Table 4 refers to three separate regressions undertaken with the same specification but using different interaction terms: the regressions in Panel A always include the Listed Building interaction; Panel B the Conservation Area interaction; and, Panel C both preservation policy interactions. Moving from the left- to the right-hand side of the table we progressively add controls to deal with the endogeneity issues discussed in Section 3.2.

Column (1) constitutes the analogue of equation (2), and includes MSOA and year fixed effects, regional trends, and LPA wages as controls. Looking at Panels A to C of column (1), it is evident that the interactions on Listed Buildings and Conservation Areas are significant when each is included in turn but when both are included jointly, only the Listed Building

[14] For example, Ito (2014) finds an average price elasticity of electricity consumption of -0.12 while Reiss and White (2005) estimate an elasticity of -0.39. Our estimates are not directly comparable as we are estimating the elasticity of energy (gas + electricity) consumption with respect to weighted energy prices, but we obtain similar magnitudes when focusing on each fuel type separately.

coefficient remains significant. We illustrate the broad magnitude of effects this specification implies by comparing the coefficients on the interaction terms to the elasticity given in column (2) of Table 3. For example, the coefficient in column (1) of Panel A of Table 4 (0.0633) implies that a one standard deviation increase in the share of Listed Buildings reduces the energy price elasticity by 0.0633/0.479 = 13.2%.

The remaining columns of Table 4 add further controls, building up to the model corresponding to equation (3). Columns (2) and (3) address the concern of correlated trends. In the first of these columns, we include a set of variables in which linear time trends are interacted with a set of demographic and socio-economic variables drawn from the 2001 Census and median net household income in 2004. In Column (3) we replace the year fixed effects by year fixed effects interacted with a set of Travel to Work Area (TTWA) by year fixed effects. Across these two columns, the estimated effects for each of the preservation policies when considered individually are fairly stable. However, when compared to column (1) the specifications in Panel C suggest that the addition of control variables and trends allows us to better disentangle the effects of the two policies such that each is separately significant conditional on the other policy.

In column (4), we attempt to condition out the effects that derive from the characteristics of the housing stock. As pointed out earlier, there may be more scope for energy efficiency upgrades in older houses independent of the impact of preservation policies. The findings in this specification demonstrate that when we compare like with like, the effects of preservation policies become stronger. This is consistent with our expectation that preservation policies apply to the dwellings with the most scope for improvement due to the age of these dwellings. In column (5), we condition out urban form issues by including the interaction between the distance from the MSOA to the TTWA centre and the one-year lagged energy price as an additional control. The preservation policy coefficients are remarkably stable.

The final column (6) of Table 4 includes the full set of controls but also drops rural MSOAs and additionally allows for idiosyncratic linear trends for each of the other rural-urban indicator classifications. Our preferred specification is Panel C in column (6). This includes both preservation policies, the full set of controls, and controls for rural-urban issues. The coefficients are generally slightly weaker than those reported in the corresponding specification in column (5) yet remain highly significant.

We estimate the broad magnitude of the impacts of the two preservation policies on the elasticity of domestic energy with respect to main energy prices, again using the estimate in column (2) of Table 3 as our benchmark elasticity. The comparison suggests that all else equal, a one standard deviation increase from the mean value in the number of Grade II Listed Buildings per 100 dwellings implies a reduction in the elasticity of 0.0211/0.479 = 4.4%. A one standard deviation increase from its mean value in the share of dwellings in Conservation Areas implies a reduction in the elasticity of 0.0169/0.479 = 3.5%. These comparisons represent conservative estimates of the effects of preservation policies because the benchmark price elasticity in the denominator is considerably more elastic than estimates found elsewhere in the literature.

Despite the size of the coefficients and their implied quantitative magnitudes, these estimates do not imply that Conservation Areas have effects that are similar in magnitude to the more restrictive Listed Buildings, which would be counter-intuitive. This is because the standard deviation of the number of Listed Buildings per 100 dwellings (2.7) is only around a fifth of the standard deviation of the share of all dwellings that are in Conservation Areas (15.7%). In fact, when we do not scale the data, our findings suggest that Listed Buildings reduce the price elasticity more than dwellings in Conservation Areas, by a factor of around seven. This is more consistent with our observation in Section 2 that, all else equal, a Listed Building is regulated by a considerably more restrictive regime than a dwelling in a Conservation Area.[15]

3.5. Robustness Checks

We first report findings from stacked regressions (equation (4)) in Table 5, which provide a powerful check on earlier findings. Reassuringly, results indicate that the policy interactions remain statistically significant when the policy variables are entered individually, or when entered together as in column (3). The relative size of the coefficients is broadly similar to those in column (6) of Table 4. However, there are some differences since in absolute terms the coefficients for the stacked regression reported in column (3) are around 20-30% larger than the results in our preferred (most rigorous) specification, suggesting that the latter estimates are likely to be conservative.[16]

Our second set of robustness checks—reported in Table 6—considers the lag structure of energy prices and other timing issues. In the first four columns of Table 6, we report preservation effects using lag energy price assumptions other than the one-year lag used in our baseline specifications: column (1) uses contemporaneous energy prices; column (2) the second lag; column (3) uses both the current price as well as the first lag; and, finally column (4) uses the first and the second lag. Results suggest that the first lag of prices dominates and that our main findings using this lag structure should be sufficient to capture overall effects. A related issue is that until now, our estimates for domestic energy consumption have been generated from year-on-year variations at the MSOA-level that deviate from the trends implied by the initial characteristics of the Census. One concern may be that these changes are unlikely to be sufficient to induce households to adopt new technologies. To explore this possibility, column (5) evaluates the long-term adjustment to energy price changes by including only the first and last years (i.e. 2006 and 2013) of our panel and dropping all of the years in between. Results are largely consistent with our main results, albeit—as expected—somewhat larger.

To provide further checks on the validity of our findings we conduct a large number of further robustness checks. We describe and report two of these in Appendix A. In the first, we

[15] To illustrate this, we calculate the effects corresponding to panel C of column (6) in Table 4, but without standardising variables. We find coefficients that imply that a 1% increase in the share of Listed Buildings reduces the energy price elasticity by around 1.5% and a 1% increase in the share of dwellings in Conservation Areas reduces the elasticity by 0.2%. Note that the maximum share of Listed Buildings in our sample is 27% so we are unable to make in-sample predictions above this limit. In general, we use the standardised versions since these allow us to simulate the effects of changing the intensity of preservation policies in plausible ways.

[16] One potential concern with the stacked regressions is that they are unweighted so that the estimation of the coefficients places equal weight on gas and electricity consumption. We obtained near identical results when weighting the regressions with the consumption share of each fuel type in each MSOA in 2005.

demonstrate that our findings are robust to using alternative dependent variables, trends, preservation policy measures, and demand shifters (Appendix Table 2). In the second, we re-run the models specified in equations (3) and (4) with Green Belts included as an alternative preservation policy but one that acts as a placebo.[17] As expected, we find no significant results when Green Belt measures are interacted with the first lag of energy prices (Appendix Table 3).

3.6 Mechanism: Home Energy Efficiency

Our results so far imply that the prevalence of historical preservation policies reduces the energy price elasticity. The aim of this sub-section is to understand the underlying mechanism behind these effects. In particular, we evaluate whether the evidence is supportive of the proposition that the effects of preservation policies could be driven by a home energy efficiency channel. Some energy efficiency upgrades in designated dwellings may be either more expensive or fail to conform to regulations and hence, are technically illegal.

To this end, in Table 7 we report similar regressions to those conducted in Table 4 but at the LPA level, replacing the dependent variable with counts of home energy efficiency installations and aggregating across all types of installations in our data. As noted in Section 3.1, installations data are taken from the Home Energy Efficiency Database (HEED). Home energy efficiency installations recorded in this data include wall insulation, loft insulation, double glazing, new boilers, new heating systems, micro-generation and energy efficient lighting. Due to data availability, our set of controls is necessarily slightly different to the specifications reported in Table 4. Table 7 reports results conditional on LPA fixed effects, time-varying counts of LPA households, LPA wages, and additional demographic controls that are only available at the LPA level (share with first degree or equivalent, share aged 16-44, and share aged 45+), as well as linear building type and vintage trends. Given our earlier considerations, we expect individuals living in designated dwellings to be less able to respond to higher energy prices, i.e. by investing in home energy efficiency, so that all else equal, the coefficients on the interaction between energy prices and the policy variables will be negative.

This is borne out in the data. Column (1) of Table 7 suggests that a one standard deviation increase in the share of Listed Buildings and Conservation Area dwellings, respectively, reduces the amount of home energy investments significantly, by around 8,750 and 5,825 installations. In the remainder of Table 7 we separate out specific installations to illustrate that, in line with our priors, Conservation Area restrictions tend to bite on external changes while those on Listed Buildings are more pervasive. For example, column (2) documents that both policies reduce wall insulations (which will sometimes be external) but in column (3) the effect of Conservation Areas on loft installations (which are internal) is insignificant. Columns (4) to (6) of Table 7 show results only for 2006 to 2007 due to the data being restricted to this period. The findings are quite similar: the coefficients for both policies are significant for double glazing (external) while effects on new heating systems and boilers

[17] Green Belts surround many urban areas in England and are covered by strict rules that make it very difficult for developers to build new houses on them. However, unlike Conservation Areas and Listed Buildings, there is little reason to expect Green Belts to act as a constraint on investments in home energy efficiency improvements.

(internal) are significant for Listed Buildings but not for Conservation Areas, consistent with our priors.[18]

Finally, we quantitatively evaluate in Table 8 the impact of home energy efficiency investments on domestic energy consumption using dwelling-scale energy consumption and installations data drawn from the National Energy Efficiency Database (NEED). Controlling for dwelling fixed effects as well as time-varying area level characteristics, we find that the installation of new boilers, loft insulation, and wall insulation are associated with reductions in energy consumption of 7%, 2.5%, and 8%, respectively. Taken together these additional results are consistent with a technology adoption channel driving the relationship between preservation policies and domestic energy consumption found in Table 4.

4. Counterfactual Analysis

To understand the implications of our findings, this sub-section presents the results from using our models to simulate energy consumption during our sample period under a range of alternative counterfactual scenarios. In all cases, the preferred model—column (6) of Panel C in Table 4—is used to make in-sample predictions. Because this specification drops rural MSOAs, we capture effects in urban areas only. Hence, we are likely to underestimate energy consumption for England as a whole.

We first use the model to predict the total cumulative energy consumption between 2006 and 2013, not considering any counterfactual changes. We do this by taking the fitted model values for log per capita domestic energy consumption for each MSOA, converting this into total domestic energy consumption and then summing up over the sample of MSOAs and years. As documented in Table 9, this gives a cumulative 2006 to 2013 total energy consumption of 2.4 million gigawatt hours (GwH). The remaining rows of Table 9 compare this baseline prediction with modelled predictions when we vary the share of all buildings that are affected by preservation policies. This allows us to assess the total impact of preservation policies on domestic energy consumption and carbon dioxide emissions.

The first set of scenarios in Panel A of Table 9—rows (1) to (3)—evaluates the amount of domestic energy savings that were not realised during our sample period due to historical preservation policies, by setting each preservation policy to zero in turn and comparing the outcome to our baseline prediction.[19] We find that cumulative 2006 to 2013 domestic energy consumption (of all dwellings in the country, not just designated dwellings) would be reduced by: 1.7% if Conservation Areas are set to zero (row 1); 1.3% if Listed Buildings are set to zero (row 2); and, 3% if both preservation policies are set to zero (row 3).

In the remaining columns of Table 9 we calculate the financial and carbon costs under DECC assumptions that: natural gas represents 73% of the domestic energy consumed; each kWh of electricity and natural gas consumed produces 0.185 kg and 0.523 kg of CO_2, respectively;

[18] While the results presented in Table 7 provide evidence in favour of the proposition that preservation policies decrease the elasticity of home energy efficiency technology adoption in response to energy price increases, these findings need to be interpreted with some caution due to data concerns (both because of the more aggregated nature of the analysis and because of the lesser quality of the underlying data compared to the data utilised in our first panel).

[19] This essentially assumes the preservation polices are removed instantly at the start of 2006. As noted above, this is not meant as a realistic scenario but rather to provide some scale to the overall quantitative effects.

and, the unit costs of electricity and natural gas are 11.5p per kWh and 3p per kWh, respectively. Based on these assumptions, the two preservation policies collectively cost residents roughly £3.8 billion over the period 2006-13 and led to an additional 20.1 million tonnes of CO_2 emitted. In the final column we demonstrate that, at 3%, the saving is a relatively small proportion of total energy consumption. However, only around 10% of England's dwellings are affected by preservation policies. This implies that absent preservation policy restrictions, energy consumption in these particular dwellings would have been reduced by more than a quarter.

Panels B to D of Table 9 describe three further counterfactual scenarios. In Panel B, the preservation policies are reverted back to 1980 levels, a scenario that we deem plausible in that most buildings with high heritage value were already designated at that point in time.[20] During the 1980s, there was a major spike in the number of Listed Buildings (see Figure 4) due to a review of the Statutory List that accelerated following public outcry at the demolition of London's (unlisted) Art Deco Firestone tyre factory, in 1980. In essence, our counterfactual reflects what may have occurred had the list review not taken place and had the numbers of designated dwellings remained at 1980 levels ever since. Reducing both policies back to 1980 levels has the effect of reducing Conservation Areas by around a third and the number of Listed Buildings by around half. Under these assumptions 2006-2013 energy consumption is reduced by 1.3% or around 31,500 GWh. This implies a cumulative saving to households of roughly £1.7 billion and 8.9 million tonnes less carbon. In Panels C and D, we explore the effects of reducing or increasing, respectively, preservation policies by one standard deviation.

5. Welfare considerations

In this section we discuss the wider welfare implications of our empirical findings. Any assessment of such welfare effects would first need to consider at least five types of *benefits* related to heritage and designation. First, there is an internal heritage effect, b_{IH}, a value attached to historic buildings irrespective of designation. Second, there are external localised heritage effects, b_{EH}, a value attached to houses nearby with views of historic buildings. Third, there may be wider external benefits such as the existence value of historic buildings (see Wright and Eppink, 2016), b_{EV}, which again may apply irrespective of designation. Fourth, there is a value for designated historic buildings, b_{DH}. If designation does not generate additional benefits, then $b_{DH} = b_{IH}$. Or put differently, $b_{IDP} = b_{DH} - b_{IH}$ is the *internal premium* in value attached to designation. Fifth, there is a value attached to houses with views of designated buildings, b_{VD}. If designation has an inherent value for nearby owners, $b_{VD} > b_{EH}$, or we can denote the *external* heritage designation *premium* as $b_{EDP} = b_{VD} - b_{EH}$.

[20] This is supported by the finding of Ahlfeldt *et al.* (2012) that property price premiums for Conservation Area dwellings increase with the time since designation and that those designated before 1981 trade at a slight premium to those designated thereafter. The idea that time since designation is positively related to heritage value also finds support from some bloggers e.g. the NLP Planning Blog in Feb 2012: "…additions to conservation areas beyond the original designations are often substantial in size, and also because in my experience extended areas are: 1) not always closely related to the character of the original designation; and, 2) often of lesser quality in historic and townscape value terms than the original core designated areas. This often raises serious questions as to why these additional areas were designated."

Maintaining heritage value and complying with preservation policy-induced legal restrictions not only generates benefits but also incurs costs, some of which may be neglected by policy makers when making decisions about whether to designate buildings or entire areas for preservation. We consider several types of costs associated with heritage and designation. First, there are two types of internal costs associated with heritage. Some of these internal costs, c_{IE}, are associated with higher energy consumption, whereas others, c_{IO}, are not (e.g., higher maintenance costs and increased costs associated with 'outdated' layouts). Similarly, *designated* heritage buildings have internal costs, c_{DE} and c_{DO}, where c_{DO} includes the increased costs associated with obtaining planning permission or the outright inability to redevelop at higher density. The internal cost of designation associated with energy, c_{IDE}, is thus $c_{DE} - c_{IE}$, which arises because designation increases the cost of energy efficiency improvements or prevents them altogether. The other internal policy costs associated with designation, c_{IDO}, are equal to $c_{DO} - c_{IO}$. Second, there is an external policy cost, c_{ED}, in the form of increased GHG emissions (and possibly other negative externalities associated with designation-induced restrictions). Third, there is likely to be a designation induced cost in the form of a general equilibrium effect c_{GE}, due to preservation policies creating aggregate constraints on housing supply at city- or country-level (Glaeser, 2011; Hilber and Vermeulen, 2016). While we cannot estimate the potential costs of such constraints, these are likely to push up house prices and thus reduce housing consumption in England significantly.[21]

Recent research has focused mainly on the benefits of historic preservation, with empirical work largely based on house price data. Based on house sales in the Netherlands, Koster *et al.* (2016) estimate the premium for houses with views of designated buildings, i.e., b_{VD}, at around 3.5%, and additionally provide results (in an Appendix) which suggest, when controlling for external effects, designated buildings do not trade at a premium, i.e., $b_{DH} - c_{DE} - c_{DO}$ =0. Ahlfeldt *et al.* (2012) estimate that houses just inside and outside Conservation Areas in England trade at a positive premium of 8.5% (= $b_{DH} + b_{VD} - c_{DE} - c_{DO}$) and 5% (=$b_{VD}$), respectively, relative to other houses and conditional on controls.[22] They also explore the impact of designation on property prices, finding it has a weak positive effect on places just outside of Conservation Areas (i.e., $b_{EDP} = b_{VD} - b_{EH} > 0$). For New York, Been *et al.* (2016) find that the act of designating historic districts offers a substantive boost to the value of properties immediately outside the district, of nearly 12%, which is significantly larger than the estimate of b_{EDP} in Ahlfeldt *et al.* (2012). However, these same properties sell at a discount (of roughly 5%) prior to the designation, suggesting unobserved differences in structural features of properties in the vicinity of newly designated historic districts or lower levels of investment in those properties.[23]

On the cost side, Been *et al.* (2016) document that in areas where the value of the option to build unrestricted is higher, designation has a less positive effect on property values within

[21] This is also consistent with Waights (2016) who finds that locations with more Conservation Areas have higher house prices for given land values and building costs (indicating lower housing productivity) and higher house prices for given wages (indicating higher 'quality of life').
[22] Also see Holman and Ahlfeldt (2015), Ahlfeldt et al. (forthcoming), and Ahlfeldt and Holman (forthcoming).
[23] Although not focused on the impact of designation per se, Koster and Rouwendal (forthcoming) use temporal variation in investments in cultural heritage to identify the impact of such investments on prices of houses not covered by designation, in the Netherlands.

the district. This suggests larger other internal costs, c_{DO}. In a similar vein, Ahlfeldt *et al.* (2012) find a zero effect of designation on house prices inside Conservation Areas (i.e. $b_{EDP} + b_{IDP} - c_{IDE} - c_{IDO}$ = 0). Interpreting this evidence leads Ahlfeldt *et al.* (forthcoming) to conclude the private benefits (arising from preservation) and costs associated with designation (e.g. in the form of higher maintenance costs or lower energy efficiency) may perfectly offset each other, which is suggestive of localised Pareto efficiency. However, similar to Koster *et al.* (2016) they neither separately estimate the internal policy costs of designation associated with energy consumption, c_{IDE}, nor attempt to quantify the external policy cost, c_{ED}, both of which are the focus of our analysis.

We infer from our first counterfactual scenario (Panel A of Table 9) that c_{IDE} approximates £3.8 billion in additional energy bills over the period from 2006 to 2013, almost £0.5 billion annually (or in perpetuity, £15.9 billion assuming a discount rate of 3%).[24] This is equivalent to a £240 increase in annual energy bills for each of the two million dwellings covered by preservation policies in England. We can express these additional energy bills as an approximate proportion of house prices. To the extent that higher energy bills are fully capitalised into lower house prices (at a discount rate of 3%), an average house price in Conservation Areas of around £240,000 implies a price effect of -3.3%. Reassuringly, this implied private cost is quite close to the hedonic value of energy efficiency certification ('green labels') in the literature of 5% in California (Kahn and Kok, 2014) and 3.5% in the Netherlands (Brounen and Kok, 2011).[25]

To quantify the external policy cost associated with designation, c_{ED}, we use an estimated marginal abatement cost of GHG emissions of £61 (non-traded, 'central range' price for 2013, at the end of our study period, in 2015 prices, following DECC, 2015). This implies a social carbon cost of preservation policies of around £1.23 billion over the period 2006-2013, around £153.3 million annually (or in perpetuity, £5.11 billion). These totals are, respectively, equivalent to an annual social cost of £76.7 (or in perpetuity £2,554) per designated dwelling. Although these costs will not be capitalised into house prices, we note that they equate to 1.1% of the average value of a house in Conservation Areas. If we only consider a relaxation of preservation policies to 1980-levels, rather than the unrealistic scenario of abolishing these policies entirely, the carbon cost savings between 2006 and 2013 amount to £540 million—or around £2.3 billion in present value terms.

If we take the finding in Ahlfeldt *et al.* (forthcoming) at face value that designation has a zero net internal effect (i.e., within designated areas) on house prices at the margin, then $b_{EDP} + b_{IDP} = c_{IDE} + c_{IDO}$. This is consistent with political economy frameworks that model preservation as the outcome of localised decision making. There are, however, at least two

[24] For ease of interpretation, we apply a discount rate of 3% throughout this section. Her Majesty's Treasury's Green Book, which informs cost-benefit analysis of UK government policy, suggests a discount rate of 3.5% for the first 30 years and declining discount rates thereafter (3% for years 31-75, 2.5% for years 76-125, 2% for years 126-200, 1.5% for years 201-300 and 1% for years 301+). Our discount rate in perpetuity of 3% is a simplified approximation of this schedule but with the advantage of making our calculations easily accessible. Also note that in estimating the social cost of carbon we assume a constant carbon price over time when carbon price schedules published by the UK's government typically assume a rising prices in the future.

[25] The hedonic value of energy efficiency certificates can be interpreted as the present value of energy savings resulting from up-to-date home energy efficiency installations (compared to 'standard' or outdated ones).

types of external benefits that are likely ignored by local residents: an existence value, b_{EV}, and an external designation premium, b_{EDP}, safeguarded by historic preservation. The recent economic literature has mainly focused on these benefits. The literature also recognises external costs associated with general equilibrium effects, c_{GE}, due to regulatory supply constraints (including those imposed by preservation policies) creating aggregate constraints on housing supply. In this paper we identify and emphasize for the first time yet another sizeable external cost: the external policy (or carbon) cost c_{ED}. These external costs are also likely ignored by local residents in determining the extent of preservation.

6. Conclusions

Policies to preserve the built environment are increasingly widespread across North America and Europe and are particularly prevalent in the UK. External benefits of these policies are well documented. At the same time, governments around the world have set ambitious energy saving and GHG emissions reductions targets. In this context, the UK government's Home Energy Efficiency Policy Framework (Committee on Climate Change, 2014) recognizes that "…beyond 2017 low-cost potential [loft, cavity wall] is increasingly exhausted". This has led to a shift in focus towards different energy-saving technologies and a focus on 9.2 million "hard-to-treat" homes, which includes many buildings in Conservation Areas as well as Listed Buildings.

In this paper we uncover a trade-off between improvements in energy efficiency and preserving built heritage. We present evidence that restrictions on alterations to dwellings that are either lying in Conservation Areas or are designated as Listed Buildings substantially increased domestic energy consumption in England between 2006 and 2013. We find that rising energy prices induce an increase in home energy efficiency installations and a corresponding decrease in energy consumption. However such energy savings are significantly less pronounced in Conservation Areas and Listed Buildings. Our findings imply that policies that aim to induce energy savings and reduce greenhouse gas emissions in the UK's housing stock ought to account for the unintended consequences of regulations induced by preservation policies.

References

Ahlfeldt, G.M., and Holman, N. (forthcoming). 'Distinctively different: A new approach to valuing architectural amenities', forthcoming *Economic Journal*.

Ahlfeldt, G.M., Holman, N. and Wendland, N. (2012). *An assessment of the effects of conservation areas on value, English Heritage,* London, UK.

Ahlfeldt, G.M., Moeller, K., Waights, S. and Wendland, N. (forthcoming). 'Game of zones: The political economy of conservation areas', forthcoming *Economic Journal*.

Allcott, H. and Greenstone, M. (2012). 'Is there an energy efficiency gap?', *Journal of Economic Perspectives*, vol. 26(1), pp. 3-28.

Aroonruengsawat, A., Auffhammer, M. and Sanstad, A.H. (2012). 'The impacts of State Level Building Codes on Residential Electricity Consumption', *Energy Journal*, vol. 33(1), pp. 31-52.

Beaumont, A., (2007). *Hard-to-Treat homes in England,* W07- Housing Regeneration and Maintenance, International Conference 25th-28th June, Sustainable Urban Area, Rotterdam 2007, Building Research Establishment, Watford, UK.

Been, V., Gould Ellen, I., Gedal, M., Glaeser, E.L. and McCabe, B. J. (2016). Preserving History or Hindering Growth? The Heterogeneous Effects of Historic Districts on Local Housing Markets in New York City, *Journal of Urban Economics*, vol. 92, pp. 16-30.

Boardman, B., Darby, S., Hinnells, M., Killip, G., Layberry, R., Palmer, J. and Sinden, G. (2005). *40% House,* ECI Research Report No. 31, Environmental Change Institute, University of Oxford, Oxford.

Brounen, D. and Kok. N. (2011) 'On the economics of energy labels in the housing market', *Journal of Environmental Economics and Management*, vol. 62, pp. 166-179.

Brounen, D., Kok, N., and Quigley, J. M. (2012). 'Residential energy use and conservation: Economics and demographics'. *European Economic Review*, vol. 56(5), pp. 931-945.

Costa, D. L., and Kahn, M. E. (2010). *Why Has California's Residential Electricity Consumption Been So Flat since the 1980s?: A Microeconometric Approach* (No. w15978). National Bureau of Economic Research.

Davis, L. W. (2011). 'Evaluating the slow adoption of energy efficient investments: are renters less likely to have energy efficient appliances?', in *The design and implementation of US climate policy,* pp. 301-316. University of Chicago Press.

DECC (Department of Energy and Climate Change) (2015) *Valuation of Energy Use and Greenhouse Gas (GHG) Emissions: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government*, (accessed November, 2016): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/483278/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal.pdf

DECC (Department of Energy and Climate Change) (2014) *Sub-national Electricity and Gas Consumption Statistics: Region, Local Authority, Middle and Lower Layer Super Output Area*, available at (accessed January 2016): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/388960/Subnational_electricity_and_gas_consumption_summary_report_2013.pdf

Dowson, M., Poole, A., Harrison, D. and Susman, G. (2012). ‘Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal’, *Energy Policy,* vol. 50, pp. 294-305.

Fowlie, M., Greenstone, M. and Wolfram, C. (2015). ‘Are the non-monetary costs of energy efficiency investments large? Understanding low take-up of a free energy efficiency program’, *The American Economic Review*, vol. 105(5), pp.201-204.

Fuerst, F., McAllister, P., Nanda, A. and Wyatt, P. (2015). ‘Does Energy Efficiency Matter to Home-Buyers? An Investigation of EPC Ratings and Transaction Prices in England’, *Energy Economics,* vol. 48, pp. 145-156.

Glaeser, E. L. and Kahn, M. E. (2010). ‘The greeness of cities: Carbon dioxide emissions and urban development’, *Journal of Urban Economics* vol. 67, pp. 404-418.

Glaeser, E. L. (2011). *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier*: The Penguin Press HC.

Hilber, C.A.L. (2017) ‘The Economic Implications of House Price Capitalization: A Synthesis’, *Real Estate Economics*, vol. 45(2), pp. 301-339.

Hilber, C.A.L. and Vermeulen, W. (2016) ‘The Impact of Supply Constraints on House Prices in England,’ in press *Economic Journal*, vol. 126(591), 358-405.

Holman N. and Ahlfeldt, G.M. (2015). ‘No escape? The coordination problem in heritage preservation’, *Environment and Planning A,* vol. 47(1), pp. 172 – 187.

Ito, K. (2014). ‘Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing’, *The American Economic Review,* vol. 104(2), pp. 537-563.

Jacobsen, G.D. and Kotchen, M.J., (2013). ‘Are building codes effective at saving energy? Evidence from residential billing data in Florida’, *The Review of Economics and Statistics*, vol. 95(1), pp. 34–49.

Kahn, M.E. and Kok, N. (2014). ‘The capitalization of green labels in the California housing market’, *Regional Science and Urban Economics,* vol. 47, pp. 25-34.

Kahn, M.E., Kok, N., and Quigley, J. (2014). ‘Carbon emissions from the commercial building sector: the role of climate, quality, and incentives’, *Journal of Public Economics*, vol. 113, pp. 1–12.

Kahn, M.E. and Walsh, R. (2015). ‘Cities and the Environment’, In: Gilles Duranton, J. Vernon Henderson and William C. Strange, Editor(s), *Handbook of Regional and Urban Economics,* Elsevier, 2015, vol. 5, pp 405-465,

Koster, H. R. A., and Rouwendal, J. (forthcoming). ‘Historic Amenities and Housing Externalities: Evidence from the Netherlands’, forthcoming *Economic Journal.*

Koster, H.R.A., van Ommeren, J.N. and Rietveld, P. (2016). ‘Historic Amenities, income and sorting of households’, *Journal of Economic Geography*, vol. 16, pp. 203-236.

Kuminoff, N.V. and Pope, J.C. (2014). ‘Do ‘Capitalization Effects’ for Public Goods Reveal the Public’s Willingness to Pay?’. *International Economic Review*, vol. 55(4), pp. 1227-1250.

Larson, W., Liu, F. and Yezer, A. (2012). ‘Energy footprint of the city: Effects of urban land use and transportation policies’, *Journal of Urban Economics*, vol. 72, pp. 147-159.

Larson, W. and Yezer, A. (2015). ‘The energy implications of city size and density’, *Journal of Urban Economics*, vol. 90, 35-49.

Reiss, P. C. and White, M. W. (2005). ‘Household electricity demand, revisited’, *Review of Economic Studies* vol. 72(3), pp. 853–83.

Rivers, N. and Schaufele, B. (2015). ‘Salience of carbon taxes in the gasoline market’, *Journal of Environmental Economics and Management*, vol. 74, pp. 23-36.

Waights, S. (2016). ‘The preservation of historic districts – Is it worth it?’, SERC Discussion Paper No. 202, June.

Watson, C. and Bolton, P. (2013). *Carbon Emissions Reduction Target (CERT)*, House of Commons Library, Standard Note: SN/SC/06196, available at (accessed February 2017): http://researchbriefings.files.parliament.uk/documents/SN06196/SN06196.pdf

Wright, W. C. C. and Eppink, F. V. (2016) ‘Drivers of heritage value: A meta-analysis of monetary valuation studies of cultural heritage’, *Ecological Economics*, vol. 130, 277–284.

TABLES

Table 1
Preservation Policies and Home Energy Efficiency Improvements

	Not Listed or CA		**Conservation Areas**		**Listed Buildings**	
	Planning	Building Regulations	Planning	Building Regulations	Planning	Building Regulations
Replacement boiler/heating					?	
New boiler/heating		AS		AS	?	AS
New doors and windows	Flats*	AS	Flats*/Art4	AS	√	AS
Loft insulation					?	?
External wall insulation	√**	√	√	√	√	√
Cavity wall insulation		AS***		AS***	√	AS***
Wind turbine	Flats	AS	Art4	AS	√	AS
Solar panels		AS	Art4	AS	√	AS
Ground & Air source heat pumps		AS	?	Add	√	Add

Notes: **AS =** Can use a tradesman registered under an Approved Scheme to avoid an application; **Add**= Additional conditions must be met; **?** = Property owner should consult with Local Planning Authority; **Art4 =** Conservation areas under Article 4 directions may require an application; **Flats =** Application needed for flats but not houses.

* Depending on the nature of the work, planning permission is needed, when not exactly a like-for-like replacement.

** Since January 2013 external wall insulation on individual dwellings (houses) has been classed as an alteration for the purposes of "permitted development", meaning planning permission may not be required.

*** No self-certification scheme until 2010, i.e. until then there had to be a building notice from the householder.

Table 2a
Summary Statistics: MSOA Main Regression Sample

	Obs.	Mean	Std. Dev. overall	Std. Dev. between	Std. Dev. within	Min.	Max.
Panel data							
Log per capita domestic energy consumption (kWh)	44,149	8.92	0.23	0.21	0.09	7.58	9.61
Log real one year lag weighted energy price per kWh	44,149	1.79	0.20	0.13	0.15	1.22	2.73
Cross-sectional data							
Planning Variables							
Grade II Listed buildings per 100 dwellings	5,665	1.41	2.68			0	27.00
Share of dwellings in Conservation Area in %	5,665	9.33	15.69			0	100
Census 2001 Variables							
Share degree educated in %	5,665	14.77	8.52			2.08	54.10
Share lone parent in %	5,665	2.68	1.38			0.35	9.75
Share owner-occupier in %	5,665	68.88	16.90			8.11	98.06
Share ethnicity white in %	5,665	90.67	14.72			11.03	100
Share aged 45-59 in %	5,665	18.80	3.58			4.47	29.61
Share aged 60 or above in %	5,665	20.61	5.73			3.46	55.61
Share Manager, Professional, Assoc. Professional in %	5,665	39.80	12.48			13.07	82.21
Share employed in %	5,665	45.88	6.61			17.25	67.32
Dwelling characteristics							
Share dwellings built before 1945 in %	5,665	38.57	23.50			0	99.51
Share dwellings built 1945-1964 in %	5,665	18.37	14.74			0	96.77
Share dwellings built 1965-1982 in %	5,665	20.47	14.71			0	99.64
Share dwellings built 1983-1999 in %	5,665	13171	11.02			0	99.16
Share dwellings built since 2000 in %	5,665	9.42	7.97			0	70.22
Share flats in %	5,665	22.18	21.62			0	99.81
Share terraced in %	5,665	27.53	17.16			0	94.66
Share detached in %	5,665	25.70	21.13			0	85.23
Share semi-detached in %	5,665	24.59	14.39			0	85.49
Other							
Distance to TTWA centre (km)	5,665	0.11	0.08			0.001	0.62
MSOA median household income in 2004 (£)	5,665	495.34	116.79			240	1120

Notes: Planning variables reported in this Table are not standardised as in the regressions.

Table 2b
Summary Statistics: LPA Regression Sample

	Obs.	Mean	Std. Dev. overall	Std. Dev. between	Std. Dev. within	Min.	Max.
Panel data							
Total home energy efficiency installations	1,510	24,714	22,963	20,444	10,510	2,895	298,444
Wall insulation	1,510	4,071	4,198	3,636	2,107	25	51,444
New loft insulation	1,510	1,226	1,508	1,162	964	7	23,042
Double glazing	604	5,447	4,447	4,215	1,427	619	55,096
Heating systems	604	1,051	1,130	1,085	316	93	13,445
New boiler	604	896	1,052	970	408	84	14,245
Log real lagged weighted energy price per kWh	1,510	1.73	0.18	0.10	0.15	1.36	2.26
Share age 16-45 in %	1,510	0.39	0.06	0.06	0.00	0.27	0.60
Share age 45+ in %	1,510	0.43	0.06	0.06	0.01	0.20	0.59
Share with degree in %	1,510	0.20	0.09	0.08	0.03	0.03	0.57
Log real male FT wage	1,510	6.37	0.16	0.15	0.04	5.99	7.21
Log heating degree days	1,510	1.74	0.10	0	0.10	1.63	1.92
Log household count	1,510	10.61	0.55	0.55	0.04	8.73	12.72
Cross-sectional data							
Planning Variables							
Grade II Listed buildings per 100 dwellings	302	1.90	2.10			0.06	11.90
Share of dwellings in Conservation Area in %	302	10.03	9.18			0.23	65.10

Notes: Planning variables reported in this Table are not standardised as in the regressions.

Table 3
Energy Price Elasticities: OLS

Dependent Variable: Log domestic energy consumption per person	(1)	(2)	(3)	(4)
Log contemporaneous weighted energy price	-0.0865***			0.00918
	(0.00777)			(0.00860)
Log one year lagged weighted energy price		-0.479***		-0.397***
		(0.00854)		(0.00925)
Log two year lagged weighted energy price			-0.187***	-0.0680***
			(0.00458)	(0.00457)
Log heating degree days	0.0508***	0.222***	0.0789***	0.203***
	(0.00239)	(0.00328)	(0.00236)	(0.00339)
Log LPA male FT real median wage	-0.0582***	-0.0210	-0.0393**	-0.0193
	(0.0188)	(0.0161)	(0.0165)	(0.0163)
MSOA fixed effects	√	√	√	√
Linear time trend x Region	√	√	√	√
Observations	38,512	38,512	38,512	38,512
Adj. R-squared	0.976	0.980	0.978	0.980

Notes: Standard errors clustered at LPA level in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 4
Baseline Specifications: OLS, Domestic Energy Consumption

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)	(4)	(5)	(6)
PANEL A: Listed Buildings						
Log one year lagged energy price	0.0633***	0.0336***	0.0305***	0.0315***	0.0324***	0.0320***
× Grade II Listed per 100 dwellings	(0.00340)	(0.00287)	(0.00274)	(0.00293)	(0.00295)	(0.00415)
Adj. R-squared	0.982	0.986	0.987	0.988	0.988	0.985
PANEL B: Conservation Areas						
Log one year lagged energy price	0.0329***	0.0220***	0.0175***	0.0225***	0.0224***	0.0222***
× Share dwellings in Conservation Area	(0.00621)	(0.00355)	(0.00363)	(0.00328)	(0.00332)	(0.00346)
Adj. R-squared	0.981	0.986	0.987	0.988	0.988	0.985
PANEL C: Historical Preservation Policies						
Log one year lagged energy price	0.0580***	0.0292***	0.0269***	0.0259***	0.0267***	0.0211***
× Grade II Listed per 100 dwellings	(0.00379)	(0.00342)	(0.00326)	(0.00313)	(0.00305)	(0.00422)
Log one year lagged energy price	0.0109	0.0129***	0.0105**	0.0153***	0.0152***	0.0169***
× Share dwellings in Conservation Area	(0.00765)	(0.00435)	(0.00418)	(0.00352)	(0.00346)	(0.00370)
Adj. R-squared	0.982	0.986	0.987	0.988	0.988	0.985
Controls, Fixed Effects and Trends						
Log LPA wages	√	√	√	√	√	√
MSOA fixed effects	√	√	√	√	√	√
Linear time trend x Region	√	√	√	√	√	√
Year fixed effects	√	√				
2001 Census and 2004 income linear trends		√	√	√	√	√
TTWA-by-year			√	√	√	√
Building age & type linear trends				√	√	
Distance to TTWA centre x energy price					√	√
Drop rural MSOAs & rural-urban linear trends						√
Observations	44,149	44,149	44,149	44,149	44,149	40,410

Notes: Standard errors clustered at LPA level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All policy variables are standardised. Energy price variable is a weighted average of real national gas and electricity prices, lagged one period. 2001 Census trends are linear time trends interacted with net household income in 2004; 2001 share with degree; share lone parents; share owner-occupiers; share ethnicity white; share ages 45-59, share aged 60+; share managers, professionals, or associate professionals; share employed. Building age categories are share built before 1945, share built 1945-1964, share built 1965-1982, share built 1983-1999 (omitted share built since 2000). Building type categories are share semi-detached, share flats and share terraced (omitted share detached).

Table 5

Robustness Check: Alternative Estimation Approach (Stacking Regression)

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)
Log one year lagged energy price	0.0369***		0.0247*
× Grade II Listed per 100 dwellings	(0.0121)		(0.0135)
Log one year lagged energy price		0.0274***	0.0206**
× Share dwellings in Conservation Area		(0.00808)	(0.00897)
Controls, Fixed Effects and Trends			
MSOA-by fuel type fixed effects	√	√	√
Region-by fuel type linear trends	√	√	√
MSOA-by-year	√	√	√
Fuel type-by-year	√	√	√
2001 Census and 2004 income linear trends x fuel type	√	√	√
Building age & type linear trends x fuel type	√	√	√
Distance to TTWA centre x energy price	√	√	√
Drop rural MSOAs & rural-urban linear trends x fuel type	√	√	√
Observations	80,836	80,836	80,836
Adj. R-squared	0.996	0.996	0.996

Notes: Standard errors clustered at LPA level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All policy variables are standardised. Energy prices are lagged by one year.

Table 6
Robustness Check: Panel Frequency and Lagged Energy Prices

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)	(4)	(5)
	Current prices	Second lag	Current & first lag	First & second lag	2006 & 2013
Log weighted energy price					
x Grade II Listed per 100 dwellings	0.0254***		0.00712		0.0274***
	(0.00547)		(0.00608)		(0.00560)
x Share dwellings in Conservation Area	0.0206***		0.00549		0.0184***
	(0.00417)		(0.00718)		(0.00471)
Lag 1: Log energy price					
x Grade II Listed per 100 dwellings			0.0207***	0.0142***	
			(0.00484)	(0.00506)	
x Share dwellings in Conservation Area			0.0132*	0.0112***	
			(0.00686)	(0.00398)	
Lag 2: Log energy price					
x Grade II Listed per 100 dwellings		0.0170***		0.00761**	
		(0.00416)		(0.00361)	
x Share dwellings in Conservation Area		0.0162***		0.00909**	
		(0.00382)		(0.00416)	
Controls, Fixed Effects and Trends					
Log LPA wages	√	√	√	√	√
MSOA fixed effects	√	√	√	√	√
Linear time trend x Region	√	√	√	√	√
Year fixed effects	√	√	√	√	√
2001 Census and 2004 income linear trends	√	√	√	√	√
TTWA-by-year	√	√	√	√	√
Building age & type linear trends	√	√	√	√	√
Distance to TTWA centre x energy price	√	√	√	√	√
Drop rural MSOAs & rural-urban linear trends	√	√	√	√	√
Observations	40,410	35,259	40,410	35,259	9,764
Adj. R-squared	0.985	0.986	0.985	0.986	0.978

Notes: Standard errors clustered at LPA level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All policy variables are standardised. Energy prices lagged as indicated.

Table 7
Mechanism: Energy Prices and Energy Efficiency Installations

Panel timespan:	2006-2010			2006-2007		
Dependent variable:	All installations	Wall insulation	Loft insulation	Double glazing	Heating	New boiler
Nature of upgrade:	Internal/External	Internal/External	Internal	External	Internal	Internal
	(1)	(2)	(3)	(4)	(5)	(6)
Log one year lagged energy price	-8,745***	-1,388***	-693***	-1,600***	-865***	-917***
× Grade II Listed per 100 dwellings	(2,372)	(495)	(226)	(603)	(163)	(216)
Log one year lagged energy price	-5,828**	-1,018*	-330	-2,127***	120	-330
× Share dwellings in Conservation Area	(2,667)	(568)	(258)	(782)	(191)	(287)
Log household count	2,606	627	302	1,465	548	176
	(4,125)	(866)	(433)	(1,386)	(376)	(403)
Controls, Fixed Effects and Trends						
LPA fixed effects	√	√	√	√	√	√
Year fixed effects	√	√	√	√	√	√
Building age and type linear trends	√	√	√	√	√	√
Demographic controls and wages	√	√	√	√	√	√
Observations	1,510	1,510	1,510	604	604	604
Adj. R-squared	0.916	0.873	0.810	0.938	0.934	0.855

Notes: Standard errors clustered at LPA level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Sample includes 304 LPAs with Conservation Area data. Installations data from the HEED database. Wall insulations include cavity wall and external wall insulation. Loft insulations capture new installations but exclude upgrades to existing insulation. All installations include a wide variety of energy efficiency installations e.g. wall insulation, loft insulations, new boiler, and heating, microgeneration and energy efficient lighting. Energy price variable is a weighted average of real national gas and electricity prices, lagged one period. Demographic controls include time varying demographic controls: share with degree, share age 16-45, share age 45+ and log FT male real average wage. Columns (4)-(6) based on 2006-2007 as data for these installations only held for this period.

Table 8
Mechanism: Energy Efficiency & Consumption

Dep Var: Log domestic energy consumption per person	(1)	(2)
New boiler	-0.0711***	-0.0703***
	(0.0006)	(0.0006)
Loft insulation	-0.0247***	-0.0244***
	(0.0006)	(0.0006)
Wall insulation	-0.0771***	-0.0793***
	(0.0007)	(0.0007)
Dwelling fixed effects	√	√
Fuel poverty decile-by-year FE		√
Deprivation decile-by-year FE		√
Observations	27,803,027	27,803,027
Adj. R-squared	0.703	0.703

Notes: *** p<0.01, **p<0.05, *p<0.1.Based on NEED database 2005-2012. Estimates based on all English dwelling types and sizes.

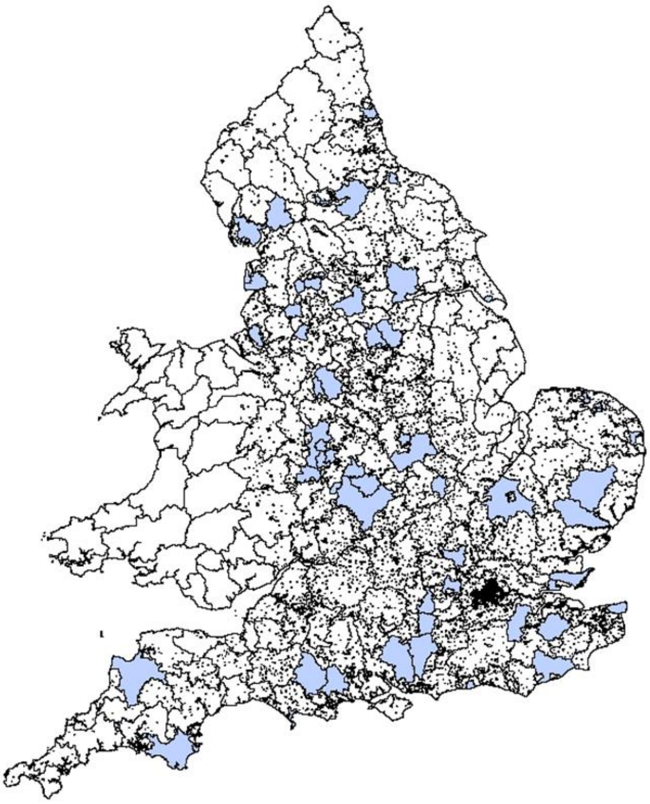
Table 9
Counterfactual Scenarios

	Total Gas + Electricity (GwH)	**Predicted GwH 2006 -2013 cumulative**	**Difference GwH**	**Difference £ million**	**Difference CO_2 (MtCO2e)**	**Difference %**
	Baseline Prediction	2,440,836				
Panel A: Remove All Preservation Policies						
(1)	Conservation Areas	2,398,140	-42,696	-2,261	-11.8	-1.7%
(2)	Listed Buildings	2,409,555	-31,281	-1,656	-8.6	-1.3%
(3)	Both Preservation Policies	2,368,214	-72,622	-3,845	-20.1	-3.0%
Panel B: Reduce to 1980 Levels						
(4)	Conservation Areas	2,424,985	-15,851	-839	-4.4	-0.6%
(5)	Listed Buildings	2,424,259	-16,577	-878	-4.6	-0.7%
(6)	Both Preservation Policies	2,408,568	-32,268	-1,709	-8.9	-1.3%
Panel C: Reduce by 1 Standard Deviation						
(7)	Conservation Areas	2,415,625	-25,211	-1,335	-7.0	-1.0%
(8)	Listed Buildings	2,417,741	-23,095	-1,223	-6.4	-0.9%
(9)	Both Preservation Policies	2,392,999	-47,837	-2,533	-13.2	-2.0%
Panel D: Increase by 1 Standard Deviation						
(10)	Conservation Areas	2,516,541	75,705	4,009	20.9	3.1%
(11)	Listed Buildings	2,536,179	95,343	5,048	26.3	3.9%
(12)	Both Preservation Policies	2,614,859	174,023	9,215	48.1	7.1%

Notes: Table uses conversion factors for 2010 Electricity kWh = 0.523 kg CO_2 and Natural gas kWh = 0.185 kg CO_2 (Source: DECC's "Tool for calculation of CO_2 emissions from organisations"). Calculations assume natural gas is 73% of total domestic (gas + electricity) based on the average total consumption in the sample MSOAs in the sample timeframe. The average unit prices for electricity and gas are taken from DECC publications for 2007 paying on credit, 11.5 pence per kWh electricity and 3 pence per kWh domestic gas.

FIGURES

Fig. 1
Conservation Areas in England



Source: English Heritage. Data missing for 50 LPAs (blue)

Fig. 2
Conservation Areas by Year of Designation

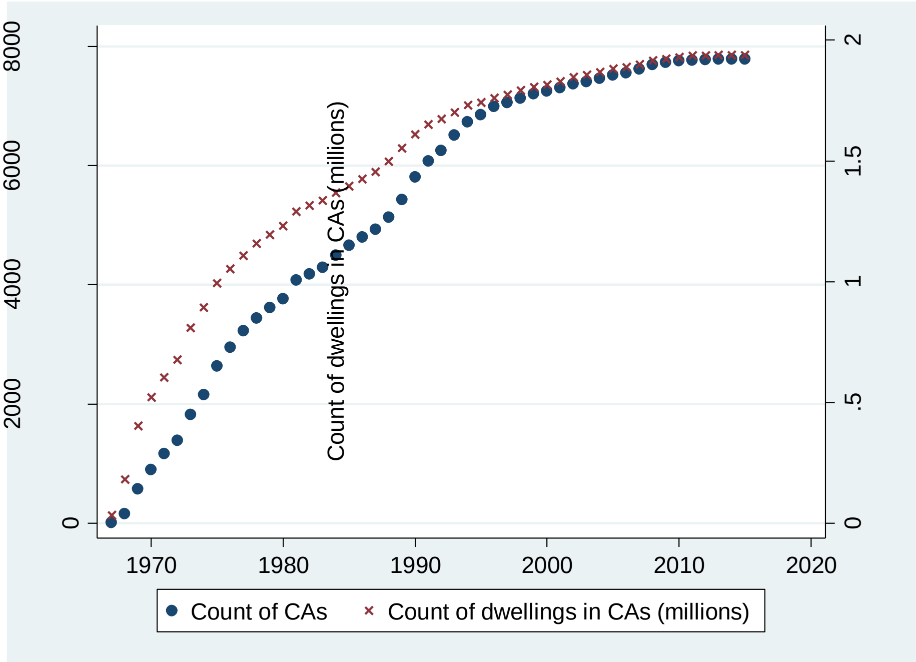
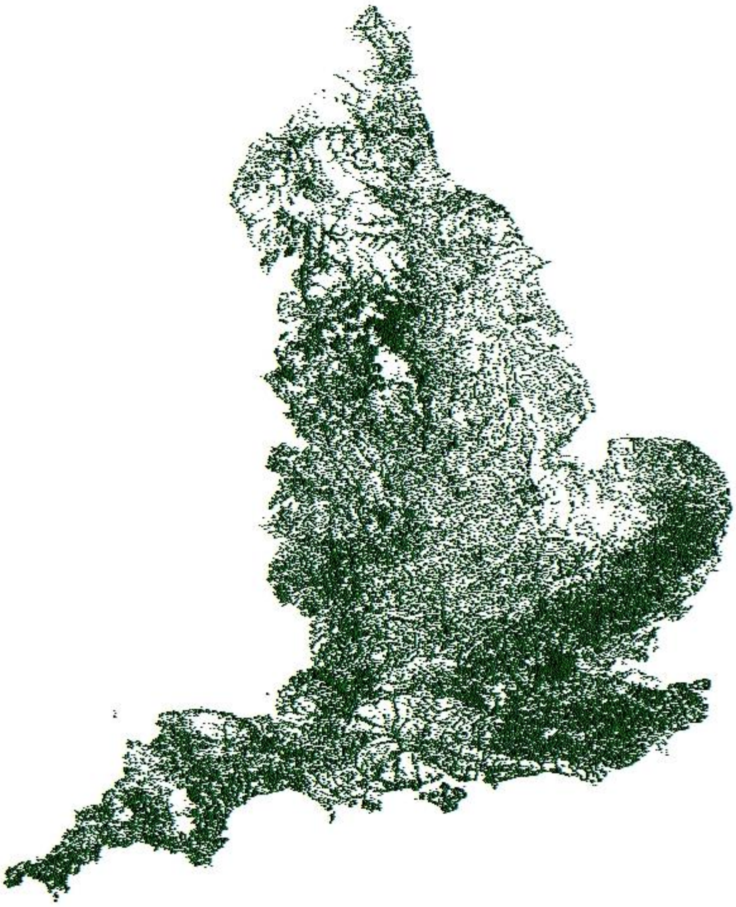


Fig. 3
Listed Buildings in England



Source: English Heritage

Fig. 4
Listed Buildings by Year of Listing

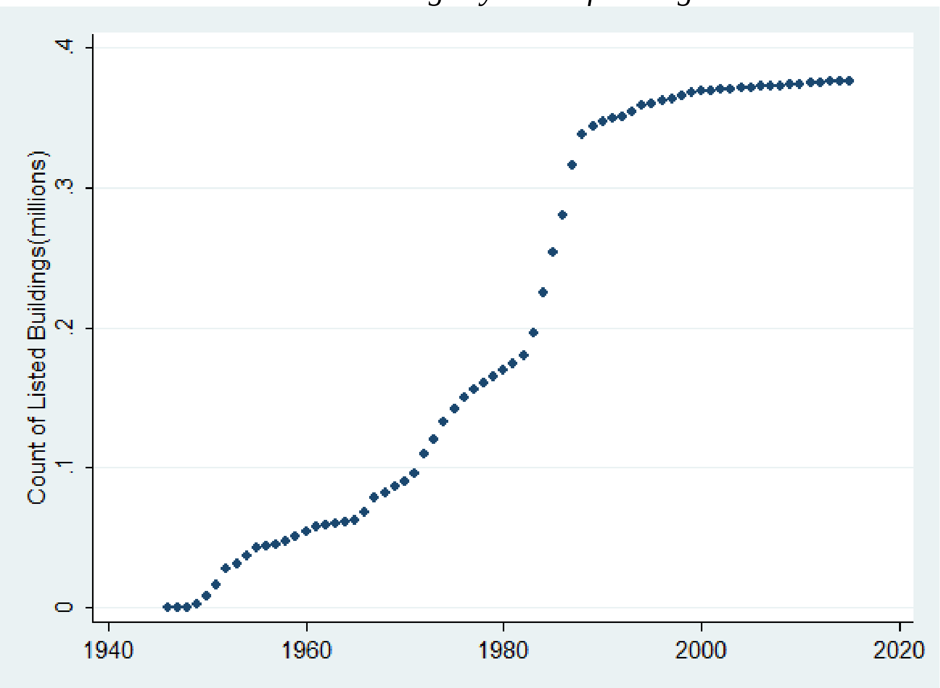


Fig. 5
Impact of Strict Preservation Policy on Investments in Home Energy Efficiency Investments and Energy Consumption

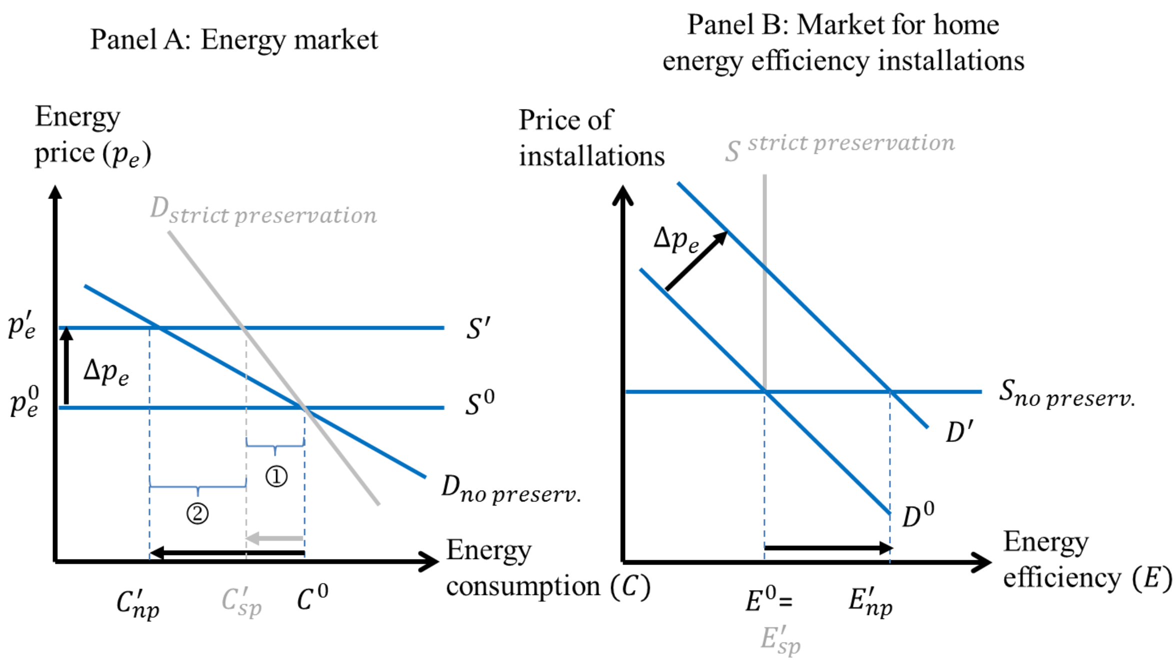
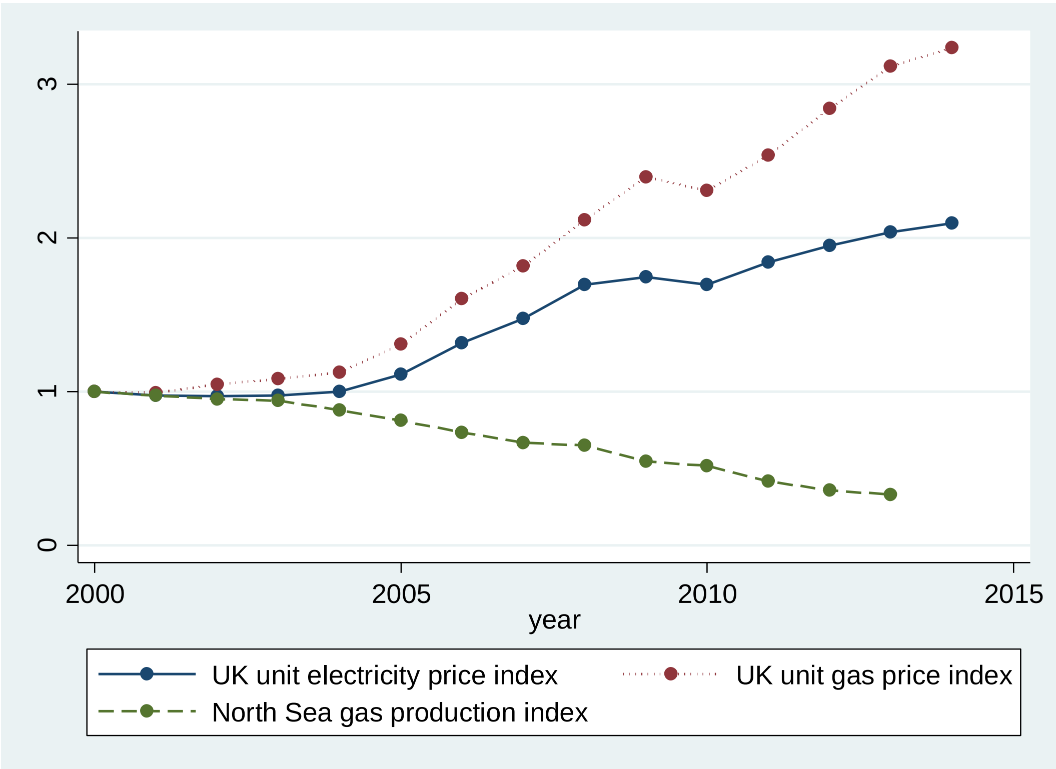
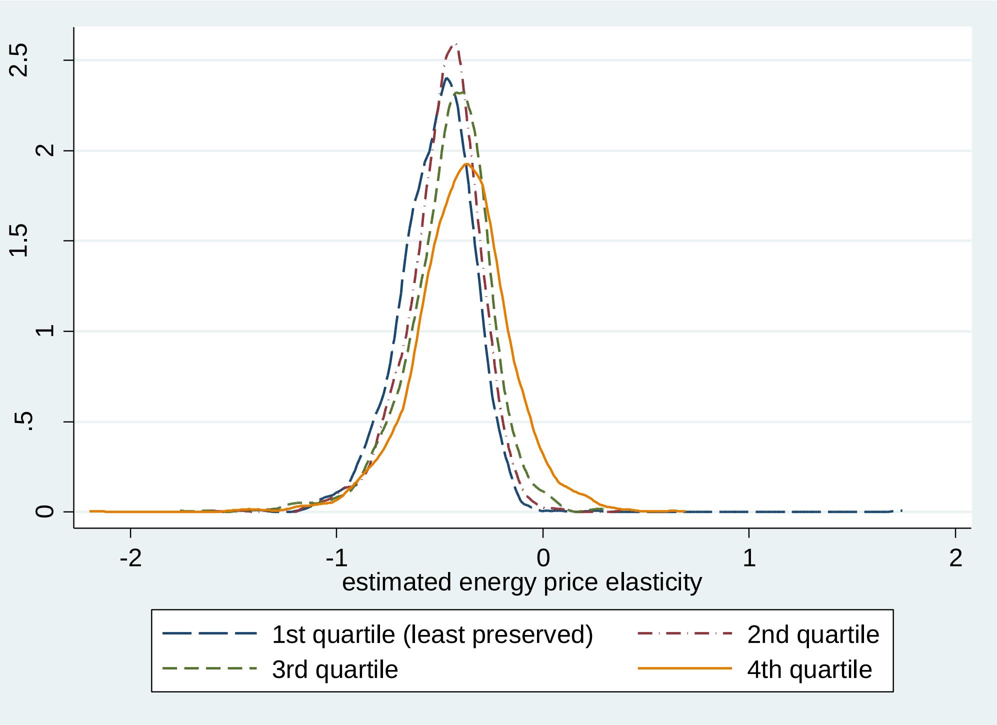


Fig. 6
UK Energy Price and Production Indices 2000- 2014



Source: DECC

Fig. 7
MSOA Energy Price Elasticity Kernel Density, by Extent of Preservation



APPENDICES

Appendix A: Robustness Checks

In this appendix, we document supplementary robustness checks we undertake in order to confirm the validity of our findings. Descriptive statistics for all variables used in these regressions are found in Appendix Table 1 while details about the underlying data are contained in Appendix B.

The first additional set of robustness checks in Appendix Table 2 reports regressions that vary individual elements of our preferred specification in column (6) of Panel C in Table 4. This specification drops a small number of cells that experience large (>25%) year-on-year changes in energy consumption. In the first two columns, we demonstrate that our overall findings are robust to alternative restrictions, either where we do not drop any MSOA-year cells (column (1)), or drop MSOA-year cells that experience very large changes (>50%). In the remaining columns of Appendix Table 2, we demonstrate that our main findings are robust to varying our control trends, planning constraints measures, and shifters of the demand for energy efficiency installations. One potential concern with our preferred specification is that our trends may not adequately control for correlated variation. To mitigate this, we show that our findings are largely insensitive to alternative trend specifications, by replacing 2001 Census trends in column (3) with 2011 Census trends and with trend variables interacted with the change in the share variables occurring between the two Censuses, in column (4), and energy prices interacted with the Census variables and building type and age variables in column (5).

Columns (6)-(8) demonstrate that findings are also robust with respect to alternative specifications of the planning variables. In column (6), we drop all MSOAs that include a Conservation Area designated after 1 January 2005 and do not count any Listed Buildings designated since this date. In column (7), we re-specify the Conservation Area measure as the share of developed (urban and suburban) land in a Conservation Area using land cover data from a 1991 survey. In column (8), we re-specify the Listed Building measure by counting all Listed Buildings rather than Grade II ones only. The final two columns focus on alternative demand shifter specifications. In column (9), we instrument log weighted energy prices using log North Sea gas production. In column (10), we weight energy prices using national proportions of each type of energy consumed (meaning the demand shifter is common to all MSOAs). All told, the results in this table suggest robustness to a variety of changes in specification and underlying data content.

In a second robustness check we conduct a test using a third type of preservation policy: Green Belts. Green Belts surround many urban areas in England and are covered by strict rules that make it very difficult for developers to build new houses inside areas under this planning designation. However, unlike Conservation Areas and Listed Buildings, there is little reason to expect Green Belts to act as a constraint on investments in home energy efficiency improvements. Thus, we consider regressions using Green Belts as a placebo test of our main results. In the first column of Appendix Table 3 we replicate the specifications from Table 4 column (6) but, as our preservation policy measure, use the number of dwellings in the Green

Belt in each LPA. In the second column, we then include all three preservation policies jointly. The coefficients on Green Belt interactions are insignificant while the coefficients on the Conservation Area and Listed Building interactions are largely unaffected by the inclusion of Green Belts. Columns (3) and (4) show that we reach similar conclusions when we repeat this exercise using the stacked regression approach.

Appendix B: Detailed Description of Data and Sources

This appendix provides details on the various sources and computation of variables used in our empirical analysis.

The analysis rests on a dataset of neighbourhood level domestic energy consumption, historical preservation policies, and control variables at the Middle Layer Super Output Area (MSOA) spatial scale. MSOAs are small area statistical geographies introduced following the 2001 Census. The 6,781 MSOAs in England with which we perform our analysis were designed to be relatively homogeneous in terms of their populations and contain between 2,000 and 6,000 households. Data for domestic energy consumption are publically available through the Department for Energy and Climate Change (DECC) sub-national consumption statistics. The dataset records the total amount of domestic mains gas distributed through the National Transmission System and electricity consumed in each MSOA in each year in kilowatt hours (kWh) between 2006 and 2013.[26] Population data from the Office of National Statistic (ONS) (mid-year Population Estimates for Lower Layer Super Output Areas in England and Wales by Single Year of Age and Sex) are then matched into the data. A small number of MSOAs that miss data for energy consumption or population are dropped. Our main domestic energy measure is generated by taking the natural log of energy consumption, summed across these two energy types, divided by population.[27]

We also provide a panel analysis of home energy efficiency installations at the Local Planning Authority (LPA)-level. This second panel is constructed using data on home energy efficiency installations from the Home Energy Efficiency Database (HEED) held by the Energy Saving Trust. Home energy efficiency installations are not available to us at the MSOA-level, so by necessity the spatial units in this panel are the 354 pre-2009 LPAs in England. The panel runs only from 2005 to 2010 after which LPAs were reorganised. We use the HEED data that records the total number of annual installations, exploiting the richness of installation types, including wall insulations, loft insulations, double glazing, new boilers, new heating systems, micro-generation and energy efficient lighting. We treat these installations as a stock (because the upgrades we focus on are durable) and specify dependent variables based on installations in levels. Control variables in this panel include household counts, share with degree education, and FT male median wages from NOMIS, and population age groups based on information obtained from the ONS.

---

[26]Some data from before 2006 are available, but much of the earlier data was collected on a different basis or is classified as experimental data so we use 2006 as our base year. As discussed below, we use 2005 MSOA energy consumption data to weight our demand shifter.

[27] Although the gas data are weather corrected, unlike the electricity data, DECC (2014, 34) reports that *"Despite these differences, the combined electricity and gas provide a good indication of overall annual household energy consumption in Great Britain at local authority, MSOA/IGZ and LSOA level, due to the robustness of the data collections and collation process"*.

We also explore the quantitative effect of home energy installations on domestic energy consumption using the National Energy Efficiency Data-Framework (NEED) End-User License File. This provides a panel of household energy (gas & electricity) consumption and property characteristics for roughly 3.8 million dwellings in England during the period 2005-2012 that have had energy performance certificates issued. The data set is anonymized but contains property characteristics (property age, type, and size brackets; region; area-based deciles for household fuel poverty and neighbourhood deprivation), as well as energy efficiency variables (energy efficiency band; gas heating; Economy 7 electricity; new boiler, cavity wall and loft installations with year of installation). The public version of the dataset however lacks information about households, tenure, and the precise location of dwellings.

We merge annual energy prices into all these data sets. Energy price measures originate from DECC's Quarterly Energy Prices publications (Table 2.3.3). We use UK average energy prices per unit for gas and electricity for customers paying on credit as data for this customer group are available for the whole period 2005-2013. Per unit (kWh) costs are generated from billing data by assuming a fixed annual consumption. They reflect the prices of all energy suppliers and include standing charges and Value Added Tax. We specify our demand shifters by taking the weighted average of these national unit costs. Our main results use time invariant MSOA-specific weights given by the share of each energy type consumed in the MSOA in 2005, i.e. the gas weight for an MSOA equals gas consumption in that MSOA in 2005 divided by total gas and electricity consumption in that MSOA in 2005. As a robustness check we use weights based on the time varying national average share of energy consumption for all MSOAs in our sample. In both cases, weighted average prices are converted into 2010 prices using the GDP deflator available from Her Majesty's Treasury before we take the natural log.

Our main right-hand side variables measure two widespread preservation policies: Conservation Areas and Listed Buildings. We obtain two shapefiles (for roughly 2008 and 2012) from Historic England (formerly English Heritage) with details of the spatial scope of individual Conservation Areas in England. Because data for some areas are missing in each file, we combine the files to minimize gaps but remained short of data for 50 Local Authorities (out of 354). Throughout the analysis, we focus solely on the 5,759 MSOAs for which we have Conservation Area data.

A dataset of Listed Buildings is downloaded from the Historic England website. Since the data do not identify building type, we cannot easily distinguish between commercial and residential Listed Buildings. However, the dataset records three levels of listing which denotes their level of historical or architectural interest: according to Historic England Grade buildings I are of "exceptional interest", Grade II* "particular importance" and Grade I of "special interest".

We construct several time invariant variables capturing the extent of local restrictions on domestic buildings at the MSOA- and LPA-level from this information. Our principal measures are based on the proportion of residential addresses in each MSOA or LPA that are covered by each of the preservation policies. To generate these measures, we first obtain counts of residential addresses for each postcode in England from the Postcode Address File

(PAF) contained in the 2010 National Statistics Postcode Directory, which we then collapse to the MSOA and LPA levels.

To measure the impact of Listed Buildings, in our baseline specifications we divide the number of Grade II Listed Buildings by the total number of residential addresses in each MSOA or LPA. This choice reflects our assumption that Grade II Listed Buildings are more likely to be residential dwellings than higher grades. As a robustness check we also use the total count of Listed Buildings in each MSOA as the numerator (see column (8) of Appendix Table 2).

To measure the impact of Conservation Areas, in our baseline specifications we divide the number of residential addresses that lay within Conservation Areas by the total number of residential addresses in each MSOA or LPA. This is possible because the postcode centroid allows us to identify which individual postcodes are within Conservation Areas and which are not. As a robustness check we use a measure based on the share of developed land in each MSOA that is within a Conservation Area (see column (7) of Appendix Table 2). The denominator in this robustness measure is the area of land in urban or semi-urban use in each MSOA, developed using data from the Land Cover Map of Great Britain 1990.

In general terms, our empirical estimations treat preservation policies as if they were time invariant. The justification for this assumption is that new preservation designations in our sample period comprise a very small proportion of the stock of Listed Buildings and Conservation Areas. Of the 8,349 Conservation Areas in our dataset, 302 (or 3.7%) were newly designated in the period 2005-2013 while 5,049 out of 376,025 (or 1.3%) Listed Buildings were added to the list in the same period. To ensure that this does not bias or attenuate out results we conduct a robustness check where we drop MSOAs that contained a newly designated Conservation Area as well as any buildings that were listed after 2005 from our counts of Listed Buildings (see column (6) of Appendix Table 2).

We use a third preservation policy, Green Belts, as a placebo test (see Appendix Table 3). Shapefiles for Green Belts are not released as officially-sanctioned data. However, the area of land within Green Belts for each Local Authority is released in spreadsheet format by the Department for Communities and Local Government. We also obtain a GIS map of Green Belts as they existed in 2011 from the website www.sharegeo.ac.uk, and estimate the number of residential addresses in land designated as Green Belt at the LPA-level using these two data sources.

Our control variables include a variety of trends and fixed effects. We use the 2001 Census to construct a series of share variables normalised by contemporaneous population at the MSOA-level: share of residents with degree, share employed, share owner-occupiers, share lone parents, share aged 45-59, share aged 60 or more. To take account of the possibility that the stock of housing could determine sensitivity of areas to energy prices, we extract Valuation Office Agency (VOA) data for the age (share built prior to 1945, between 1945 and 1964, 1965 and 1982, between 1983 and 1999 and share built after 2000) and type (detached, semi-detached, terrace, flat) of housing stock in each MSOA and LPA. These data date from 2014. We also generate additional time varying controls by allowing for flexible Travel to Work Area and household income trends. The latter is based on estimated MSOA household net income in 2004/5. The choice of this strategy reflects the unavailability of any time varying income data at the MSOA-scale.

In robustness checks, we replace the 2001 Census trends with linear time trends interacted with the same share variables calculated using the 2011 Census, as well as the change in the same share variables between these two Censuses (see columns (2) and (3) of Appendix Table 2).

Finally, in some specifications we control for urban-rural issues on the basis that rural places often do not have access to mains gas and will likely have a different mix of domestic energy types and exposure to fuel prices. We do so by dropping places where mains gas consumption is zero and also those places that were recorded as being in a “sparse” or “village” setting in the 2011 Census. We also interact a trend variable with the remaining rural-urban classifications, namely: Rural town and fringe; Urban city and town; Urban major conurbation; Urban minor conurbation.

Appendix Tables

Appendix Table 1
Summary Statistics: Additional MSOA Robustness Variables

	Obs.	Mean	Std. Dev. overall	Std. Dev. between	Std. Dev. within	Min.	Max.
Panel data							
Log lag energy price per kWh: alternative weighting	44,149	1.79	0.17	0.01	0.17	1.47	2.00
Log North Sea gas production (million cubic meters)	44,149	10.98	0.28	0.03	0.28	10.55	11.35
Cross-sectional data							
Planning Variables							
Share of LPA dwellings in Green Belt in %	5,665	1.95	4.01			0	36.75
Census 2011 Variables							
Share degree educated in %	5,665	22.42	9.79			3.51	62.62
Share lone parent in %	5,665	2.97	1.36			0.19	9.64
Share owner-occupier in %	5,665	64.54	17.11			7.58	96.53
Share ethnicity white in %	5,665	85.84	18.52			5.62	99.46
Share aged 45-59 in %	5,665	19.50	3.19			2.99	27.84
Share aged 60 or above in %	5,665	22.47	7.45			3.15	57.14
Share Manager, Professional, Assoc. Professional in %	5,665	40.46	12.72			11.67	83.92
Share employed in %	5,665	47.67	5.91			22.24	72.01

Appendix Table 2
Robustness Check: Alternative LHS & RHS Variables

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nature of differences from baseline:	---- Sample restriction ----			---- Trends ----		------ Planning measures ------			--- Demand shifter ---	
Log one year lagged energy price × Listed	0.0211***	0.0215***	0.0160***	0.0235***	0.0202***	0.0196***	0.0267***	0.0219***	0.0217***	0.0187***
	(0.00494)	(0.00454)	(0.00430)	(0.00458)	(0.00425)	(0.00433)	(0.00394)	(0.00431)	(0.00546)	(0.00390)
Log one year lagged energy price × Conservation Area	0.0197***	0.0174***	0.0150***	0.0145***	0.0165***	0.0180***	0.0127***	0.0167***	0.0188***	0.0164***
	(0.00404)	(0.00384)	(0.00387)	(0.00377)	(0.00407)	(0.00367)	(0.00326)	(0.00366)	(0.00462)	(0.00362)
Controls, Fixed Effects and Trends	√	√	√	√	√	√	√	√	√	√
Specific change relative to baseline spec:	No sample restriction	Weaker sample restriction	2011 Census trends	Δ2001-2011 Census trends	Replace linear trends with energy prices	Drops preservation policies since 2005	Share land in CA instead of share dwellings	All Listed Buildings instead of Grade II	IV energy price interactions with north sea gas production	Weight prices with national energy split in 2005
Observations	41,279	40,805	40,410	40,410	40,410	38,784	40,410	40,410	40,410	40,410
Adj. R-squared	0.946	0.972	0.986	0.986	0.985	0.985	0.985	0.985	0.985	0.985
Kleibergen-Paap F									4,318	

Notes: Standard errors clustered at LPA level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All policy variables are standardised.

Appendix Table 3
Robustness Check: Placebo using Green Belt

Approach:	--- Weighted ---		--- Stacked ---	
Dep Var:	------- Log domestic energy consumption per person -------			
	(1)	(2)	(3)	(4)
Log one year lagged energy price	-0.0024	-0.0024	0.0060	0.0070
× Share LPA dwellings in Green Belt	(0.00221)	(0.0221)	(0.00713)	(0.00702)
Log one year lagged energy price		0.0200***		0.0241*
× Grade II Listed per 100 dwellings		(0.00421)		(0.0135)
Log one year lagged energy price		0.0170***		0.0213**
× Share dwellings in Conservation Area		(0.00378)		(0.00901)
Controls, Fixed Effects and Trends	√	√	√	√
Observations	40,410	40,410	80,836	80,836
Adj. R-squared	0.985	0.985	0.996	0.996

Notes: Standard errors clustered at LPA level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All policy variables are standardised. Energy prices are lagged by one year.