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THE ENERGY COSTS OF HISTORIC PRESERVATION*

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THE ENERGY COSTS OF HISTORIC PRESERVATION

Abstract

We explore the impact of historic 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. Historic preservation policies increase private energy costs and the social cost of carbon per designated dwelling by around £11,600 ($19,100) and £2,400 ($4,000), respectively. These costs ought to be weighed against any benefits of preservation.

JEL classification: Q48, Q54, R38, R52.

Keywords: Historic preservation, 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 parts of 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.*, 2017; Been *et al.*, 2016), we know little about the costs these policies generate. In this paper, we quantify the foregone energy efficiency savings and the corresponding social cost of carbon. We find that they are substantial.

The theoretical mechanism is straightforward. In the absence of historic preservation policies, households 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 because they often mandate restrictions on the type and extent of changes that can be made to residential units ('dwellings'). Restrictions on say the types of windows that can be installed may increase the cost of adopting energy efficiency technologies or 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 historic preservation policies on domestic energy consumption in England. We focus on two well-established policies: 'Conservation Areas', which preserve entire areas of buildings and 'Listed Buildings', which preserve individual buildings. We collate a rich panel dataset at the neighbourhood-level ('Middle Layer Super Output Area'), spanning the years 2006-2013. During this period, energy prices, defined in our paper as a local weighted average of national gas and electricity prices per kilowatt hour, increased every year but one, and per capita energy consumption fell by around 20%.

In Figure 1 we plot a simple cross-sectional relationship, at the neighbourhood level, between per capita domestic energy consumption and Listed Buildings (per 100 dwellings). It indicates that more preservation is correlated with lower energy consumption. However, a naïve cross-sectional comparison does not compellingly identify the causal effect of preservation on energy consumption. This is partly because the prevalence of preservation is not randomly assigned across space. For example, Listed Buildings tend to be concentrated in older, richer and more urbanised areas.

One might try to overcome these endogeneity concerns by employing a panel regression with dwelling fixed effects. In such a model, changes in dwelling-specific energy consumption would be identified by changes in a dwelling's Listed Building-designation status (from 0 to 1), ceteris paribus. However, such an approach is infeasible because we only have cross-sectional neighbourhood-level data on the prevalence of historic preservation and because the vast bulk of preservation designations occurred before the 1990s. More importantly, it would fail to properly identify the full energy cost of preservation. This is because at the time of designation, the dwelling owners would have optimised energy efficiency, so the switch to designation (0 to 1) itself will not adversely affect energy efficiency and will not increase energy consumption. Only over time, as energy prices increase and/or energy efficiency technology advances, will the dwelling's original level of energy efficiency no longer be optimal and the preservation-induced constraints start to bite. Owners would then want to invest in energy efficiency improvements, yet the preservation-induced constraints would prevent them from doing so. This is what induces the energy costs of preservation and explains why our empirical approach focuses on changes in national energy prices over time, in a period of rapidly rising prices.

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 historic preservation. We capture this effect by interacting energy prices with the neighbourhood-level prevalence of preservation at the start of our sample period. Our focus on *rising* energy prices is therefore important for identification. When prices fall, there are no positive incentives to invest in energy efficiency improvements and the prevalence of historic preservation policies should not matter.

Using a fixed effects approach that controls for neighbourhood specific time-invariant unobserved characteristics, we first document that rising national energy prices induce a reduction in local energy consumption. Next, we explore the sensitivity of the price elasticity of energy consumption with respect to the incidence of historic preservation by interacting energy prices with the prevalence of preservation. In our baseline specification, we control for location and year fixed effects, linear time-trends interacted with neighbourhood characteristics as well as flexible trends for each commuting zone, and the neighbourhood's distance from the centre of the commuting zone. We also carefully control for the age and composition of the housing stock, thereby helping us to disentangle the effects of historic preservation policies from vintage effects.

We demonstrate that the energy-saving effect is significantly less pronounced in Conservation Areas and in places with higher concentrations of Listed Buildings. Using a conservative but plausible energy demand price elasticity point estimate (-0.48) obtained from the data, our findings suggest that a one standard deviation increase in the share of dwellings in Conservation Areas reduces the energy price elasticity by 3.5%, while a one standard deviation increase in the number of Listed Buildings reduces the elasticity by 4.4%. We provide evidence that the mechanism for this decline is the capacity of preservation policies to limit the uptake of home energy efficiency improvements.

In our empirical analysis, we face two sets of challenges that threaten a causal interpretation. Regarding the first set, a key concern is that the prevalence of dwellings in Conservation Areas and Listed Buildings may be correlated with income and other confounding factors. To address this concern, we first employ an alternative estimation approach, a 'stacked regression'. This allows us to control for all factors that commonly affect per capita domestic electricity and gas consumption in each neighbourhood-year cell. Second, we directly control for the interaction between energy prices and a number of socioeconomic neighbourhood characteristics addressing, for example, the concern that higher-income residents may respond less sensitively to energy price hikes. Third, we add neighbourhood pair-by-year fixed effects to the baseline specification, where pairs are adjacent observations when ranking neighbourhoods on a number of candidate confounders (e.g. house prices or income), allowing us to control less parametrically for these possible threats to identification. Fourth, we employ a placebo test using a preservation policy—Green Belt designation—that does not focus on protecting buildings and is not expected to affect energy efficiency investments. This allows us to test whether our findings might be driven by factors such as general planning restrictiveness or local socio-economic characteristics that correlate with extensive preservation. All these tests support our main findings.

A second set of challenges centres on how we specify energy and historic preservation variables. In our baseline specification, we estimate the response of domestic energy (gas plus electricity) consumption to one year-lagged energy prices, weighting prices across the two energy types in our data. Yet, the timing of the response may not be lagged by one year. We show that changes in the panel frequency or in the lag- or lead-structure of energy prices do not materially affect our findings. A related issue is how we measure energy use. In addition to the stacked approach, which explicitly separates gas and electricity, we show that our baseline estimates are insensitive to using domestic gas consumption as the dependent variable, and to instrumenting for energy prices with North Sea gas production. Finally, we show that alternative specifications of our preservation variables do not alter our findings.

Counterfactual simulations suggest that preservation policies in England during our study period imposed additional private costs of energy consumption with a present value of £23.2 ($38.3)[1] billion and a social cost of carbon of £4.8 ($7.9) billion. With two million designated dwellings, this equates to roughly £11.600 ($19,100) and £2,400 ($4,000) per designated dwelling, respectively. Limiting Conservation Areas and Listed Buildings to 1980 levels—a moderate reversion that would bring back levels to a point in time when dwellings with the highest heritage value were likely already designated—would have lowered total domestic energy consumption between 2006 and 2013 by 1.3%. This amounts to a monetary saving of £10.3 ($16.9) billion and a carbon reduction of 8.5 million metric tons of carbon dioxide equivalent.

Our paper ties into a recent literature on the house price effects of historic preservation. Ahlfeldt *et al.* (2017), like us, focus on designated Conservation Areas in England. They find 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. Been *et al.* (2016) explore historic preservation policies in New York City, also finding 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) explore the impact of historic preservation within Dutch cities, finding 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.* (2017) and Been *et al.* (2016) both suggest that historic preservation significantly increases prices of nearby dwellings, 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, factors other than supply constraints

[1] Our Pound Sterling cost estimates are based on average energy unit prices for 2013. At the year-end of 2013 one GBP (£) was worth 1.65 USD ($).

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, not all externalities are capitalised into property prices. One example is that some people may value the sheer existence of a historic building—such as the Cathedral of Notre Dame in Paris—even if they do not live close by. Our study highlights another: historic preservation limits energy efficient home improvements, thereby increasing energy consumption and generating greenhouse gas (GHG) emissions.

Our paper is also related to a growing literature on the energy and climate impacts of land use regulations. Glaeser and Kahn (2010) document a strong negative association between carbon dioxide emissions and land use regulations and point out that restricting new development in the cleanest areas effectively pushes new development towards places with higher emissions. Larson *et al.* (2012) trace the energy footprint of transportation, housing and land use policies, highlighting that, counterintuitively, minimum lot zoning may reduce energy consumption because it drives up the price of housing and causes household densities in the unregulated, inner parts of the city to rise. Finally, Larson and Yezer (2015) demonstrate that density limits and Green Belts can positively or negatively affect both city welfare and energy use. Our contribution to this literature is the careful empirical identification of energy consumption effects of historic preservation policies. To our knowledge, we are the first to evaluate and quantify the energy and climate costs of such policies.

Our findings have important implications for climate policy. In the UK, this is guided by the 2008 Climate Change Act, which legislates for an ambitious 100% (or 'net zero') reduction in GHG emissions by 2050. The 'least-cost path' to this target entails a major contribution from energy efficiency improvements in buildings, including designated dwellings. Our findings indicate that the extent of historic preservation in England signifies a considerable obstacle to achieving such an ambitious target. More generally, by demonstrating that preservation limits 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). Finally, another measure by which the UK hopes to meet its target is via a carbon tax, known as the Carbon Floor Price. Currently frozen at £18 ($30) per metric ton of carbon dioxide, this is projected to increase 'rapidly' after 2020. Our results suggest that individuals living in designated dwellings are unlikely to respond to a rising tax 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. The subsequent section describes the data, discusses our baseline specifications and presents our main results along with robustness checks and evidence of the proposed mechanism driving the results. In Section 4 we conduct a counterfactual analysis to provide a quantitative interpretation of our findings. Section 5 considers welfare implications. The final section concludes.

2. Institutional Setting and Theoretical Considerations

2.1. Historic Preservation Policies: Listed Buildings and Conservation Areas

The British 'development control' land use planning system dates back to the Town and Country Planning Act of 1947. Its main aim is urban containment. This is achieved through horizontal constraints on urban development ('green belts'), as well as vertical constraints (mainly height limits and 'view corridors'). Another characteristic of the system is the almost complete lack of fiscal incentives at local level to permit residential development (Hilber and Vermeulen, 2016). Britain's planning system differs starkly from the American zoning system or even the Continental European master planning system. In contrast to both of these systems, which are rule-based, Britain's planning system arbitrarily expropriates development rights. Each change of use of any land parcel (e.g., constructing a garage) has to undergo a rigorous local planning application process, which includes a consultation with neighbours. As such, there are no areas 'zoned' for residential purposes and any new development is subject to local political calculations. Even minor alterations are subject to 'Nimbyism' thus making the system very restrictive and uncertain in nature.

Britain's historic preservation policies are embedded within this planning system. Indeed, the preservation policies add a further layer of restrictiveness. Similar to 'historic district' designation in New York City (Been et al., 2016), 'Conservation Areas' were established to protect certain areas (typically urban or the core of a village) of special historic or architectural interest. The 'Listed Buildings' policy is a more radical form of preservation of entire individual buildings, i.e., of both the façade and the interior of a building. This policy is perhaps even more radical than the 'landmark status' applied to some properties in New York City. Such properties are subject to regulations that protect their historic nature while allowing owners to continue to use and maintain their properties.

The British historic preservation 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 is the Planning (Listed Buildings and Conservation Areas) Act 1990. According to Historic England, 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 areas of buildings rather than just individual buildings, and Listed Buildings can be found in Conservation Areas.

Figure 2 shows the distribution of Conservation Areas in England from data collected by Historic England in 2008 and 2012, at the Local Planning Authority scale. The time trend in the total number of Conservation Areas since the late-1960s is shown in Figure 3. 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 are distributed all over England (Figure 4). After rapid growth in the 1980s, the designation of new Listed Buildings also plateaued in the 1990s, at around 0.3 to 0.4 million Listed Buildings (Figure 5).

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

Historic 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.[2] However, preservation policies 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 policy standards. Households are also typically restricted in the extent to which they can reconfigure, redevelop, or alter the fabric of designated dwellings. One particular implication of preservation-induced restrictions 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 the policies. In many Conservation Areas, planning consents are required for external improvement projects. For example, many Conservation Areas are subject to locally-imposed regulations, known as '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 – as well as planning permission, changes require a separate consent known as a 'Listed Building consent' – and the restrictions also cover internal upgrades, e.g. cavity wall insulation. The planning guidance even states that households living in a Listed Building must consult with planning authorities before installing a new heating system or boiler. Thus, owners of Listed Buildings face additional delays (through planning consultations, and the planning process), potential costs (through planning fees, and pre-application fees) and uncertainty (through planning decisions), even for the simplest energy efficiency upgrades to their homes.

Some restrictions imposed by preservation policies may not prevent home energy efficiency improvements altogether but are likely to drive up costs. For instance, a homeowner living in a Conservation Area wishing to install new, energy-efficient windows needs to ensure that they are consistent not only with the character of the owner's dwelling but also with that of the surrounding buildings. Often, this obliges owners to install expensive timber windows, rather than much less costly and more energy-efficient aluminium or uPVC windows.[3] For Listed Buildings, this issue is compounded both because of the additional range of installations subject to planning authority consent, and the tighter nature of the approval process. We are not aware of any major changes to the restrictions during our sample period. While there could be local

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[2] Holman and Ahlfeldt (2015) point out that even if heritage value is fully capitalised into property prices, coordination failure is likely. This is because individual homeowners may be tempted to inappropriately alter their dwelling, thus free-riding on the historic character of nearby properties.

[3] Timber windows are typically 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 ($6,600 to $8,250), https://www.harrow.gov.uk/www2/documents/s61817/Revised%20PWPE_Appendix1.pdf.

variation in the application of exemptions applied in Conservation Areas (Article 4 Directions), such variation is likely to be small because the rules are essentially the same across England.

Figure 6 illustrates the proposed theoretical mechanism and its implications for the demand price elasticity and resulting energy consumption. The figure 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 negative 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 6, 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 respond to this shock in two ways. First, the price increase provides greater incentives to save more energy (e.g. by turning down the heating thermostat). 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 6—this equates to an increase in the demand for 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 in terms of amenities and housing stock but with one difference: the neighbourhood has a strict historic preservation policy that prevents new home energy efficiency installations altogether, implying a perfectly inelastic supply curve—illustrated in Panel B of Figure 6—in the market for such installations. Even though the energy price shock will also induce an increase in demand for installations, the policy prevents an uptake of more installations and hence, prevents an increase in energy efficiency. Consumers in the preserved location will still reduce their energy consumption, but less so, all else equal, than those in the non-preserved location. In the energy market, consumers in the preserved location thus have a more price inelastic demand for energy, 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-preserved neighbourhood, by the amount of ②.

2.3. Energy Price Dynamics and Path Dependency

While our theoretical considerations above are based on a static setting and are independent of the path of past energy price dynamics, our empirical analysis is dynamic in nature and the response of households to positive national energy price shocks can be expected to be path dependent; past energy price hikes drive earlier investment decisions and determine the stock and nature of existing energy efficiency installations. Moreover, the energy consumption-response to a price shock will depend on the availability and cost-effectiveness of energy efficiency installations at the point in time when a shock occurs. Our findings should be interpreted in this context.

Figure 7 documents that UK energy prices rose quickly between the mid-1970s and the early-1980s, but then fell steadily until 2006—the start of our panel. During this period of falling prices, there were several developments in energy efficiency technologies, including the widespread availability of loft and cavity wall insulation, and the introduction of uPVC-windows, while the energy efficiency of windows and boilers has been continuously improving over the last few decades. In sum, households in 2006 could access several technologies that were either unavailable or not cost-effective during the last comparable period of sustained energy price rises, from the mid-1970s to early-1980s. We thus anticipate a reasonably large scope for energy efficiency upgrades in response to rising prices during our sample period.

3. Empirical Analysis

3.1. Data

No dataset for England 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, our empirical analysis focuses on 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 neighbourhood-level, while the second combines the same policy measures, but with measures of the uptake of home energy efficiency installations at planning authority-level. We briefly describe the data below and display summary statistics for the two panels in Tables 2a and 2b. Appendix A provides full details.

The first panel describes domestic energy consumption per person, prevalence of preservation policies, and various control variables at neighbourhood-level. Our neighbourhoods are Middle Layer Super Output Areas, small area statistical units introduced after the 2001 Census. Each contains between 2,000 and 6,000 households. The domestic energy consumption per person[4] variable is generated at the neighbourhood-spatial scale by linking sub-national consumption statistics 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 (i.e. gas supplied by pipelines)—the two fuel types available in neighbourhood-level data.[5]

The second panel is constructed at planning authority-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 historic preservation and control variables. Because counts of home energy efficiency installations are unavailable at a finer spatial scale, by necessity the spatial units in this panel are England's 354 pre-2009 planning authorities.[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

[4] Households are not counted at neighbourhood-level and therefore we are unable to standardise by household.

[5] Some neighbourhood appear to have unfeasibly large year-to-year changes in energy consumption. These could plausibly result from measurement error or factors we do not observe, e.g. new connections to the gas pipeline. To ensure these outliers do not drive our results, in our main regressions we drop neighbourhood-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 Area-data for some planning authorities, we run regressions on 304 of the 354 planning authorities.

(because the upgrades we focus on are mostly durable) and in our baseline specifications we specify dependent variables based on installations in levels, controlling for household counts.

The HEED data do not contain domestic energy consumption, so 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 historic preservation policies. NEED contains data for energy consumption and some household and dwelling characteristics for almost four million dwellings in England.

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 by DECC. In our main specifications, we lag this price by a year because domestic energy consumers are arguably likely to take time to respond to changes in the price of energy, for example, in order to select and install energy efficiency measures.[7]

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 demand shifter 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.[8] The cost of gas and electricity hardly varies across the UK, presumably because consumers can switch between suppliers. Figure 8 shows national gas and electricity prices in real terms along with North Sea gas production. Both prices remained relatively flat 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 variables rely on the estimated proportion of residential addresses in each neighbourhood or planning authority that are covered by each of the policies. For both, the denominator is calculated from counts of residential addresses for each postcode in England. For Listed Buildings the numerator is the count of Grade II Listed Buildings in the neighbourhood or planning authority.[9] For Conservation Areas the numerator is calculated by allocating postcodes to polygons using shapefiles provided by Historic England and postcode

[7] We test alternative assumptions in our robustness checks (Section 3.5).

[8] 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.

[9] We use Grade II Listed Buildings only and not the higher grades (Grade II* and Grade I) because the latter are less likely to be in residential use. To support this claim, we examine the proportion of churches in the data using textual analysis of the Listed Building names. We assume churches contain the words "Church" or "Cathedral" but do not contain a number (typically a street address) or the words "Street", "Cottage", or "House". This approach suggests that churches represent 3% of Grade II Listed Buildings but 31% of Grade II* and Grade I Listed Buildings. The resulting measure – Grade II Listed Buildings per 100 dwellings – proxies for the local prevalence of *residential* Listed Buildings, which we are unable to observe directly. Alternative measures of Listed Buildings that attempt to exclude non-residential Listed Buildings based on text contained in the address field, are tested in Web Appendix Table 1; results are very similar to those generated when using our chosen measure.

centroids. Alternative measures are constructed from the same underlying data for robustness checks (see Appendices A and B).

3.2. Identification Strategy

We empirically test the extent to which historic preservation policies influence domestic energy consumption per capita and investments in home energy efficiency installations. Our focus is on dynamic effects because preservation policies reduce the viability or restrict the ability of households to respond to energy price shocks by installing energy efficiency measures.

The empirical set-up we adopt is consistent across the two panels (neighbourhood- and planning authority scale) 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 planning authority home energy efficiency panel below. The neighbourhood level panel is composed of all neighbourhoods in England (indexed by subscript *i*) spanning the years 2006 to 2013 (indexed by subscript *t*).

We first obtain benchmark estimates of the energy price elasticity:

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

We regress 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 neighbourhood fixed effects γ_{i}. Following the literature (e.g., Aroonruengsawat *et al.*, 2012) we also include log local wages w_{jt} (measured at the planning authority level (denoted *j)* since time-varying wage data are unavailable at the neighbourhood-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. Energy prices vary at the national level. Therefore, 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 historic preservation policies on price elasticities by interacting the energy price demand shifter p_{t-m} with time invariant measures of local historic 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, we standardise the planning variables by centring on the mean and dividing by the standard deviation throughout. Our goal is to estimate the effect of historic preservation policies on energy price elasticities rather than the elasticities themselves. Therefore, 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 national level, e.g. macroeconomic conditions or national policy changes to subsidise energy efficiency:

$$\mathrm{e}_{ijrt} = \beta_2 \mathrm{p}_{t-m} \times \overline{\mathrm{List}_i} + \beta_3 \mathrm{p}_{t-m} \times \overline{\mathrm{CA}_i} + \alpha_1 \mathrm{w}_{jt} + \gamma_t + \gamma_i + \textstyle\sum_{r=1}^{9} \delta_r \mathrm{D}_r \, \mathrm{t} + \varepsilon_{ijrt}. \quad (2)$$

This specification tests whether the prevalence of preservation policies conditions local energy demand responses to price changes. The coefficient β_1 estimated in equation (1) can be interpreted as the elasticity of domestic energy consumption with respect to real unit energy prices. As we standardise the preservation policy measures, the coefficients β_2 and β_3 represent the extent to which a one standard deviation increase in the share of residential Listed Buildings and the share of dwellings within Conservation Areas, respectively, modify this price elasticity. Our expectation is that, all else equal, 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 historic preservation. This could operate through a variety of channels. Koster *et al.* (2016) find that richer households in the Netherlands have strong preferences for historical amenities and sort into historic neighbourhoods. Rich individuals are likely to have a relatively price inelastic demand for energy and may also be more likely to own their homes. 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 controls, fixed effects and trends to the specification in equation (2). We first include variables in which linear time trends are interacted with time-invariant demographic and socio-economic characteristics. These comprise neighbourhood median household income in 2004 as well as variables drawn from the 2001 Census: share of residents with further education 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. These controls allow us to identify the impacts of historic 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).[10]

It is also possible that localised factors, such as temperature, could be driving energy consumption patterns, so we next include a full set of commuting zone (known in the UK as Travel to Work Areas) by year fixed effects. This 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 commuting zones 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 help us disentangle the effect of

[10] We cannot test whether our findings are different for owner-occupied versus rental dwellings because our data are measured at the neighbourhood-level and not the home-level. However, we control for linear trends interacted with the neighbourhood-wide share of owner-occupied homes.

historic preservation from effects associated with the vintage of properties, we 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 the omitted category being share detached), and a vector of neighbourhood building vintage variables (share built pre-1900 and between: 1900-1918; 1919-1929; 1930-1939; 1945-1964; 1965-1982; 1983-1999; with the omitted category being share built after 2000; 1940-1946 is missing as essentially no new homes were built during the Second World War and statistics are not available). The former set of trends reflects that different house types could imply different home energy needs or efficiency requirements. For example, detached houses usually have more external wall area than other dwelling types. 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 important in our setting where the housing stock comprises dwellings built using a range of building technologies and under various energy efficiency standards.[11] In turn, localised variation in these features could be relevant in determining home energy consumption and the scope for improvements in 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 historic preservation. To address this, and to control for other possible confounding factors, we introduce the interaction between the distance between the neighbourhood centroid and the population weighted centre of the commuting zone ($\overline{S_i}$) with our energy price demand shifter.

Our final control strategy reflects that households in rural and urban areas tend to rely on a different mix of fuels for heating homes. Over two million dwellings in England, or 10% of the total, are not connected to the gas transmission network (DECC, 2014). The vast majority of these dwellings are in rural areas, and are heated by alternative fuels, including electric heating and Liquefied Petroleum Gas. Thus, households living in such dwellings are more likely than those residing in urban areas to consume a different mix of fuels and be exposed to a different set of fuel prices, neither of which we observe. Off-gas-grid homes are also considered to be "hard-to-treat" in terms of improving home energy efficiency (Beaumont, 2007). Thus, we drop most rural neighbourhoods, that is, we drop neighbourhoods that have zero mains gas

[11] In general, the older the dwelling, the less likely it is that it was built with energy efficiency measures already installed. For example, dwellings built prior to the introduction of national Building Regulations in 1965 were rarely insulated, and there was no requirement to insulate dwellings until the 1980s. Dwellings 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 technologies. Thus, while older dwellings 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). Our vintage data only go back to 1900. However, this is not a material concern because 96% of dwellings built pre-1850 and 92% of those built between 1850 and 1899 are "hard to treat", compared to 47% of dwellings built between 1919 and 1944 (Building Research Establishment, 2008).

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.

Taking account of these strategies, our final specification is:

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

where our time effects $g(t)$ are captured by commuting zone -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 additional regressions in which we: (i) use an alternative estimation approach—stacked regression—that exploits the richness of our data; (ii) explore the robustness of our main approach to changing the panel frequency or the lag or lead price structure (i.e., varying *m*); (iii) explore the robustness of our findings to using alternative control trends, preservation policy measures, sample restrictions, demand shifters, and dependent variables; (iv) use Green Belts as a placebo test; and (v) adopt an approach—pairwise fixed effect regression—in which we control flexibly for neighbourhood-level characteristics.[12]

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 neighbourhood-year cell has two rows in the data. This permits us to adopt the following specification:

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

We regress the natural log of domestic energy consumption per capita for fuel type *f* on the policy variables interacted with the one-year lag (*m*=1) of the log national real price for fuel type *f* and a number of controls. These include local wages, fuel-specific neighbourhood fixed effects (γ_{fi}) as well as a set of fuel and year specific effects $g(f,t)$: year-by-fuel type fixed effects, neighbourhood-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 neighbourhood-year fixed effects, which partial out any factors that have a common effect on per capita gas and electricity consumption in each neighbourhood-year cell. As such, this approach—in which we rely on divergences in electricity and gas prices for identification—provides a powerful cross-check on our main specification.

Robustness checks (ii)-(iv) return to our main specification (equation (3)). All checks use domestic energy consumption and price variables that combine the two fuel types (gas and electricity). We conduct our placebo test with Green Belts (iv) using both the main specification and the stacked regression approach (equation (4)).

Our final robustness check (v) is designed to control flexibly for neighbourhood-level factors (such as income) or dynamic processes (such as gentrification) that could correlate with the extent of historic preservation and simultaneously determine the responsiveness of energy consumption to energy prices. To control for these factors less parametrically than in our

[12] We also provide further checks on outliers, and non-linearities, respectively, in Web Appendix Tables 2 and 3.

baseline regression, we use a pairwise fixed effect approach, repeating the specification in equation (3) but adding a neighbourhood pair-by-year fixed effect where pairs constitute adjacent observations when ranking neighbourhoods on various observable characteristics, e.g. average house prices, income, and various measures of gentrification.

3.3. Energy Price Elasticities

Before exploring the effects of historic preservation policies on domestic energy-related outcomes, Table 3 reports 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, our intention is to provide benchmark elasticities against which we can interpret the effects of historic 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). In this and all subsequent tables, except where indicated, standard errors are clustered at planning authority 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. 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 suggests that the coefficient on the one-year lag (-0.479) in Column 2 is a good approximation for the aggregate effect across all three price measures in Column 4, which together sum to -0.456. Based on these results, we adopt the coefficient from Column 2 as a benchmark elasticity against which we interpret subsequent results. The elasticity implies that for every 10% increase in the price of energy, per capita domestic energy consumption falls by 4.8%. While energy consumption in England appears to be relatively price elastic, our estimate is broadly comparable with previous estimates of short-term energy price elasticities.[13]

3.4 Baseline Specifications – Domestic Energy Consumption

Our analysis now turns to the extent to which historic preservation policies condition energy price elasticities. We introduce preservation policies by including interaction terms between the one-year lagged weighted energy price demand shifter and our measures of preservation policies. Each column of Table 4 refers to 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 neighbourhood and year fixed effects, regional trends, and planning authority-level wages as controls. Looking at Panels A to C of Column 1, it is evident that the interactions on Listed Buildings and Conservation Areas

[13] 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 evaluate the elasticity of energy (gas + electricity) consumption with respect to weighted energy prices. However, we obtain similar magnitudes when focusing on each fuel type separately.

are significant when each is included in turn but when both are included jointly, only the Listed Building 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 linear time trends interacted with demographic and socio-economic characteristics drawn from the 2001 Census and median net household income in 2004. In Column 3, we replace the year fixed effects by a set of commuting zone interacted with 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.

Given the scope for energy efficiency upgrades in older houses independent of the impact of historic preservation, in Column 4, we control for the housing characteristics (including age). However, the findings are essentially unchanged.[14] In Column 5, we condition out urban form issues by including the interaction between the distance from the neighbourhood- to the commuting zone -centre and the one-year lagged energy price as an additional control. The historic preservation policy coefficients are remarkably stable.

The final Column 6 of Table 4 includes the full set of controls but also drops rural neighbourhoods and additionally allows for idiosyncratic linear trends for each of the other rural-urban indicator classifications. Our preferred specification is Panel C.[15] This includes both preservation policies. 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 consumption with respect to 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 0.0199/0.479 = 4.2%. A one standard deviation increase from its mean value in the share of dwellings in Conservation Areas implies a reduction in the elasticity of 0.0164/0.479 = 3.4%. These comparisons represent conservative estimates of the effects of preservation policies because the benchmark price elasticity in the denominator is more elastic than estimates 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

[14] As the age profile of homes may be the result of historic preservation policies, the vintage controls could be interpreted as being bad controls. Yet, the lack of material differences in coefficients when we include these variables should allay concerns.

[15] We provide the full results for this specification in Web Appendix Table 4.

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 by a factor of around seven compared to dwellings in Conservation Areas. This is 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.

3.5. Robustness Checks

We first report findings from stacked regressions (equation (4)) in Table 5. Reassuringly, results indicate that the policy interactions remain statistically significant when the policy variables are entered individually, or when entered jointly 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 more than 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, we report historic preservation effects using lag energy price assumptions other than the one-year lag used in our baseline specification: 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, Column 4 uses the first and the second lag. Results suggest that the first lag of prices dominates and that using this lag structure should be sufficient to capture overall effects.[17] Under perfect information, rational households may respond to future expected energy prices rather than past prices. In Column 5, we test this by including the first lag and the first lead. We again find that the first lag dominates and the lead is not statistically significant. In Column 6, we compute a rolling weighted average of the current energy price and future energy prices over the subsequent nine years, where energy prices are actual prices (up to 2015), or else 2015 DECC forecasts (for 2016 and later); weights are based on discount factors using an annual discount rate of 3.5%.[18] We again find that the first lag dominates and the future price is not statistically significant. A related issue is that until now, our estimates for domestic energy consumption have been generated from year-on-year variations at the neighbourhood-level that deviate from the trends implied by the initial characteristics of the Census. One concern is that these changes are unlikely to be sufficient to induce households to adopt new technologies. To explore this possibility, Column 7 evaluates the long-term adjustment to energy price changes by including only the first and last year (i.e.

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[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 obtain near identical results when weighting the regressions with the consumption share of each fuel type in each neighbourhood in 2005.

[17] This is because, for each of the two preservation policies, the sum of coefficients from the two lags is very close in magnitude to the first lag alone. Our counterfactual results in Section 4 are extremely similar when we use the first lag alone or both lags together. For ease of interpretation, we proceed using the first lag alone.

[18] Weights given to energy prices in current and future years $\tau \in$ (t, t+9) are $w_\tau = \frac{df_\tau}{\sum_{\tau=t}^{\tau=t+9} df_\tau}$ where df_τ is the discount factor from using an annual discount rate of 3.5% i.e. $df_\tau = 1.035^{-(\tau-t)}$. Thus the discount factor for the current energy price is 1 and the discount factor for the energy price nine years ahead is 0.73.

2006 and 2013) of our panel and dropping the years in between. Results are largely consistent with our main results, albeit—as expected—somewhat larger.

We conduct a number of additional checks in Appendix B; the additional variables used in these are shown in Appendix Table 1 and the results are reported in Appendix Tables 2-4. In Appendix Table 2, we demonstrate that our findings are robust to using alternative (i) control trends including interacting energy prices (rather than linear trends) with average household net income at neighbourhood-level, Census characteristics, and dwelling types and ages, (ii) historic preservation policy measures, (iii) sample restrictions (dropping the only year in our sample with falling prices,[19] retaining outliers, and dropping London neighbourhoods), (iv) demand shifters, and (v) dependent variables. In Appendix Table 3, we re-run the models specified in equations (3) and (4) with a non-historic preservation policy measure—share of planning authority dwellings in Green Belts—that acts as a placebo. As expected, we find no significant results. In Appendix Table 4, we return to equation (3) but use pairwise fixed effects to control flexibly for potential confounders such as income or house price growth. Again, we find no material differences to our baseline results when using a strategy that relies on comparing places that are near-identical on these factors.[20]

3.6 Mechanism: Home Energy Efficiency

Our results so far imply that preservation policies reduce the energy price elasticity. In this sub-section, we evaluate whether the evidence supports our proposition that the effects of preservation policies are driven by a home energy efficiency channel, that is, some energy efficiency upgrades in designated dwellings may be either more expensive or fail to conform to regulations and hence, are technically illegal.

In Table 7, we report similar regressions to those in Table 4 but at the planning authority level, replacing the dependent variable with counts of all home energy efficiency installations in the HEED data. These 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: planning authority fixed effects, time-varying counts of households, planning authority-level wages, and additional demographic controls that are only available at the planning authority-level (share with further education degree or equivalent, share aged 16-44, and share aged 45+), as well as linear trends interacted with building type and the full set of vintage share variables. If individuals living in designated dwellings are less able to respond to higher energy prices by investing in home energy efficiency, we should expect the coefficients on the interaction between energy prices and the policy variables to 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 by 8,680 and 4,350 installations. Separating out specific installations illustrates that, in line with our priors, Conservation Area restrictions tend to bite

[19] The issue here, as highlighted in the introduction, is that we would not expect falling prices to incentivise investments in energy efficiency improvements regardless of the prevalence of historic preservation policies.

[20] In the Web Appendix we show that results are robust to dropping neighbourhoods with the highest and lowest intensity of preservation (Web Appendix Table 2), and that preservation policy effects can be found in neighbourhoods with varying degrees (quartiles) of preservation (Web Appendix Table 3).

on external changes while those on Listed Buildings are more pervasive. 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 show results only for 2006 to 2007 due to the data being restricted to this period. The findings are again consistent with our priors: the coefficients for both policies are larger in absolute terms for double glazing (external), albeit marginally insignificant for Conservation Areas, while effects on new heating systems and boilers (internal) are meaningful and significant for Listed Buildings but not for Conservation Areas.[21]

In Table 8 we evaluate the impact of home energy efficiency investments on domestic energy consumption using dwelling-scale energy consumption and installations data drawn from the NEED. Controlling for dwelling fixed effects and 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.[22] These results are consistent with a technology adoption channel driving the relationship between historic preservation policies and domestic energy consumption found in Table 4.

4. Counterfactual Analysis

To understand the implications of our findings, we use our models to simulate energy consumption during the 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 neighbourhoods, we capture effects in urban areas only. Hence, we are likely to underestimate England's total energy consumption.

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 neighbourhood, converting this into total domestic energy consumption and then summing up over the sample of neighbourhoods 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 dwellings that are affected by historic preservation policies. This allows us to assess the total impact of the 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 domestic energy savings that were not realised during our sample period due to preservation policies, by setting

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[21] These findings should be interpreted with some caution, both because of the more aggregated nature of the analysis and the lower quality of the underlying data compared to our first panel. Consistent with these reservations, when we normalise the dependent variables in these regressions by home counts or specify the dependent variable as log ratios (adapting the formulation used by Gillingham and Bollinger, 2017) the policies are individually significant when estimated in isolation but are not both statistically significant when they are estimated together: see Web Appendix Table 5.

[22] To provide further support for our proposed mechanism, we conduct an planning authority-level IV regression with domestic energy consumption per person as the dependent variable, the total number of installations in an planning authority as endogenous explanatory variable and the preservation policies interacted with the energy price demand shifter as instruments. These IV estimates support our mechanism in that they suggest that preservation policies affect energy consumption through an energy efficiency investment mechanism: see Web Appendix Table 6.

each policy to zero in turn and comparing the outcome to our baseline prediction. We find that cumulative 2006 to 2013 energy consumption (of *all* dwellings in our sample) declines by 1.7% if Conservation Areas are set to zero (Row 1); 1.2% if Listed Buildings are set to zero (Row 2); and, 2.9% if both policies are set to zero (Row 3). In Figure 1, we showed that areas with more preservation are associated with less – not more – domestic energy consumption in the cross-section. The results in Panel A of Table 9 convey instead that, after controlling for confounders, energy consumption in these areas would be substantially lower in the absence of preservation.

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; and, the unit costs of electricity and natural gas are 15.8p per kWh and 5.1p per kWh, respectively. Based on these assumptions, the two policies collectively cost residents roughly £5.6 ($9.2) billion over the period 2006-13 and led to an additional 19.2 million tonnes of CO_2 being emitted. In the final column, we demonstrate that, at almost 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 dwellings with high heritage value were already designated at that point in time.[23] During the 1980s, there was a major spike in the number of Listed Buildings (see Figure 5) due to a review of the Statutory List following public outcry at the demolition of London's (unlisted) Art Deco Firestone tyre factory, in 1980. 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 31,000 GWh. This implies a cumulative saving to households of roughly £2.5 ($4.1) billion and 8.5 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 welfare implications of our empirical findings. There are at least five types of *benefits* related to heritage and designation. First, an internal heritage effect, b_{IH}, i.e., a value attached to historic dwellings irrespective of designation. Second, external localised heritage effects, b_{EH}, i.e., a value attached to dwellings nearby with views of historic dwellings. Third, wider external benefits, e.g., the existence value of historic dwellings (Wright and Eppink, 2016), b_{EV}, which again may apply irrespective of designation. Fourth, a value for designated historic dwellings, 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

[23] Ahlfeldt *et al.* (2012) find 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.

designation. Fifth, a value attached to dwellings with views on designated dwellings, b_{VD}. If designation has an inherent value for nearby owners, then $b_{VD} > b_{EH}$, or we can denote the *external* heritage designation *premium* as $b_{EDP} = b_{VD} - b_{EH}$.

Maintaining heritage value and complying with preservation restrictions also incurs costs, which may be neglected by policy makers. First, there are two types of internal costs associated with heritage. Some, 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 dwellings have internal costs, c_{DE} and c_{DO}, where c_{DO} includes the increased costs associated with, e.g., obtaining planning permission. 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 negative externalities such as increased GHG emissions. Third, there may 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 thus reducing housing consumption in England.

Recent research has focused mainly on the benefits of historic preservation, with empirical work largely based on house price data. Koster *et al.* (2016) estimate the premium for houses with views of designated buildings, i.e., b_{VD}, at around 3.5%. Additional results suggest that 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.[24] They also find a weak positive effect of designation on property prices just outside Conservation Areas (i.e., $b_{EDP} = b_{VD} - b_{EH} > 0$). For New York, Been *et al.* (2016) find that historic designation boosts the value of properties immediately outside the designated district, by nearly 12%, which is substantially 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 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.[25]

On the cost side, Been *et al.* (2016) document that where the value of the option to build unrestricted is higher, designation has a less positive effect on property values within the district. This suggests larger, other internal costs, c_{DO}. Similarly, Ahlfeldt *et al.* (2012) find a zero effect of designation on house prices inside Conservation Areas (i.e., $b_{EDP} + b_{IDP} - c_{IDE} - c_{IDO} = 0$), leading them to conclude that the private benefits (arising from historic preservation) and costs associated with designation (e.g., in the form of higher maintenance costs or lower energy efficiency) may perfectly offset each other. This is suggestive of localised Pareto efficiency. However, similar to Koster *et al.* (2016) they neither separately estimate the

[24] Also see Holman and Ahlfeldt (2015), Ahlfeldt *et al.* (2012), and Ahlfeldt and Holman (2018).

[25] Koster and Rouwendal (2017) use temporal variation in investments in cultural heritage in the Netherlands to identify the impact of such investments on prices of houses not covered by designation.

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 £5.6 ($9.2) billion in additional energy bills over the period from 2006 to 2013, around £0.7 ($1.1) billion annually, or, in perpetuity[26], £23.2 ($38.3) billion assuming a discount rate[27] of 3%.This is equivalent to a £348 ($574) increase in annual energy bills for each of the two million dwellings covered by historic preservation policies in England. Expressed as a proportion of house prices and to the extent that higher energy bills are fully capitalised into lower house prices, an average house price in Conservation Areas of around £240,000 ($396,000) implies a price effect of -4.8% (roughly £11,600 ($19,100)). 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).[28]

To quantify the external policy cost associated with designation, c_{ED}, we use an estimated marginal abatement cost of GHG emissions of £60 ($99) (following DECC (2015), the non-traded, 'central range' price for 2013 is £61 ($100) in 2015 prices. We deflate this to 2013 prices using the GDP deflator). This implies a social carbon cost of historic preservation policies of around £1.2 ($1.9) billion over the period 2006-2013, around £144 ($238) million annually (or in perpetuity, £4.8 ($7.9) billion). These totals are, respectively, equivalent to an annual social cost of £72 ($119) (or in perpetuity £2,406 ($3,970)) per designated dwelling. Although these costs will not be capitalised into house prices, we note that they equate to roughly 1% of the average value of a house in Conservation Areas. If we only consider a relaxation of historic 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 £520 ($858) million—or around £2.2 ($3.6) billion in present value terms.

If we take the finding in Ahlfeldt *et al.* (2017) 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 historic preservation as the outcome of localised decision-making. There are, however, at least two 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

[26] This is a simplifying assumption. It highlights the fact that the foregone energy efficiency savings do not stop in 2013 but will continue into the future. It ignores, however, the fact that the estimated differences in energy costs are context specific, that is, they depend on an evolving stock of energy efficiency installations, a particular history of energy price dynamics, the lifespan of energy efficiency technologies and the future rate of innovation in such technologies (see Section 2.3). Whether the cost actually realised ex post (i.e., in perpetuity) of preservation policies is larger or smaller than our estimated present value is not per se clear.

[27] We apply a discount rate of 3% throughout. The HMT Green Book suggests a discount rate of 3.5% for the first 30 years and declining discount rates thereafter. Our discount rate in perpetuity of 3% is a simplified approximation of this schedule but with the advantage of making our calculations accessible and is consistent with empirical estimates of housing market discount rates in the UK in Bracke *et al.* (2018) and Koster and Pinchbeck (2018). In estimating the social cost of carbon, we also assume a constant carbon price over time.

[28] 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).

costs associated with general equilibrium effects, c_{GE}, due to regulatory supply constraints (including those imposed by historic 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 historic preservation.

6. Conclusions

Historic preservation policies are widespread across Europe and parts of North America. The external benefits of these policies are well documented. At the same time, governments around the world have set ambitious energy saving and GHG emissions reduction 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 dwellings 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 GHG emissions, ought to account for the unintended consequences of regulations induced by historic preservation policies. Potential exemptions from the restrictions governing Conservation Areas and Listed Buildings could be made for energy efficiency upgrades. Such exemptions may work well for internal improvements in Listed Buildings; exemptions for external alterations must balance reductions in external costs against reductions in external benefits.

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TABLES

Table 1
Historic Preservation Policies:
Planning Consents and Home Energy Efficiency Improvements

	Not Listed or CA	Conservation Areas	Listed Buildings
Replacement boiler/heating	No consent needed	No consent needed	Listed Building consent may be required; consult with planning authority
New boiler/heating	No consent needed	No consent needed	Listed Building consent may be required; consult with planning authority
New doors and windows	Planning consent required for: some flats*	Planning consent required for: some flats*; homes under relevant Article 4 Directions, especially for front facing windows	Planning and Listed Building consents are required
Loft insulation	No consent needed	No consent is usually required; consult with planning authority	Listed Building consent may be required; consult with planning authority
External wall insulation	No consent is usually required**	Planning consent is required	Planning and Listed Building consents are required
Cavity wall insulation	No consent needed	Planning consent may be required	Planning and Listed Building consents are likely required: consult with planning authority
Wind turbine	No consent usually required	Planning consent required for: places facing a highway, homes under relevant Article 4 Directions	Planning and Listed Building consents are required
Solar panels	No consent needed	Planning consent required for: places facing a highway, homes under relevant Article 4 Directions	Planning and Listed Building consents are required
Ground & Air source heat pumps	No consent needed	Planning consent may be required; consult with planning authority	Planning and Listed Building consents are required

Notes:

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

** Since January 2013 external wall insulation has been classed as an alteration for the purposes of "permitted development", meaning planning permission is not required.

Planning consent is a permission to proceed with a proposed development. Responsibility for granting permission generally lies with local planning authorities (usually the planning department of the district or borough council). An application for planning permission may be refused. Planning applications are subject to fees: the standard planning application fee is currently £206 ($356).

Article 4 Directions: These impose additional restrictions in many Conservation Areas by withdrawing specified permitted development rights.

Listed Building Consent: These are separate from planning permissions i.e. in some cases both consents may be required. Listed Building consents are not subject to additional fees, although where a planning consent is required, the usual fee will apply.

Consultations with planning authority: Many authorities charge for pre-application advice e.g. for advice on Listed Building consents fees range from nominal amounts up to £3,500 ($5,775). Source: https://www.designingbuildings.co.uk/wiki/Charging_for_Listed_Building_Consent_pre-application_advice#Fees_or_exclusions_for_others_services.

Building regulations approval is needed for changes to homes irrespective of whether planning consent is required. Building regulations are standards for the design and construction of buildings that ensure health and safety in those buildings. A local authority building control approval verifies modifications are (or will be) in compliance with these standards. Building control fees vary by planning authority. For example, the fee for replacing under 10 windows in Liverpool in 2014 was between £135-210 (£270-420). Various Approved Schemes have operated since 2001. Using a tradesman registered under an Approved Scheme obviates the need to apply for building regulation approval. Building regulation requirements may be varied in some cases for Listed Buildings and for homes in Conservation Areas.

Table 2a
Summary Statistics: Neighbourhood-Level 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 1900 in %	5,665	15.78	16.75			0	90.14
Share dwellings built 1900-1918 in %	5,665	5.69	8.76			0	85.10
Share dwellings built 1919-1929 in %	5,665	5.41	7.77			0	93.56
Share dwellings built 1930-1939 in %	5,665	11.68	13.59			0	96.24
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	13.71	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 commuting zone centre (km)	5,665	0.11	0.08			0.001	0.62
N'hood 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: Planning Authority-Level 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 boilers	604	896	1,052	970	408	84	14,245
Wall insulation per dwelling	1,510	0.06	0.04	0.03	0.03	0	0.25
New loft insulation per dwelling	1,510	0.02	0.01	0.01	0.01	0	0.11
Double glazing per dwelling	604	0.08	0.03	0.02	0.02	0	0.22
Heating systems per dwelling	604	0.02	0.01	0.01	0.01	0	0.06
New boilers per dwelling	604	0.01	0.01	0.01	0.01	0	0.06
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 planning authority male FT real median wage	-0.0582***	-0.0210	-0.0393**	-0.0193
	(0.0188)	(0.0161)	(0.0165)	(0.0163)
Neighbourhood 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 planning authority 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***	0.0294***	0.0302***	0.0298***
× Grade II Listed per 100 dwellings	(0.00340)	(0.00287)	(0.00274)	(0.00334)	(0.00330)	(0.00449)
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***	0.0206***	0.0206***	0.0211***
× Share dwellings in Conservation Area	(0.00621)	(0.00355)	(0.00363)	(0.00322)	(0.00323)	(0.00338)
Adj. R-squared	0.981	0.986	0.987	0.988	0.988	0.985
PANEL C: Both Historic Preservation Policies						
Log one year lagged energy price	0.0580***	0.0292***	0.0269***	0.0245***	0.0253***	0.0199***
× Grade II Listed per 100 dwellings	(0.00379)	(0.00342)	(0.00326)	(0.00342)	(0.00332)	(0.00444)
Log one year lagged energy price	0.0109	0.0129***	0.0105**	0.0144***	0.0143***	0.0164***
× Share dwellings in Conservation Area	(0.00765)	(0.00435)	(0.00418)	(0.00335)	(0.00329)	(0.00350)
Adj. R-squared	0.982	0.986	0.987	0.988	0.988	0.985
Controls, Fixed Effects and Trends						
Log planning authority wages	√	√	√	√	√	√
Neighbourhood fixed effects	√	√	√	√	√	√
Linear time trend x Region	√	√	√	√	√	√
Year fixed effects	√	√				
2001 Census and 2004 income linear trends		√	√	√	√	√
commuting zone -by-year			√	√	√	√
Building age & type linear trends				√	√	√
Distance to commuting zone centre x energy price					√	√
Drop rural neighbourhoods & rural-urban linear trends						√
Observations	44,149	44,149	44,149	44,149	44,149	40,410

Notes: Standard errors clustered at planning authority 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 pre-1900, share built between 1900 and 1918, share built between 1919 and 1929, share built between 1930 and 1939, share built between 1945 and 1964, share built between 1965 and 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 (Stacked Regression)

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)
Log one year lagged energy price	0.0393***		0.0267*
× Grade II Listed per 100 dwellings	(0.0121)		(0.0137)
Log one year lagged energy price		0.0300***	0.0231**
× Share dwellings in Conservation Area		(0.00765)	(0.00863)
Controls, Fixed Effects and Trends			
Neighbourhood-by fuel type fixed effects	√	√	√
Region-by fuel type linear trends	√	√	√
Neighbourhood-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 commuting zone centre x energy price	√	√	√
Drop rural neighbourhoods & 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 planning authority 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 per person	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Current prices	Second lag	Current & first lag	First & second lag	First lag & first lead	First lag & rat. exp.	2006 & 2013
Log weighted energy price							
x Grade II Listed per 100 dwellings	0.0237***		-0.00029			0.0217***	0.0262***
	(0.00579)		(0.00631)			(0.00580)	(0.00594)
x Share dwellings in Conservation Area	0.0198***		0.00503			0.0134***	0.0178***
	(0.00380)		(0.00710)			(0.00370)	(0.00439)
Lag 1: Log energy price							
x Grade II Listed per 100 dwellings			0.0202***	0.0130**	0.0193***		
			(0.00483)	(0.00518)	(0.00407)		
x Share dwellings in Conservation Area			0.0130*	0.0109***	0.0163***		
			(0.00686)	(0.00395)	(0.00519)		
Lag 2: Log energy price							
x Grade II Listed per 100 dwellings		0.0157***		0.00713*			
		(0.00440)		(0.00369)			
x Share dwellings in Conservation Area		0.0156***		0.00873**			
		(0.00358)		(0.00405)			
Lead 1: Log energy price							
x Grade II Listed per 100 dwellings					0.00124		
					(0.00633)		
x Share dwellings in Conservation Area					0.00018		
					(0.00627)		
Forward looking: Log energy price						-0.0295	
x Grade II Listed per 100 dwellings						(0.00373)	
						0.0420	
x Share dwellings in Conservation Area						(0.00347)	
Controls, Fixed Effects and Trends	√	√	√	√	√	√	√
Observations	40,410	35,259	40,410	35,259	40,140	40,140	9,764
Adj. R-squared	0.985	0.986	0.985	0.986	0.985	0.985	0.978

Notes: Standard errors clustered at planning authority level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All policy variables are standardised. Energy prices lags or leads 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	-8,679***	-1,657***	-664***	-1,203***	-859***	-958***
× Grade II Listed per 100 dwellings	(2,464)	(547)	(233)	(589)	(177)	(254)
Log one year lagged energy price	-4,353*	-1,347**	-108	-1,076	163	-319
× Share dwellings in Conservation Area	(2,525)	(567)	(257)	(745)	(197)	(234)
Log household count	3,159	751	371	1,507	544	161
	(4,103)	(931)	(433)	(1,386)	(379)	(399)
Controls, Fixed Effects and Trends						
Planning authority 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	0.874	0.811	0.939	0.934	0.854

Notes: Standard errors clustered at planning authority level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Sample includes 304 planning authorities 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.

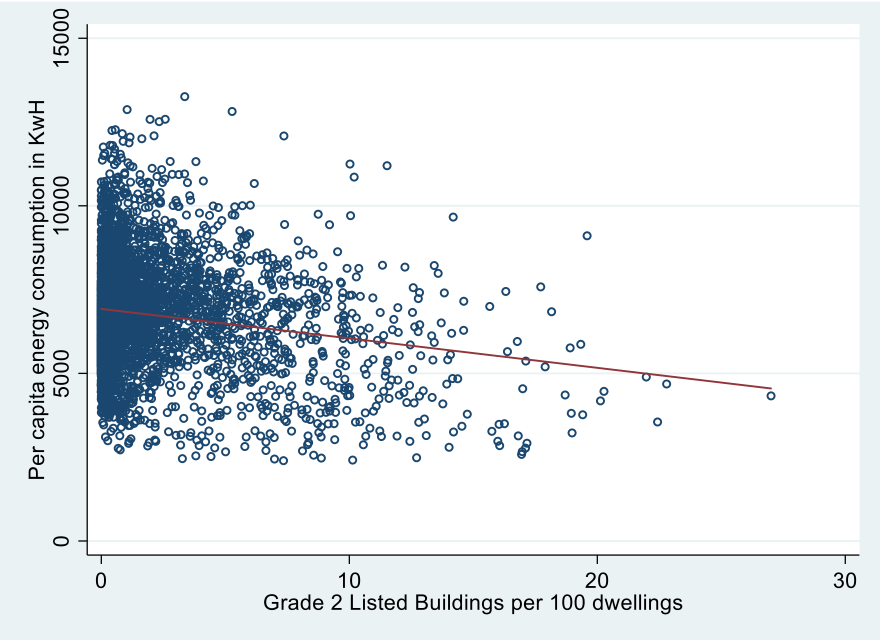
Table 9
Counterfactual Scenarios

	Total Gas + Electricity (GWh)	**Predicted GWh 2006 -2013 cumulative**	**Difference GWh**	**Difference £ million**	**Difference $ million**	**Difference CO_2 (MtCO2e)**	**Difference %**
	Baseline Prediction	2,440,836					
	(Actual Energy consumption	2,440,785)					
Panel A: Remove All Historic Preservation Policies							
(1)	Conservation Areas	2,399,426	-41,410	-3,308	-5,459	-11.4	-1.7%
(2)	Listed Buildings	2,411,330	-29,506	-2,357	-3,889	-8.2	-1.2%
(3)	Both Policies	2,371,161	-69,675	-5,566	-9,185	-19.2	-2.9%
Panel B: Reduce to 1980 Levels							
(4)	Conservation Areas	2,425,469	-15,367	-1,228	-2,026	-4.2	-0.6%
(5)	Listed Buildings	2,425,210	-15,627	-1,248	-2,060	-4.3	-0.6%
(6)	Both Policies	2,409,989	-30,848	-2,464	-4,066	-8.5	-1.3%
Panel C: Reduce by 1 Standard Deviation							
(7)	Conservation Areas	2,416,402	-24,435	-1,952	-3,221	-6.8	-1.0%
(8)	Listed Buildings	2,419,068	-21,768	-1,739	-2,869	-6.0	-0.9%
(9)	Both Policies	2,395,062	-45,774	-3,657	-6,034	-12.6	-1.9%
Panel D: Increase by 1 Standard Deviation							
(10)	Conservation Areas	2,514,147	73,310	5,857	9,664	20.3	3.0%
(11)	Listed Buildings	2,530,531	89,694	7,166	11,823	24.8	3.7%
(12)	Both Policies	2,606,551	165,715	13,239	21,844	45.8	6.8%

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 neighbourhoods in the sample timeframe. The average unit prices for electricity and gas are taken from DECC publications for 2013 paying on credit, 15.8 pence (26 cents) per kWh electricity and 5.1 pence (8.4 cents) per kWh domestic gas.

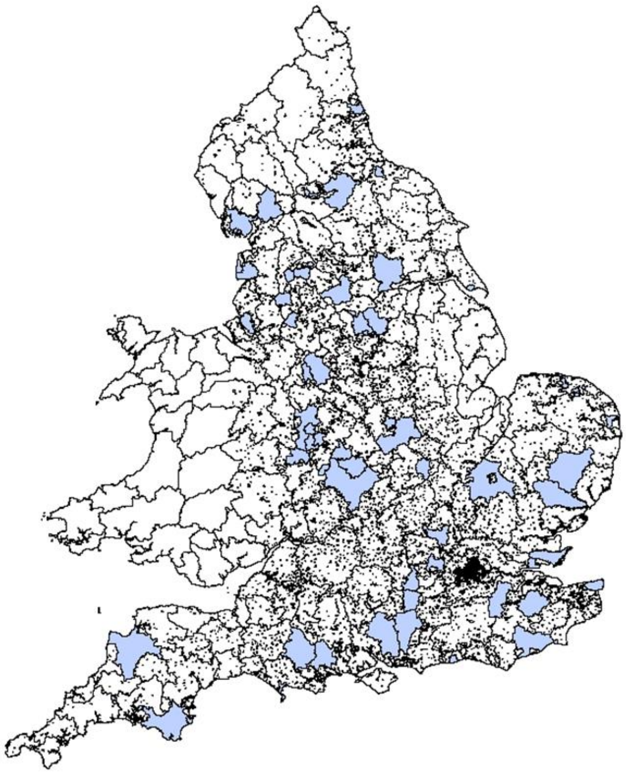
FIGURES

Fig. 1
Cross-Sectional Correlation between Listed Buildings and Domestic Energy Consumption



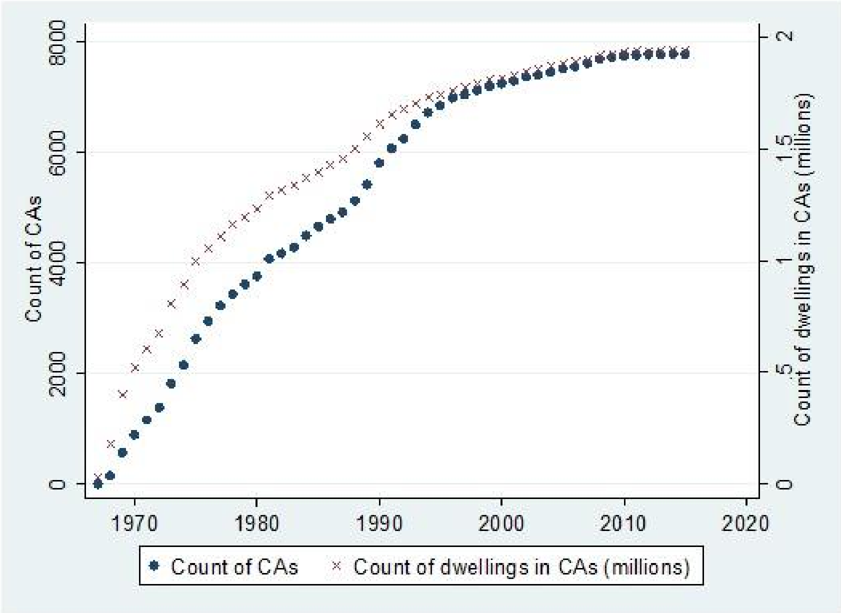
Notes: Measured at neighbourhood-level. Red line = best fit. Correlation = -0.21.
Sources: Historic England and DECC.

Fig. 2
Conservation Areas in England



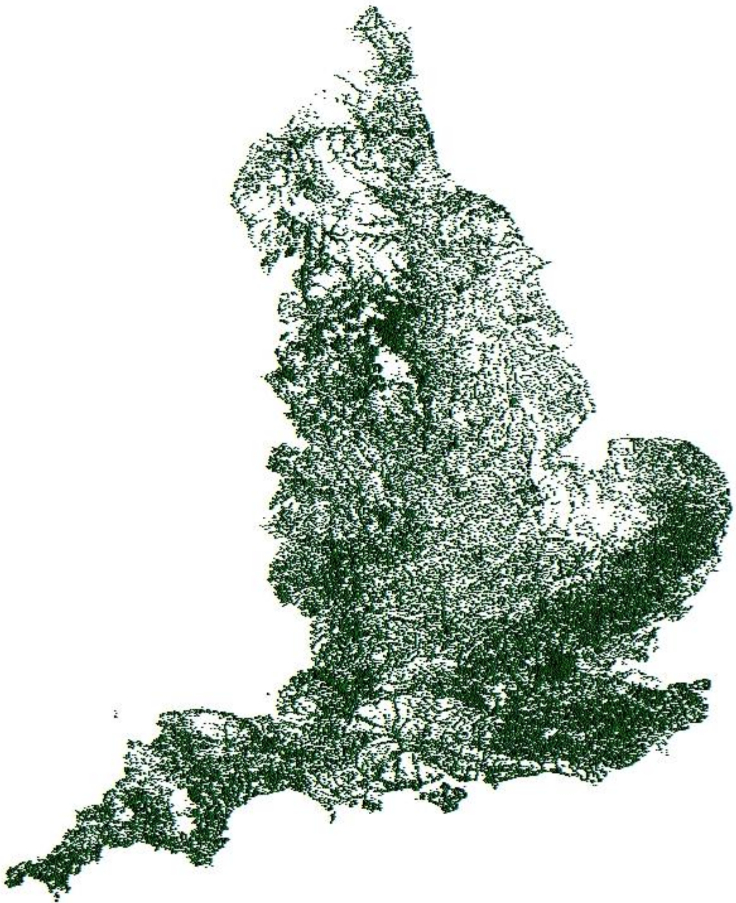
Note: Data missing for 50 planning authorities (blue).
Source: Historic England.

Fig. 3
Conservation Areas by Year of Designation



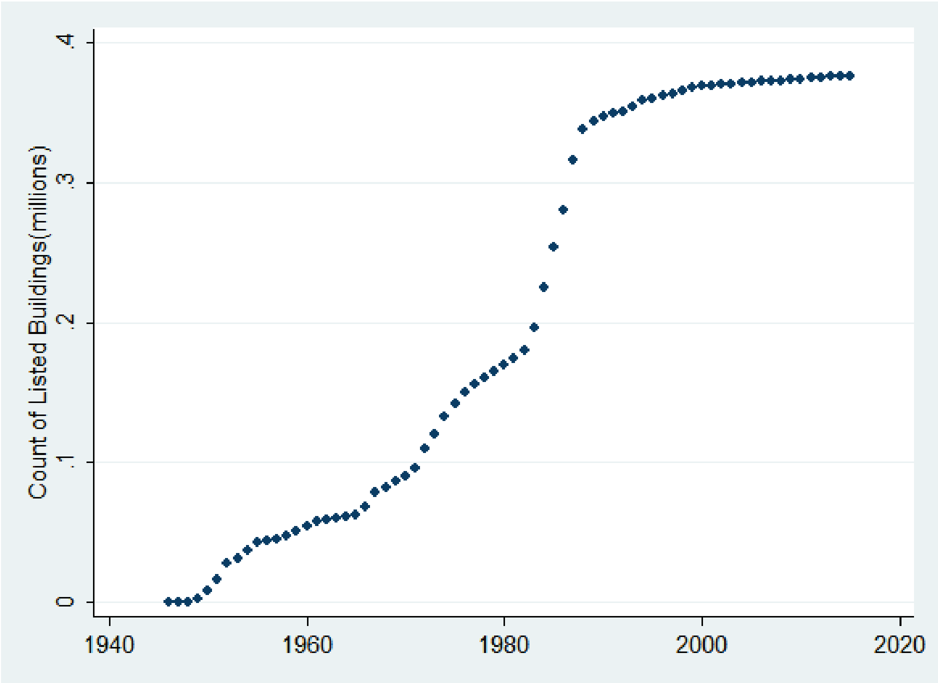
Source: Historic England.

Fig. 4
Listed Buildings in England



Source: Historic England.

Fig. 5
Listed Buildings by Year of Listing



Source: Historic England.

Fig. 6
Impact of Strict Historic Preservation Policy on Investments in Home Energy Efficiency Investments and Energy Consumption

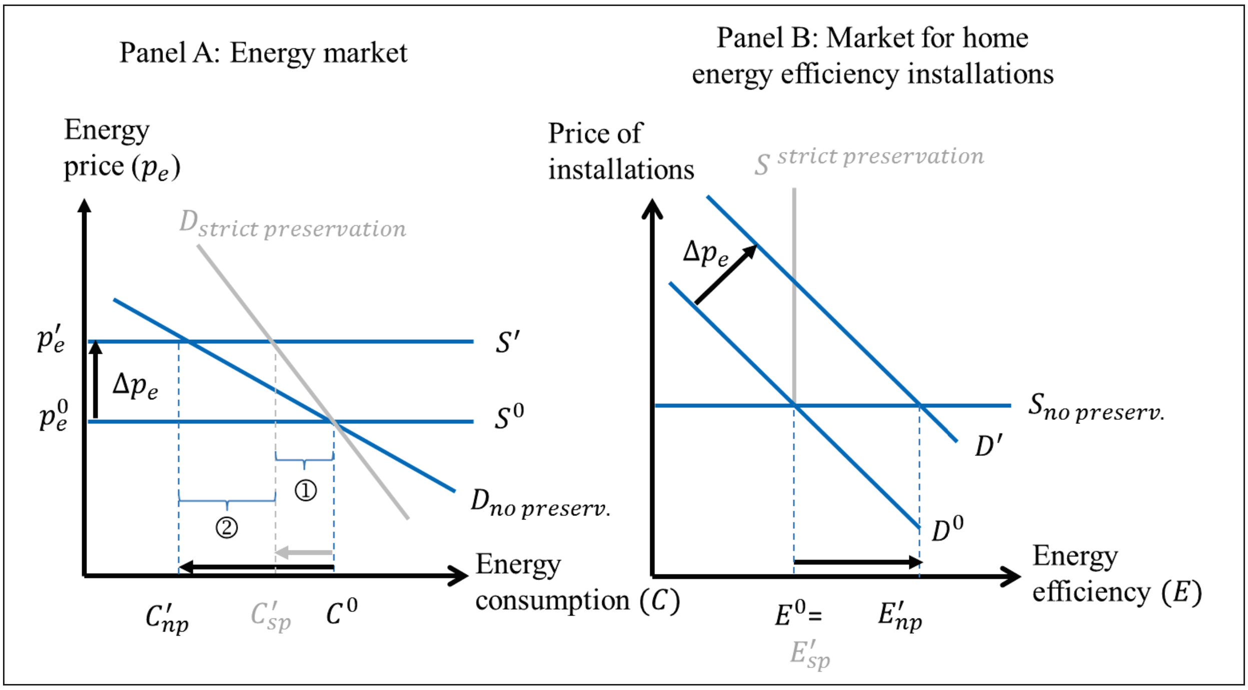
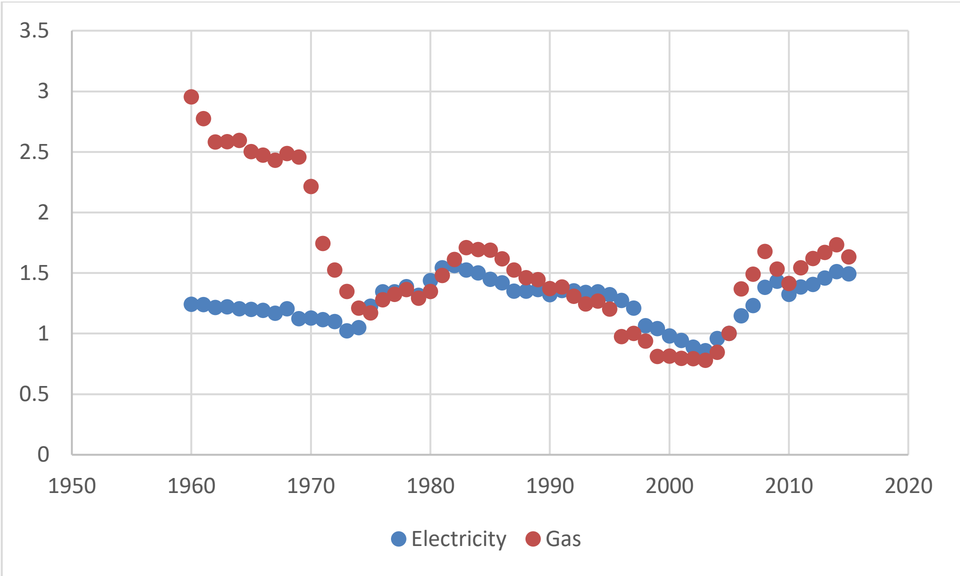
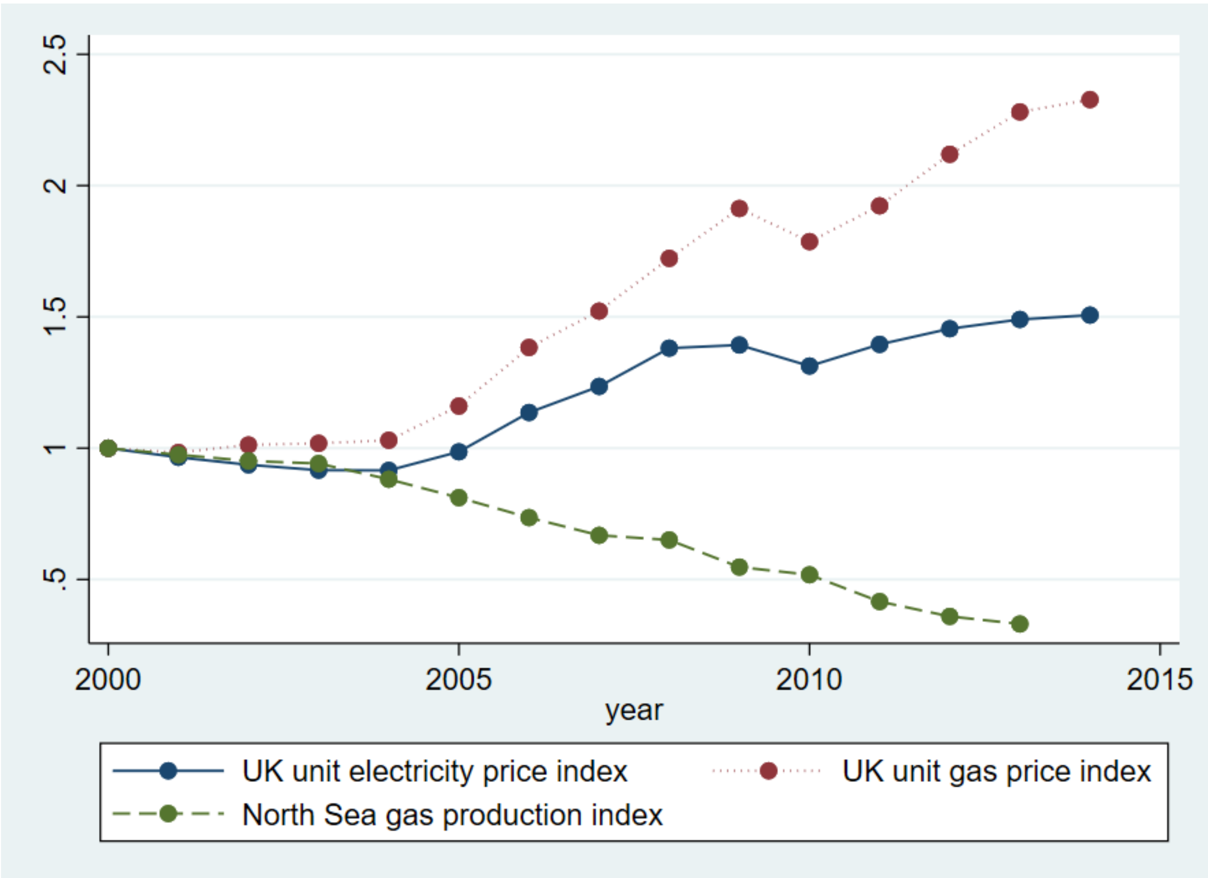


Fig. 7
UK Real Retail Electricity and Gas Price Indices, 1960-2015



Note: Year 2005 is normalised to 1.
Source: Digest of UK Energy Statistics (DUKES).

Fig. 8
UK Real Energy Unit Costs and Production Indices 2000-2014



Note: Year 2000 is normalised to 1.
Source: DECC.

APPENDICES

Appendix A: 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 domestic energy consumption, historic preservation policies, and control variables at the Middle Layer Super Output Area (neighbourhood) spatial scale. Middle Layer Super Output Areas are neighbourhood-level statistical geographies introduced following the 2001 Census. The 6,781 neighbourhoods 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 publicly 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 neighbourhood per year in kilowatt hours (kWh) between 2006 and 2013.[29] 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 neighbourhoods that lack 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.[30]

We also provide a panel analysis of home energy efficiency installations at the planning authority-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. The data is collected from surveys, and the data providers warn that it cannot necessarily be regarded as representative of the housing stock as a whole. This is because much of the data comes from government-led installation programmes (such as CERT, CESP and EAP). As a result, it is biased towards measures installed in those schemes, such as insulated cavity walls and lofts. Home energy efficiency installations are not available to us at the neighbourhood-level, so by necessity the spatial units in this panel are the 354 pre-2009 planning authorities in England. The panel runs only from 2005 to 2010 after which planning authorities 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

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

[30] Although the gas data are weather corrected, unlike the electricity data, DECC (2014, 34) reports that *"Despite these differences, the combined electricity and gas [data] 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"*.

household counts, share with degree education, and FT male median wages from NOMIS, and population age groups based on information obtained from the ONS.

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. Real 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 neighbourhood-specific weights given by the share of each energy type consumed in the neighbourhood in 2005, i.e. the gas weight for a neighbourhood equals gas consumption in that neighbourhood in 2005 divided by total gas and electricity consumption in that neighbourhood in 2005. As a robustness check we use weights based on the time varying national average share of energy consumption for all neighbourhoods in our sample. In both cases, weighted average prices are converted into constant 2013 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 historic preservation policies: Conservation Areas and Listed Buildings. We obtain two shapefiles (for 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 neighbourhoods for which we have Conservation Area data.

A dataset of Listed Buildings is downloaded from the Historic England website. As 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 neighbourhood- and planning authority-level from this information. Our principal measures are based on the estimated proportion of residential addresses in each neighbourhood or planning authority 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 contained in the 2010 National Statistics Postcode Directory, which we then collapse to the neighbourhood and planning authority 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 neighbourhood or planning authority. 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 neighbourhood as the numerator (see Column 6 of Appendix Table 2). Further checks, in which we use the text contained in the address field to remove non-residential Listed Buildings, are reported in the Web Appendix.

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 neighbourhood or planning authority. 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 neighbourhood that is within a Conservation Area (see Column 5 of Appendix Table 2). The denominator in this robustness measure is the area of land in urban or semi-urban use in each neighbourhood, developed using data from the Land Cover Map of Great Britain 1990.

In general, our empirical estimations treat historic preservation policies as if they were time invariant. The justification for this assumption is that new historic 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 verified robustness to dropping neighbourhoods that contained a newly designated Conservation Area as well as any buildings that were listed after 2005 from our counts of Listed Buildings (see an earlier working paper version of this study: Hilber *et al.*, 2017).

We use a third—non-historic—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 planning authority-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 neighbourhood-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 pre-1900, share built between 1900 and 1918, share built between 1919 and 1929, share built between 1930 and 1939, share built between 1945 and 1964, share built between 1965 and 1982, share built 1983-1999 and share built after 2000) and type (detached, semi-detached, terrace, flat) of housing stock in each neighbourhood and planning authority. These data date from 2014. We also generate additional time varying controls by allowing for flexible commuting zone and household income trends. The latter is based on estimated neighbourhood household net income in 2004/5. The choice of this strategy reflects the unavailability of any time varying income data at the neighbourhood-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 1 and 2 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 those places that were recorded as being in a "sparse" or "village" setting in the 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 B: 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 A.

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. One potential concern with our baseline specification could be that we do not adequately control for correlated trends in energy consumption. To mitigate this, Panel A of Appendix Table 2 demonstrates that our findings are largely insensitive to alternative trend specifications, by replacing 2001 Census trends in Column 1 with 2011 Census trends, and with trend variables interacted with the change in the share variables occurring between the two Censuses, in Column 2. In Column 3, we interact income in 2004 with energy prices instead of the linear trends we use in our baseline specification. In Column 4, we push this approach further by additionally replacing the linear trend with energy prices in the interactions with the Census and building age and type variables. In all cases, results are materially unchanged.

Columns 5-6 demonstrate that findings are also robust with respect to alternative specifications of the planning variables. In Column 5, 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 6, we re-specify the Listed Building measure by counting all Listed Buildings rather than Grade II ones only. In Column 7 we allow for differential linear trends either side of the 2008 recession.

Panel B of Appendix Table 2 reports various further robustness checks. In the first three columns we vary the sample restriction. In Column 8 we drop the one year with negative energy price growth. In Column 9 we relax the restriction in the baseline specification that drops a small number of cells that experience large (>25%) year-on-year changes in energy consumption. In Column 10, we show our findings are robust to removing all neighbourhoods in London. The final four columns focus on alternative uses of energy variables in our specifications. In Column 11, we instrument log weighted energy prices using log North Sea gas production. In Column 12, we weight energy prices using national proportions of each type of energy consumed (meaning the demand shifter is common to all neighbourhoods). Finally, in Columns 13 and 14 we use per capita gas consumption and electricity consumption as the dependent variable. 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 re-run our regressions 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 will 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 planning authority. 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.

Our third robustness check, a pairwise fixed effect approach, is designed to control for potentially confounding factors such as income in a less parametric way. In particular, we repeat the specification in equation (3) but now exclusively rely on comparisons between neighbourhoods that are almost identical on a candidate confounding factor. We do this by adding a neighbourhood pair-by-year fixed effect where pairs constitute adjacent observations when ranking neighbourhoods on either: average house prices in 2001-2004; household income in 2004; share homes built before 1945; average annual change in house prices between 2004 and 2013; change in share with degree between the 2001 and 2011 Census; or change in share of lone parents between the 2001 and 2011 Census. Our findings are largely unchanged.

Appendix Tables

Appendix Table 1
Summary Statistics: Additional Neighbourhood Robustness Variables

	Obs.	Mean	Std. Dev. overall	between	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 planning authority 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 Specifications

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Change relative to baseline spec:	2011 Census trends	Δ2001-2011 Census trends	Replace income x linear trend with income x energy prices	As (3), but also replace linear trend with energy prices for Census & building type & age cntrls	Share land in CA instead of share dwellings	All Listed Buildings instead of Grade II	Allow for different trends pre and post 2008 recession
Panel A: Trends & Alternative Historic Preservation Variables							
Log one year lagged	0.0146***	0.0237***	0.0177***	0.0194***	0.0251***	0.0207***	0.0210***
energy price × Listed	(0.00448)	(0.00462)	(0.00457)	(0.00466)	(0.00429)	(0.00452)	(0.00424)
Log one year lagged	0.0141***	0.0153***	0.0177***	0.0177***	0.0122***	0.0161***	0.0169***
energy price × CA	(0.00365)	(0.00368)	(0.00363)	(0.00409)	(0.00306)	(0.00346)	(0.00364)
Controls, Fixed Effects and Trends	√	√	√	√	√	√	√
Observations	40,410	40,410	40,410	40,410	40,410	40,410	40,410
Adj. R-squared	0.986	0.986	0.985	0.984	0.985	0.985	0.985

	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Change relative to baseline spec:	Drop year (i.e., 2010) with falling energy prices	No sample restriction	No London neighbour-hoods	IV energy prices with North Sea gas production	Weight prices with national energy split in 2005	Gas consumption dependent variable	Electricity consumption dependent variable
Panel B: Further Robustness Checks							
Log one year lagged	0.0201***	0.0198***	0.0191***	0.0203***	0.0176***	0.0160***	0.0117***
energy price × Listed	(0.00464)	(0.00513)	(0.00401)	(0.00587)	(0.00411)	(0.00471)	(0.00589)
Log one year lagged	0.0170***	0.0191***	0.0125***	0.0180***	0.0159***	0.0176***	0.0165***
energy price × CA	(0.00341)	(0.00387)	(0.00282)	(0.00415)	(0.00343)	(0.00361)	(0.00523)
Controls, Fixed Effects and Trends	√	√	√	√	√	√	√
Observations	35,245	41,279	31,684	40,410	40,410	40,410	40,410
Adj. R-squared	0.985	0.946	0.986	0.985	0.985	0.990	0.927
Kleibergen-Paap F				4,318			

Notes: Standard errors clustered at planning authority 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	-0.0025	-0.0020	0.0061	0.0074
× Share planning authority dwellings in Green Belt	(0.00223)	(0.0226)	(0.00714)	(0.00705)
Log one year lagged energy price		0.0200***		0.0261*
× Grade II Listed per 100 dwellings		(0.00441)		(0.0136)
Log one year lagged energy price		0.0163***		0.0239**
× Share dwellings in Conservation Area		(0.00350)		(0.00868)
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 planning authority level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. All policy variables are standardised. Energy prices are lagged by one year.

Appendix Table 4
Robustness check: Pairwise Fixed Effects

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)	(4)	(5)	(6)
Pair defined by rank on:	Average house prices	Household income	Share homes built pre '45	Δ house prices	Δ share with degree	Δ share lone parents
Log one year lagged energy price × Listed	0.0191***	0.0247***	0.0194***	0.0204***	0.0220***	0.0191***
	(0.00475)	(0.00574)	(0.00510)	(0.0546)	(0.0477)	(0.00510)
Log one year lagged energy price × Conservation Area	0.0118***	0.0133***	0.0173***	0.0141***	0.0177***	0.0168***
	(0.00361)	(0.00413)	(0.00413)	(0.00380)	(0.00375)	(0.00375)
Controls, Fixed Effects and Trends	√	√	√	√	√	√
Pair-by-Year	√	√	√	√	√	√
Observations	39,518	39,612	39,520	39,512	39,566	39,536
Adj. R-squared	0.984	0.984	0.983	0.983	0.983	0.983

Notes: Standard errors clustered at planning authority level in parentheses, *** p<0.001, ** p<0.05, * p<0.1. All policy variables are standardised. Regressions are as baseline specification but additionally include a pair by year fixed effect where pairs are defined as adjacent observations when ranking neighbourhoods on variable indicated: in Column 1 average house prices in 2001-2004; in Column 2 household income in 2004; in Column 3 share homes built before 1945; in Column 4 average annual change in house prices between 2004 and 2013; in Column 5 change in share with degree between the 2001 and 2011 Census; in Column 6 change in share lone parents between the 2001 and 2011 Census.

WEB APPENDIX

This Web Appendix documents further ancillary regressions.

Web Appendix Table 1 provides reassurance that our proxy for Listed Buildings is a reasonable one. In our baseline specifications, we compute the Listed Building measure using the number of Grade II Listed Buildings per 100 dwellings. This is a proxy for the number of Listed residential dwellings which we do not observe in our data. It has the benefit of simplicity and transparency. In Column 1 of Web Appendix Table 1 we repeat our baseline specification for reference. For the two remaining columns we have generated new measures of Listed Buildings per 100 dwellings based on information in Grade II Listed Building names. In Column 2 we attempt to purge non-residential buildings from our counts of Listed Buildings. We do so by removing any Listings that contain around 40 keywords, such as “Church”, “Cathedral”, “Factory”, “Office”, “Hotel”, “Library”, “Museum”, “Shop”, “Wall”, “Monument”, “Warehouse”, “Headstone”) but do not contain a number (typically a street address) or words suggestive of a residential address (“Street”, “Avenue”, “Road” etc.). This latter condition is adopted because many residential addresses contain a keyword (e.g. “8, Upper Church Street”). Using this procedure, we exclude around 10% of Grade II Listed Buildings (or 35,000 Listings Buildings). Findings using this alternative measure are almost identical to our baseline results.

In Column 3 we attempt to allow for a Listing covering multiple residential units i.e. dwellings. We do so by first identifying Listed Building names that suggest a Listing covers more than one dwelling, and then where possible assigning that Listed Building a number of homes that is suggested by the text. For example, if the text contains a string such as “1, 2, and 3a Upper Church Street”, we assign it three Listed Buildings; “1 & 2 Upper Church Street” is assigned two listed dwellings. Sometimes it is not possible to identify the number of homes covered (e.g. “Cottages in Upper Church Street”) and in this case we make an assumption. By this process we assign multiple listed homes to around 35,000 Listed Buildings. Results when using this alternative measure are again highly similar to our baseline findings. Although the coefficient is slightly smaller than the baseline specification, the overall effect is very similar. This is because the coefficient tells us the effect of a one standard deviation increase from the mean, and the smaller coefficient in Column 3 is offset by the fact that the standard deviation of this measure is slightly larger (2.90 for Column 3 compared to 2.67 in the baseline specification).

Web Appendix Table 2 explores the effect of outliers in preservation policies on our main estimates. Column 1 corresponds to our baseline estimate from Table 4, panel C, Column 6. In Columns 2 and 3 we drop, respectively, neighbourhoods in the top decile of Listed Buildings per 100 dwellings and neighbourhoods in the top decile of the proportion of homes in Conservation Areas (CAs). In Column 4 we implement the two restrictions concurrently. Around one third of neighbourhoods in the top decile of prevalence for one policy is also in the top decile for the other: we lose some further neighbourhoods where these become singletons conditional on our fixed effects. Column 5 repeats the specification in Column 4 but now additionally drops neighbourhoods in the bottom decile for either preservation policy.

Results are less precisely estimated but remain broadly comparable to our baseline model throughout.

Web Appendix Table 3 checks for non-linearities in neighbourhoods with different intensities of preservation. This undertaking is not straightforward because our main results are estimates of the extent to which preservation policies modify the underlying energy price elasticity, and these underlying elasticities may themselves vary.

Notwithstanding this caveat, we split the neighbourhoods into quartiles of the respective preservation policy measures, to estimate a baseline effect. Subsequently, we test for statistically significant differences from this baseline in the first, second, and third quartiles. For simplicity, we do this for each of the preservation policies separately, that is, we test for differences across the quartiles for one policy while imposing a common effect for the other policy. In Columns 2 and 3 we estimate the effect of Conservation Areas in different quartiles. Column 2 is akin to our baseline model, while in Column 3 we allow for differential trends in the different quartiles by interacting several of our control trends (region trends; rural-urban trends; and income trends) with a quartile indicator.

We find little evidence of non-linearities for CA effects. For example, in Column 2 the baseline effect of CAs across all CA-quartiles is 0.0170. This can be interpreted as the effect in the top quartile. The effect in other quartiles can be calculated by adding the baseline effect and the additional quartile-specific estimates. However, these quartile specific effects are not statistically distinguishable from 0. The same findings arise in Column 3.

Non-linearities are more evident in Listed Building effects. For example, in Column 4, we find that the effect in the top two quartiles is 0.0152; while the implied effect in the bottom quartile is 0.0459 (i.e., 0.0152+0.0343) and in the second quartile it is 0.0424 (i.e., 0.0152+0.0272). This is suggestive of greater effects of Listed Buildings in the least preserved areas, which could reflect possible social interactions/ learning around technology adoption in areas with more dwellings covered by historic preservation. However, we should caveat that (a) differences are only marginally significant, particularly when we include quartile specific trends in Column 5 and (b) the underlying energy price elasticity in these quartiles may be systematically different to the elasticity elsewhere.

Web Appendix Table 4 provides the full output for our baseline specification.

Web Appendix Table 5 provides robustness checks on the planning authority-level regressions reported in the main body of the paper by re-specifying the dependent variable. Specifically, in Columns 1 to 3 we normalise the stock of all installations using the count of dwellings. This yields statistically significant effects for the two preservation policies individually, but when both are included simultaneously only the Listed Building coefficient is significant.

In columns 4 to 6 we obtain qualitatively similar findings when we specify the dependent variable as $ln\left(\frac{installations_{LPAt}}{dwellings_{LPA}}\right) - ln\left(1 - \frac{installations_{LPAt}}{dwellings_{LPA}}\right)$, where the counts of dwellings are for the year 2010. We use this formulation, rather than the log odds ratio of market shares specified in Gillingham and Bollinger (2017), because in our setting households can make multiple installations of the same type (e.g. adding additional energy efficient windows, or additional loft insulation) or of different types. It is thus unclear how to define market share.

Web Appendix Table 6, finally, provides further support for our proposed mechanism. In Columns 1 to 3 we show the reduced form estimates at the planning authority-level where we regress log per capita energy prices on preservation policies interacted with the energy price demand shifter and controls in an planning authority-version of equation (4). These reduced form effects, which are the actual effects of the policy, are reasonably close to the neighbourhood estimates in Table 4, although, at the planning authority level the magnitude of the coefficients on Listed Buildings and CAs are more or less swapped around. In Columns 4 to 6, we report IV estimates, where we instrument total installations (rescaled by dividing by 1000) with preservation policies interacted with the energy price demand shifter. The first stages are shown in the bottom panel. These IV estimates qualitatively support our mechanism in that they suggest that preservation polies affect energy consumption through an energy efficiency investment mechanism.

WEB APPENDIX TABLES

Web Appendix Table 1
Listed Building Additional Robustness Checks: OLS

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)
	Baseline	Residential LB only	Allow for multiple homes per listed
Log lagged energy price × Listed	0.0199***	0.0206***	0.0182***
	(0.00444)	(0.00451)	(0.00421)
Log lagged energy price × CA	0.0164***	0.0161***	0.0159***
	(0.00350)	(0.00343)	(0.00351)
Controls, Fixed Effects, Trends	√	√	√
Observations	40,410	40,410	40,410
Adj. R-squared	0.985	0.985	0.985

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

Web Appendix Table 2
Outliers: OLS

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)	(4)	(5)
	Baseline	Drop top 10% CA	Drop top 10% Listed	Drop top 10% both	+ drop bottom 10% both
Log lagged energy price × Listed	0.0199***	0.0219***	0.0269***	0.0280***	0.0301***
	(0.00444)	(0.00490)	(0.00768)	(0.00768)	(0.00857)
Log lagged energy price × CA	0.0164***	0.0145***	0.0174***	0.0140**	0.0112*
	(0.00350)	(0.00534)	(0.00380)	(0.00552)	(0.00576)
Controls, Fixed Effects, Trends	√	√	√	√	√
Observations	44,140	36,576	38,603	35,585	19,022
Adj. R-squared	0.985	0.986	0.986	0.986	0.988

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

Web Appendix Table 3
Non-linearities: OLS

Dep Var: Log domestic energy consumption per person	(1)	(2)	(3)	(4)	(5)
	Baseline	CA quartile interactions		Listed quartile interactions	
Log lagged energy price × Listed	0.0199***	0.0202***	0.0236***	0.0152***	0.0162***
	(0.00444)	(0.00438)	(0.00454)	(0.00477)	(0.00474)
Log lagged energy price × CA	0.0164***	0.0170***	0.0155***	0.0154***	0.0132***
	(0.00350)	(0.00428)	(0.00449)	(0.00353)	(0.00320)
× lowest quartile indicator		-0.00711	0.00699	0.0343**	0.0257*
		(0.0120)	(0.0117)	(0.0140)	(0.0145)
× second quartile indicator		-0.00250	0.0155	0.0272*	0.0155
		(0.0123)	(0.0143)	(0.0139)	(0.0155)
× third quartile indicator		-0.000464	0.0165	0.0278	0.0307
		(0.0177)	(0.0144)	(0.0171)	(0.0203)
Controls, Fixed Effects, Trends	√	√	√	√	√
Additional quartile trend controls			√		√
Observations	44,140	44,140	44,140	44,140	44,140
Adj. R-squared	0.985	0.985	0.985	0.985	0.985

Notes: Standard errors clustered at planning authority level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Table tests for non-linearities in quartiles of extent of preservation policies. In Columns 2 and 3, the second row is the implied effect of CAs on the energy price elasticity for neighbourhoods in the top quartile (most CAs) while interaction effects are the additional effect in lower quartiles. In Columns 4 and 5, the first row is the implied effect of Listed per 100 dwellings on the energy price elasticity for neighbourhoods in the top quartile (most Listed) while interaction effects are the additional effect in lower quartiles. Additional quartile trend controls are interactions between a quartile indicator and (a) region trends (b) rural-urban trends and (c) income trends.

Web Appendix Table 4
Baseline, full results: OLS

	Coefficient	Standard error
Log lagged energy price × Listed	0.0199***	(0.00444)
Log lagged energy price × CA	0.0164***	(0.00350)
Log lagged energy price × Dist commuting zone	-0.0055*	(0.00305)
Log planning authority wages	-0.0133	(0.02032)
Trend × share built pre 1900	0.0323***	(0.00390)
Trend × share built 1900-1918	0.0280***	(0.00344)
Trend × share built 1919-1929	0.0273***	(0.00404)
Trend × share built 1930-1939	0.0341***	(0.00322)
Trend × share built 1945-1964	0.0003***	(0.00004)
Trend × share built 1965-1982	0.0004***	(0.00004)
Trend × share built 1983-1999	0.0004***	(0.00004)
Trend × share flat	-0.0001**	(0.00003)
Trend × share terrace	-0.0001***	(0.00002)
Trend × share semi-detached	-0.0000	(0.00002)
Trend × degree share 2001	-0.0001	(0.00008)
Trend × lone parent share 2001	-0.0018***	(0.00032)
Trend × SOC A share 2001	0.0000	(0.00006)
Trend × employed share 2001	-0.0003***	(0.00007)
Trend × homeownership share 2001	-0.0001	(0.00003)
Trend × ethnicity white share 2001	0.0001***	(0.00003)
Trend × middle aged share 2001	0.0000	(0.00015)
Trend × sixty or above share 2001	-0.0001	(0.00005)
Trend × avg net h'hold income in 2004	0.0000***	(0.00001)
Trend × East Midlands	0.0088***	(0.00183)
Trend × East of England	0.0007	(0.00083)
Trend × London	0.0032*	(0.00191)
Trend × North East	0.0023	(0.00159)
Trend × North West	0.0018	(0.00215)
Trend × South East	0.0033	(0.00229)
Trend × West Midlands	0.0033***	(0.00110)
Trend × Rural town and fringe	0.0030***	(0.00093)
Trend × Urban city and town	0.0005	(0.00094)
Trend × Urban major conurbation	0.0009	(0.00107)
Observations	40,410	
Adj. R-squared	0.985	

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

Web Appendix Table 5
Robustness planning authority regressions: OLS

	(1)	(2)	(3)	(4)	(5)	(6)
Dep Var: All installations	Normalised by home count			Log ratio		
Log lagged energy price × Listed	-8.118***		-7.186***	-0.249***		-0.228***
	(1.095)		(1.189)	(0.0394)		(0.0433)
Log lagged energy price × CA		-5.934***	-2.113		-0.171***	-0.0497
		(1.250)	(1.340)		(0.0453)	(0.0486)
Main controls	√	√	√	√	√	√
Observations	1510	1510	1510	1510	1510	1510
Adj. R-squared	0.978	0.976	0.978	0.980	0.979	0.980

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

Web Appendix Table 6
Planning authority regressions: IV

	(1)	(2)	(3)	(4)	(5)	(6)
Dep Var: Log domestic energy consumption per person	Reduced Form			IV: 2nd stage		
Log lagged energy price × Listed	0.0216***		0.0127***			
	(0.00444)		(0.00485)			
Log lagged energy price × CA		0.0269***	0.0202***			
		(0.00438)	(0.00515)			
Total installations/1000				-0.00204***	-0.00300***	-0.00229***
				(0.000523)	(0.000903)	(0.000547)
Main controls	√	√	√	√	√	√
Observations	1510	1510	1510	1510	1510	1510
Adj. R-squared	0.975	0.975	0.978	0.935	0.891	0.926
Kleibergen-Paap				21.025	14.137	22.697
Dep Var: Total installations/1000				IV: 1st stage		
Log lagged energy price × Listed				-10.60***		-8.697***
				(2.333)		(2.464)
Log lagged energy price × CA					-8.968***	-4.353*
					(2.397)	(2.525)
Main controls				√	√	√
Observations				1510	1510	1510
Adj. R-squared				0.675	0.675	0.680

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