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Quantitative modelling of why and how homeowners decide to renovate energy efficiently

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HIGHLIGHTS

- Contextually-rich analytical framework for renovation decision-making.
- Path analysis and multivariate probit regression to model renovation decisions.
- Integrative model explaining both why and how homeowners decide to renovate.
- Results of national survey of renovation intentions of UK homeowners.
- New insights on policies and service provision for energy efficient renovations.

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ABSTRACT

Understanding homeowners' renovation decisions is essential for policy and business activity to improve the efficiency of owner-occupied housing stock. This paper develops, validates and applies a novel modelling framework for explaining renovation decisions, with an emphasis on energy-efficiency measures. The framework is tested using quantitative data from a nationally-representative survey of owner-occupied households in the UK (n = 1028).

The modelling advances formal representations of renovation decisions by including background conditions of domestic life to which renovating is an adaptive response. Path analysis confirms that three conditions of domestic life are particularly influential on renovation decisions: balancing competing commitments for how space at home is used; signalling identity through homemaking activities; and managing physical vulnerabilities of household members. These conditions of domestic life also capture the influence of property characteristics (age, type) and household characteristics (size, composition, length of tenure) on renovation decisions but with greater descriptive realism.

Multivariate probit models are used to provide rigorous, transparent and analytically tractable representations of the full renovation decision process. Model fits to the representative national sample of UK homeowners are good. The modelling shows that renovation intentions emerge initially from certain conditions of domestic life at which point energy efficiency is not a distinctive type of renovation. The modelling also shows clearly that influences on renovation decisions change through the decision process. This has important implications for policy and service providers. Efficiency measures should be bundled into broader types of home improvements, and incentives should target the underlying reasons why homeowners decide to renovate in the first place.

1. Introduction: Energy efficient renovation decisions

Improving the energy efficiency of the housing stock is integral to climate change mitigation and energy system objectives [1]. Long-term scenarios show energy use in buildings rising three to fivefold worldwide by 2100 [2]. Energy use for heating and cooling buildings is expected to grow globally by up to 40% to 2050 while "*efficiency retrofits present a tremendous opportunity to decrease energy use worldwide*" [3]. In the EU, retrofit rates have to increase from their current 0.5–1.5% to around 2.5–3% of the housing stock per year to achieve policy goals [4]. In the UK, up to 50% of energy used in homes could be saved through energy efficient renovations and other measures, contingent on policy to support household decision-making [5].

Around 67% of UK homes are owner-occupied, a proportion similar

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to the US and just below the EU average of 70% [6]. In owner-occupied homes, decisions to renovate with efficiency measures are the necessary precursor to energy-saving outcomes. Understanding why homeowners decide to renovate is therefore essential for effective policy design.

The objectives of this paper are to develop, validate and apply a descriptively-realistic model of energy efficient renovation decisions made within the context of everyday domestic life, and to demonstrate the relevance of this model for informing policy. This is consistent with Friege and Chappin [7]'s recent review of decision models which concluded: "*a deeper understanding of the decisions of homeowners is needed and we suggest that a simulation model which maps the decision-making processes of homeowners may result in … developing new mechanisms to tackle the situation*" (p196).

These objectives are consistent with the scope and concerns of *Applied Energy*. Research in this journal on energy-efficient home renovations has one of three broad aims: (1) improving analytical techniques and understanding of renovation measures, including in different housing types [e.g., 8,9]; (2) evaluating the technical and economic consequences of renovation activity in terms of future energy consumption, building performance, or performance gaps between estimated and actual energy savings [e.g., 10–12]; (3) understanding how renovation activity can be effectively stimulated through technical, policy or business-model innovations which support renovation decisions [e.g., 13–15].

By asking why and how homeowners decide to renovate energy efficiently, this paper is consistent with the third aim, although its findings are also relevant for more technical analysis. Occupant behaviour is frequently cited in *Applied Energy* articles as one of the main reasons why analytical models over-estimate [12] or under-estimate [16] expected energy savings from energy efficient renovations. More broadly, user-responsive home energy management (under the rubric of 'intelligent energy systems') is one of seven headline issues tackled in applied energy research [17]. Deviations from normative or optimised modelling assumptions emphasise the importance of research on how household *actually* make decisions to adopt and use energy-saving measures in order to understand the realistically-achievable potential for improving energy efficiency in homes [8,18,19]. This is an issue of global importance. A study of different retrofit projects in China concluded that: "*in order to improve the effectiveness of energy-saving interventions, the motives, intentions and living habits of residents need to be given more consideration when designing and implementing retrofitting*" [13].

1.1. Quantitative modelling of energy efficient renovation decisions

Choice experiments and other survey techniques for studying homeowners' decision making are important for identifying the drivers and barriers behind renovation investment decisions [20], and the reasons why homeowners may or may not participate in programmes delivering energy-saving measures [21]. Understanding why certain homeowners have higher propensities to renovate can also help service providers segment their customer base [22].

The dominant framing of energy efficient renovation decisions sees financial considerations as paramount [23]. Financial considerations include upfront costs, costs of capital, future cost savings, and payback periods [24]. Commonly cited barriers to cost-effective efficiency investments include a lack of available capital or access to capital, unreliable contractors, a perceived deficit of credible information on renovation measures and outcomes, and the hassle and inconvenience of renovating [14,20,25]. These barriers prevent otherwise positive beliefs and strong intentions towards energy efficiency from being realised [26,27].

Quantitative models of renovation decisions reinforce this basic financial framing. Discrete choice models based on stated preference data strongly emphasise financial attributes as explanatory variables. These allow the effectiveness of financial policy instruments like grants, subsidies and taxes to be evaluated [7,28–31]. Decision models based on observed market behaviour similarly focus on financial attributes [27], but can also include a wider range of decision influences. These include property characteristics including size, age, type and location, and household characteristics including size, lifecycle, and the duration and type of home tenure [32–34].

There is long-standing evidence that homeowners' decisions to carry out energy efficient renovations are not narrowly financial. Numerous cost-effective investment opportunities remain which homeowners do *not* pursue [11,35]. Even in rented properties, ample opportunities exist to recoup efficiency investments through increased rental prices or lower energy costs [10].

Some quantitative models broaden their explanatory variables to non-financial decision attributes. Models of heating system adoption decisions have included ease of use [36], and potential environmental benefits through CO_2 emission reductions [37]. Models of energy efficient renovation decisions have included installation and contractor hassle [38], thermal comfort [39], and air quality, noise reduction, and aesthetics [40]. Models of adoption decisions for specific renovation measures like energy efficient windows have identified the influence of supply-chain actors (window sellers and installers) as well as homeowners' awareness of the cost and performance of windows with lower U values [15].

1.2. The changing contexts of renovation decisions

Energy efficient renovation decisions tend to be formally represented as being discrete financially-motivated events, subject to exogenous constraints or barriers [23].

This representation of deliberative, instrumental, and isolable decisions has been criticised for failing to account for the context in which decisions to renovate are made. As Guy and Shove [41] conclude with respect to narrowly-framed research on energy efficiency: "*greater attention should be paid to the changing contexts of energy-related decision-making*" (p135). For energy efficient renovations, these "*changing contexts*" mean life at home, or as Maller and Horne [42] put it, "*the conventions and practices of households*" (p61). In other words, renovation decisions are situated within and emergent from everyday life at home and need to be analysed as such.

There are three important descriptively-realistic features of renovation decision making made in the context of everyday life at home.

First, decisions to renovate and subsequent renovation activities are part of a process by which households continually adapt their homes to the demands of domestic life. As Karvonen [43] argues: "*Domestic retrofit is not an activity of changing a house … from poor energy performance to exceptional energy performance, but an intervention into the rhythms of domestic habitation*" (p569).

Second, from a decision-making perspective, efficiency measures are not a distinct type of renovation. Judson and Maller [44] found that efficiency measures in one part of the home often went hand-in-hand with expansions or intensifications of other parts of the home (e.g., additional bathrooms). Noonan et al. [45] found that US neighbourhoods with homes undergoing larger remodelling projects had greater adoption rates for energy-efficient heating and cooling systems.

Third, models of renovation and other home-related decisions invariably represent the decision statically as a discrete point in time with a characteristic set of influences [46]. Yet renovation decisions are long-drawn out processes or 'journeys', not singular events [47].

These three features of renovation decision-making are omitted from quantitative analysis and modelling of energy efficient renovation decisions which narrowly emphasise:

i. renovation decision events, but not the processes preceding them nor the origins of the decision process;
ii. property and household characteristics, but not the conditions of domestic life from which renovation decisions emerge;