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Residential renovations: Understanding cost-disruption trade-offs

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ABSTRACT

Disruption and mess associated with energy efficiency retrofits is one aspect that is rarely considered in studies investigating households' preferences for energy renovations. Using a choice experiment, we estimate a price for residential retrofit disruption, finding it represents a substantial proportion of associated energy cost savings among some households. There is considerable variance in willingness to pay for both energy cost savings and disruption avoidance, consistent with experience of many households investing in energy retrofits but also of government retrofit schemes falling far short of policy targets. Just 1-in-4 households are actively receptive to retrofit policy supports, and disruption posing a significant barrier to undertaking energy retrofits, means both contribute to the slow progress against public policy targets to improve residential energy efficiency.

1. Introduction

The residential sector is responsible for a substantial percentage of greenhouse gas emissions, over 20% across EU countries,[1] and is expected to share the burden of policy measures. The sector is tasked with increasing energy efficiency and reducing energy use. Individual households are being asked to consider implementing actions such as installing insulation and decarbonising home heating. Households' response to government policy incentives is reflected in a decline in household energy consumption per capita for heating and cooling[2] but this represents relatively minor progress towards policy targets. The disruption to home life during retrofit works has been acknowledged as a potential barrier to households upgrading the energy efficiency of their homes, but few studies have tried to quantify its scale or relative importance in impacting retrofit decisions. A better understanding of how disruption features within households' energy retrofit decisions is essential to improving the residential sector's energy efficiency and emissions performance.

In the EU approximately 90% of buildings must be upgraded to achieve the 2050 decarbonisation vision (BPIE, 2017, 2023). In Ireland, policy ambition under the Climate Action Plan (DECC, 2022) is to retrofit approximately one-quarter of the housing stock (i.e., 500,000 homes) by 2030, including 400,000 existing dwellings using heat pumps. In terms of progress to target, at the end of 2022 just 18,527 homes were retrofitted to the target specification (SEAI, 2023a). There are multiple potential explanations for the slow progress towards these policy targets. One issue is cost. For example, the average cost of utilising a registered 'one-stop-shop' to complete a retrofit in 2023 was €56,000 in Ireland, with 25% of households facing costs in excess of €75,000, exclusive of grant support of approximately 33%–37% (SEAI, 2023b). But it is well recognised that the reason why households do not adopt cost-effective energy efficiency opportunities is that there are multiple, overlapping, non-cost barriers to adoption (Sorrell et al., 2004). Literature reviews on the barriers to energy efficiency adoption cite many issues, including information problems, bounded rationality, or a status quo bias (Dolšak, 2023; Cattaneo, 2019). The wider literature is often framed in terms of overcoming technical problems, or addressing market failures. Disruption and mess associated with energy efficiency retrofits is sometimes cited as a barrier to energy retrofits or discussed in qualitative studies, but few studies include a quantitative assessment of households' preferences for such disruption. For example, the most common attributes considered in choice experiment studies examining preferences for residential energy retrofits include investment costs, operating costs, energy cost savings, environmental benefits, and installation guarantees (e.g., Rouvinen and Matero, 2013; Achtnicht and Madlener, 2014; Kastner and Matthies, 2016; Franceschinis et al., 2017; Fernandez-Luzuriaga et al., 2022). Only occasionally are disruption or installation time evaluated in such studies, with Scarpa and Willis (2010), Meles et al. (2022) and Schleich et al. (2022) being notable examples. In the UK (Scarpa and Willis,

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[1] See Eurostat, data series code: env_ac_aigg_q.

[2] See Eurostat, data series code: nrg_ind_esc__custom_7983100.

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2010) find that the garden being dug-up is considered the worst inconvenience, with a willingness to pay to avoid it in excess of £500 in 2007. In Poland, householders are willing to pay up to €500/day for shorter installation times (Schleich et al., 2022). Meles et al. (2022) find that Irish households are, on average, willing to pay in excess of €5000 to avoid high, relative to low, levels of installation hassle.

Each of these latter three cited papers, and this paper also, employs the discrete choice experiment methodology estimated via a Multinomial Logit Model (McFadden, 1973). The methodology uses survey data where respondents are asked to choose one from several alternatives, each of which are described by a finite number of attributes (e.g. investment cost, energy savings, etc.), but across successive choice options the attribute levels vary. Econometric analysis of the data allows an estimation of households' preferences for the attributes. The distinguishing feature of these three papers compared to other choice experiment studies of energy retrofits is that they include a definition of disruption as an attribute. However, disruption is defined quite differently across all three. In Schleich et al. (2022) it relates to installation time, whereas in Scarpa and Willis (2010) it relates to garden works and space allocations for fuel and equipment. In the case of Meles et al. (2022) it relates to installation hassle, but the attribute's levels have the nebulous values of low, moderate, and high. While it is welcome that disruption is incorporated into these studies, further research is necessary to provide greater scope on types of disruption that households have preferences over, as well as providing greater precision on how disruption is defined. For instance, Meles et al. (2022) find that 95% of households are willing to pay between €2600 and €8000 to avoid high, relative to low, levels of disruption, but precisely what distinguishes high relative to low is not clear, and hence of is of minimal practical value to policy-makers.

In addition to the need for more studies quantifying preferences over retrofit disruption, there is also a policy need to understand how preferences vary across population cohorts. For instance, are preferences related to retrofit disruptions associated with income or other socio-demographic characteristics, which would allow policy interventions to be designed to lessen the disruption barrier? While Meles et al. (2022) find that there is considerable preference heterogeneity with respect to disruption across their sample of households, they find little to guide policy-makers on which types of households are most adverse to the disruption associated with energy retrofits. Neither Schleich et al. (2022) nor Scarpa and Willis (2010) investigate the underlying source of preference heterogeneity surrounding retrofit disruption. More generally, the absence of an association between preferences and socio-demographic characteristics or environmental attitudes is common in many empirical studies (e.g., Lange et al., 2014; Ramos et al., 2016; Curtis et al., 2018).

An alternative conceptual framework to explain apparent preference heterogeneity is advocated by Wilson et al. (2015), who challenge the conventional applied behavioural approach that identifies personal or socio-demographic influences on homeowners' renovation decisions. Their criticism is rooted in sociological research on domestic life, arguing that renovation decision-making occurs in the context of families rather than decision makers, amenity renovations rather than energy efficiency, and homes rather than houses. The current study represents an opportunity to empirically assess Wilson et al.'s thesis, which is further developed in Wilson et al. (2018) where they contend that decisions on renovations emerge from the conditions of everyday domestic life (CDL), intentional decision-making (IDM), and one-off, high salience events that act as triggers, all of which are subject to different levels of influence depending on where the family is positioned along a series of stages of home renovation, from not thinking about renovations up to implementing renovations. CDLs describe issues, tensions or imbalances within homes and domestic life to which renovating is an adaptive response. For example, an uninsulated property with older occupants might be more likely to renovate to improve comfort and energy cost efficiency. Wilson et al. (2018) identifies five CDL characteristics associated with renovating households, which are reproduced in Table 1. Positive attitudes towards renovation outcomes and perceived social norms on renovating are the main forms of personal influence termed intentional decision-making (IDM). Triggers describe one-off events that can either precipitate renovation decisions or expedite decision processes. Examples include a broken boiler, a change in household composition, or new life circumstance (e.g., new baby, retirement). Wilson et al. (2018) suggest that CDL and IDM variables are grouped by renovation decision stage, and conclude that CDLs explain why households switch from a position of not thinking about home renovations to thinking about home renovations, which represents a potential policy hook to better promote energy retrofits to homeowners at different decisions stages.

In summary, there are 3 research objectives in this paper. The first is to add to the sparse literature that quantitatively estimates the impact of retrofit disruption on decisions to renovate. We show that disruption is not merely a minor, negatively perceived attribute that can be overcome by financial supports, rather it is an important element of households' preferences, the salience of which varies considerably across the population. The second objective is to examine preference heterogeneity across retrofit decisions using the conventional approach that identifies which socio-demographic and other characteristics are correlated with personal and contextual influences on homeowners' renovation decisions. Similar to Meles et al. (2022) and others, we find little empirical evidence with practical policy relevance that correlates energy retrofits decisions with a range of socio-demographic characteristics. This result is not unexpected, and its anticipation motivated the third research objective, which is to empirically assess Wilson et al.'s thesis that factors such as CDL, IDM, or high salience trigger events are better indicators for home retrofit decisions. We do not find empirical support for Wilson et al.'s thesis either.

The paper contributes to the literature in several ways. First, we ascertain, for a representative sample of the population, the extent to which households are currently considering investment in energy efficiency retrofits. Second, we estimate the implied cost of renovation disruption to households and quantify its distribution across the households examined. Finally, we investigate how socio-demographic characteristics, as well as variables measuring CDL, IDM, and trigger events are associated with both retrofit stage, and the implicit cost of disruption. Thus, we provide information for policy-makers on the drivers of and barriers to residential retrofits across a range of parameters, which in turn can guide decision-making on subsidisation and funding of residential heating decarbonisation.

The remainder of this paper is structured as follows. Section 2 outlines the methodology employed, including the choice experiment conducted and the econometric analysis undertaken. Section 3 summarises the results, while Section 4 provides a discussion and Section 5 concludes.

2. Methods

2.1. Analytical approach

We undertake a series of analyses to answer the questions posed above. The first is to ask households to self-declare into a series of renovation retrofit decision categories, and subsequently analyse inclusion in these categories by means of a standard multinomial regression analysis. This is relevant to policymakers, as it provides insight on homeowners that may be more or less disposed to act upon policy incentives to undertake energy efficiency retrofits. The second piece of analysis uses a choice experiment to understand homeowners' preferences with respect to energy retrofit disruption. The empirical evidence will show that disruption can be a substantial barrier but that there is considerable heterogeneity in preferences. Finally, data on disruption preferences is analysed to investigate whether certain identifiable

Table 1
Conditions of domestic life associated with renovation decisions (Wilson et al., 2018).

Condition of domestic life	Description
Prioritising (CDL1)	The balancing of competing and at times conflicting commitments in domestic life
Embodying (CDL2)	The impact of the body and its abilities on how space at home is used and arranged, including old age and caring
Demonstrating (CDL3)	The generation of thoughts and ideas for changing the home, including the absorption of social norms, media representations, and other external influences between the current design and feel of the home and information signalled about how others have their homes
Home as project (CDL4)	The meaning of home as a 'project' to be continually updated to express a household's identity
Adapting (CDL5)	The tacit acknowledgement or explicit awareness of a need to change the physical characteristics of the home to solve perceived problems with objects or the use of space between the home as it is and the home as it is could be adapted better to perceived needs

homeowner cohorts are more affected by disruption barriers, which may potentially render them less amenable to existing energy efficiency retrofit policies. We begin in the next section with a description of the data collected for the analysis, which is followed in subsequent sections by a description of the choice experiment and methodological approaches utilised.

2.2. Data

Data were collected online from an opt-in respondent panel of a professional survey company. In general, online based surveys have many advantages, with data quality no lower than more traditional survey modes (Lindhjem and Navrud, 2011), though Johnston et al. (2017) assert that the highest quality data is based on probability-based sampling. In practice, non-probability (i.e., opt-in or convenience) based samples have become more popular because they are substantially less expensive. A distinct disadvantage of opt-in samples is that some respondents may pay little attention to the questions and speedily complete the survey, resulting in relatively low-quality data (Goodrich et al., 2023). However, some practical steps are feasible to mitigate the impact on research results. Several recent papers compare outcomes for probability-based representative samples versus non-probability convenience samples, including across valuation metrics, finding that while there are differences, there are many similarities, and conclude overall in favour of the use of opt-in samples (Whitehead et al., 2023; Penn et al., 2023; Sandstrom et al., 2023).

The target population for the survey was adults living in owner-occupied properties. Sampling quotas were implemented across gender, age, education and region to match shares from the most recent census data for the target population. To address any concern that respondents may not provide earnest responses or pay adequate attention to the survey questions, we followed two approaches. First, we embedded a specific question to directly capture inattention, with respondents who failed the test immediately excluded from the survey. Second, observations where the survey completion time was under 7 min (n = 120) were excluded from subsequent analysis, as this was considered below the minimum time required to give proper consideration to the survey questions. The mean and median survey completion times of all respondents are 15 and 12 min respectively. In total, 1928 respondents initiated the survey, with 799 excluded because they were not in the target population (i.e., owner-occupier), sampling quotas had been filled, or they failed the attention test. 1129 respondents completed the full questionnaire and after excluding the 120 respondents that completed the survey in under 7 min, a sample size of 1009 responses was available for analysis. In addition to a choice experiment, the survey also included questions to elicit the socio-demographic characteristics of the respondents.

A copy of the questionnaire is available in the online supplementary material accompanying this paper. The questions capturing data on CDL and IDM were adopted from the study by Wilson et al. (2018), details of which are available via the UK Data Service (http://dx.doi.org/10.5255/UKDA-SN-7773-1). The CDL and IDM variables were recorded using a 7-point Likert scale ranging from strongly disagree to strongly agree, but recoded for analysis as in agreement with the specific statement (scales 5–7) versus not in agreement (scales 1–4). One-off, high salience trigger events were captured simply as the respondent agreement with the outlined statements. All three sets of variables, along with the shares of respondents answering affirmatively, are reported in Table 2. Energy retrofits are often considered in a binary context, e.g., renovated/not renovated, whereas the process of retrofitting may follow a broader continuum of stages. Greater understanding of where households fall within this categorisation may provide greater insight to policymakers wishing to encourage a greater level of residential energy efficiency. While Wilson et al. (2018) propose six renovation stages, we amalgamate to four, where renovation decision stages move from 'not thinking about renovations' (stage 0), through 'thinking about renovations as a possibility' (stage 1), 'planning renovations' (stage 2), and a final category 'implementing/completed renovations' (stage 3). In Wilson's et al.'s categorisation, stage 2 above ('planning renovations') is treated as two categories, one where plans are being finalised and the other where renovation planning will be completed 'in the near future'. Wilson et al. also treat stage 3 above ('implementing/completed renovations') as two categories, one where renovations are underway at the time of the survey, and one where renovations are already completed. We merged these categories as outlined, partly as there are only subtle differences in the pre-merge categories, but also to maintain more tractable analytical outputs.

2.3. Choice experiment

A stated choice experiment (CE) is a preference elicitation method where respondents are asked to express their preferred choices across a set of alternatives, iteratively. Each alternative (i.e., retrofit option) is described by a set of attributes (e.g., cost, disruption, etc.) characterised by levels that vary across alternatives. Choice cards in this experiment included two alternatives and an opt-out that could be selected by respondents who did not like either of the two retrofit alternatives. This opt-out alternative increases the realism of the task.

The allocation of the attribute levels across the choice cards was based on experimental design with a Bayesian information structure that minimised the expected D_b-error and optimised for a Bayesian WTP-efficiency (Vermeulen et al., 2011; Scarpa et al., 2007). We generated a D-efficient orthogonal design based on an MNL model to obtain Bayesian parameter priors.[3] D-efficient MNL-based designs perform well even for models with a different asymptotic variance–covariance estimator, such as those with continuous or discrete preference mixing (Scarpa et al., 2013; Bliemer and Rose, 2010). This design was used in the pilot survey of 55 respondents (from the main target population). Parameter estimates from the pilot were used as the priors for the experimental design for the main survey. The final CE survey consisted of a set of 8 choice questions, each comprising two experimentally designed renovation alternatives and a "None" or opt-out option. Before commencing the choice experiment, respondents were shown an

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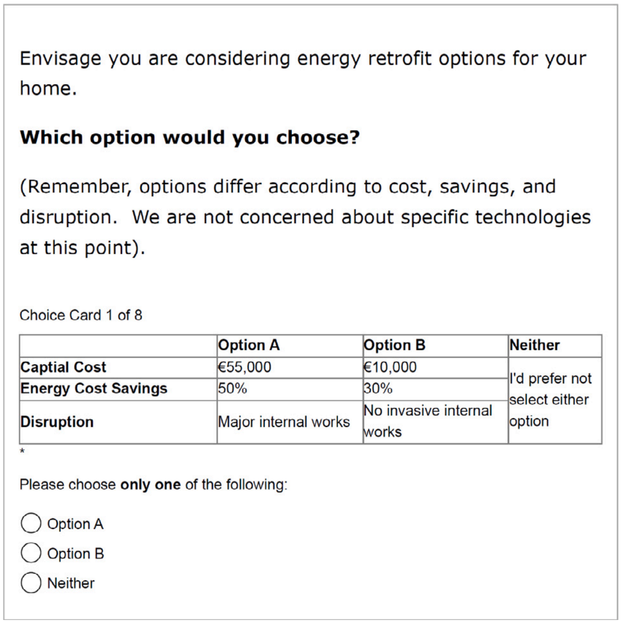
[3] One drawback to D-efficient modelling is the dependence on priors about the population values of the parameters to be estimated. With no available reliable priors, we establish parameter priors by setting the initial values close to zero and use Ngene (ChoiceMetrics, 2012) to generate the design needed to obtain new priors from the pilot survey, which we subsequently use for the main experimental design.

Table 2
Definitions of CDL, IDM, and trigger variables.

Variable	%	Statement from respondent questionnaire
CDL1	49.5	New things we're doing in our lives mean we have to rethink the way we use our home
CDL2	35.9	Physical issues faced by some household members influence how our home is arranged
CDL3	31.6	We take on board how other people have their homes when doing things to our home
CDL4	49.8	We see our home as a project, somewhere we can spend time and effort expressing ourselves and how we want to live
CDL5	22.8	We're always changing things around at home
IDM1	65.8	The pros of renovating to improve the quality of life at home clearly outweigh the cons
IDM2	64.7	The pros of reducing the energy used in homes clearly outweigh the cons
IDM3	74.6	People think favourably of renovating living spaces in homes (like kitchens, living rooms and bedrooms)
IDM4	74.4	People think favourably of renovating to make homes more energy efficient
Trig1	25.4	Had major problems with your home (e.g., breakdown of heating system, leaking pipes, roof/window damage)
Trig2	8.60	Received large windfall sum of money (e.g., inheritance, redundancy payment, lottery win, etc.)
Trig3	30.9	More personal time for projects and interests (e.g., retirement, reduction in working hours, unemployment)
Trig4	17.0	Family member in need of care (e.g., physical disability from sickness or accident, old age, frailty)
Trig5	24.7	Change in family composition (e.g., childbirth, adult moving in/out, or death of family member)

Table 3
Attributes and attribute levels.

Attribute	Levels	Label
Capital cost	10, 25, 40, 55, 85 (€'000)	
Energy cost savings	10%, 30%, 50%, 70%	
Disruption:	✦ No invasive work affecting walls, floors or ceilings — full use of property during renovations	No invasive internal works
	✦ Minor internal works, dust and materials affecting use of some rooms during renovation	Minor internal works
	✦ Moderate internal works, some rooms are not suitable for use at times during renovations	Moderate internal works
	✦ Major internal works, whole property is not suitable for use during renovations	Major internal works



Envisage you are considering energy retrofit options for your home.

Which option would you choose?

(Remember, options differ according to cost, savings, and disruption. We are not concerned about specific technologies at this point).

Choice Card 1 of 8

	Option A	**Option B**	**Neither**
Captial Cost	€55,000	€10,000	I'd prefer not select either option
Energy Cost Savings	50%	30%	
Disruption	Major internal works	No invasive internal works	

*

Please choose **only one** of the following:

○ Option A
○ Option B
○ Neither

Fig. 1. Choice card example.

example choice card, as well as text describing the extent of potential disruption associated with renovation options. The CE attributes and their corresponding levels are listed in Table 3, and one of the 8 choice cards is shown in Fig. 1.

2.4. Econometric analysis

The analysis of stated CE data is based on the Random Utility Model (RUM), which postulates that an individual's utility is composed by a deterministic component and a stochastic component (Manski, 1977). In mathematical terms, the utility U that an individual n derives from alternative i in a choice situation t is the following:

$$U_{int} = \beta X_{int} + \epsilon \tag{1}$$

where βX_{int} is a linear combination of the vector X of attributes of each alternative in the choice cards and an unknown vector β of coefficients to estimate. The statistical model to use for estimation depends on the assumptions about the distribution of the error term ϵ. The most common approach is to assume a Gumbel-distributed ϵ, which implies the use of a Multinomial Logit Model (MNL) for estimation (McFadden, 1973). The MNL model has the following probability distribution function across respondents:

$$LL = \sum_{n=1}^{N} log \left\{ \frac{exp(U_{int})}{\sum_{i=1}^{I} exp(U_{int})} \right\} \tag{2}$$

An important limitation of the MNL model is that parameters are fixed in value, thus implying that preferences are homogeneous across respondents. This preference homogeneity restriction is not likely to hold in practice, in fact preferences for various goods and services are most commonly heterogeneous in a given population. To address this limitation, the analysis of CE data commonly adopts more flexible specifications that better model preference heterogeneity for the attributes of the alternatives. In this work preference heterogeneity is modelled by means of a mixed logit model with random parameters (RPL), which is one of the most common alternatives to relax the assumption of homogeneity in preferences in discrete CE analysis. Within RPL, parameters are not fixed but follow a certain probability distribution, therefore relaxing the preference homogeneity assumption. The RPL log-likelihood has no closed form, and it is therefore approximated using random draws from the underlying probability distribution of the parameters. Using R random draws, the RPL has the following probability distribution function across N respondents:

$$LL = \sum_{n=1}^{N} ln \left(\frac{1}{R} \sum_{r=1}^{R} \left(\prod_{t=1}^{T} \frac{exp(U_{int})}{\sum_{i=1}^{I} exp(U_{int})} \right) \right) \tag{3}$$

There is no consensus in the literature on the most appropriate choice probability distribution, however in environmental and energy applications it is common practice to assume normally-distributed random parameters.

Table 4
Renovation decision stages, definition and survey responses.

	Stage (0–3)	%	Questionnaire scenario description
0.	Not thinking about renovations	22.9	We're content with our home as it is. We wouldn't dream of making any major changes to its layout or physical properties
1.	Thinking about renovations as a possibility	29.6	We are aware of things we could change about our home by renovating. We may go ahead and renovate at some point in the future, or we may not, it all depends. We haven't yet got a good sense of the costs, contractors available, and how to get the work done
2.	Planning renovations	26.4	Planning renovation works but still finalising the details. We have some information about costs and financing options. We've talked to experts or contractors, and one or more has visited our home.
3.	Completed major renovations	21.1	Renovations are completed or all the details of our renovations are decided and renovations underway with contractors.

3. Results

3.1. Retrofit decision stages

Table 4 reports the proportion of households self-classifying into the four retrofit decision categories. Just 26.4% of households are actively contemplating home renovations, and therefore either have been or are potentially open to influence by public policy measures and incentives to undertake energy retrofits. The three other categories are outside the active influence of policy supports to undertake energy retrofits. Those at stage 0 "wouldn't dream of making any major changes to" their home, accounting for 22.9% of households. Almost 30% of households are at stage 1, and while potentially receptive to renovating their home, as they actively visualise some renovations, they have not taken concrete steps to investigate retrofit options. Finally, those at stage 3, some 21.1% of households, have already completed some type of home renovation and are not actively considering further renovations. The households at stage 3 are likely to encompass those with shallow energy retrofits only, as up to 90% of retrofit grant applications are for 1 or 2 measures only, with 50% for attic and cavity insulation (Collins and Curtis, 2016, 2017; Mac Uidhir et al., 2020).

A multinomial logistic regression was estimated to examine whether there are respondent and household attributes associated with renovation decision stage. The overall conclusion from the estimation is that a wide range of socio-demographic variables are not systematically associated with renovation stage. Variables included in the regression include property type, size and age; heating type; educational attainment; and income.

The CDL, IDM and Trigger variables described earlier were also included as explanatory variables, with their relative risk ratio estimates reported in Table 5. The Trig1 variable, that the respondent's home had experienced major problems such as heating system breakdown, has a relative risk ratio of 0.61 for stage 0. This means that in households with an infrastructural problem compared to households without such a problem, the relative risk of being in stage 0 versus stage 3 (i.e., completed renovations) would decrease by a factor of 0.61. For Trig3, which is more personal time for projects and interests, the relative risk ratio is 0.58. For Trig5, which is a change in family circumstances, the relative risk ratio is 0.64 for stage 0. For the other two trigger variables, the relative risk ratio is not statistically different than 1. What these results indicate is that certain one-off salient events are associated with households that have completed renovations. Broadly similar relative risk ratios and statistical significance occur for the trigger variables comparing stage 2 (i.e., planning renovations) with stage 0, which bolsters the inference just drawn.

Some of the relative risk ratios for the CDL and IDM variables reported in Table 5 are statistically different than 1. However, across the entirety of the estimates (including against other baseline categories) and except for the trigger variables, Wilson et al. (2018)'s argument that decisions on renovations emerge from the conditions of everyday domestic life (CDL), intentional decision-making (IDM) does not find strong empirical support in this instance.

3.2. Preferences related to retrofit disruptions

Table 6 reports the results of the econometric models used to assess respondents' preferences for the CE alternatives. The table shows an MNL model, which represents the baseline for the analysis, and a RPL model with correlated random parameters. Estimates are consistent, with coefficients having the same sign in the two models. The higher log-likelihood value obtained in the RPL model, together with lower AIC and BIC statistics, indicate a better fit of this model compared to the baseline MNL. This result indicates that accounting for preference heterogeneity provides a better fit for the choice data.

All attribute coefficients are significant at the 1 percent confidence level, which indicates that all attributes were relevant for respondents in their choices. The first remark we make on the estimated results relates to the coefficient associated with the capital cost of the refurbishment alternatives. The negative coefficient is as anticipated by economic theory: a negative sign indicates that respondents are cost-sensitive, and the utility of home refurbishment decreases as costs increase. The alternative specific constant (ASC) coefficient is also negative, which indicates that opting-out from refurbishment options generally reduces respondents' utility. This is an interesting result, which suggests that the sample had a generally positive attitude towards refurbishment.

The energy cost savings that are likely to accrue to respondents all have positive coefficients. The magnitude of the coefficients increases as the discount increases, which is also in line with economic theory: respondents obtain larger utility benefits in the presence of larger savings. This result was expected, as savings represent the main benefits that respondents obtain from the renovation alternatives.

In terms of disruption, coefficient estimates have negative signs, which reveal general disutility. Furthermore, coefficient sizes increase at increasing disruption levels. This result complies with the idea that disruptive internal home works represent a barrier to refurbishment.

The RPL model with correlated random parameters estimates coefficients that represent the elements of the Cholesky decomposition matrix, from which variances of random parameters are retrieved. All elements of the Cholesky matrix are available in Table 9. All variances are statistically significant at the 1 percent confidence level, indicating that preferences are heterogeneous across the sample of respondents. The last column in Table 6 shows the coefficient of variation (CV),[4] which offers a measure of the extent of variability in relation to the mean of the sample. As a general interpretation rule, larger CVs correspond to parameters with large preference heterogeneity. The ASC coefficient is associated with a CV of about 1.8, which indicates that respondents have a relatively large degree of variability in their preferences for undertaking home refurbishment. The coefficients associated with energy cost savings have instead a relatively small amount of variation, as the CV is constantly lower than 1 and close to .8 for all

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[4] The CV is calculated as $\frac{\delta}{\mu}$, where δ is the standard deviation of the random parameter and μ the mean.

Table 5

Relative risk ratio estimates:[a] retrofit decision stages.

Variable	Stage 0		Stage 1		Stage 2	
	Not thinking about renovations		Renovations a possibility		Planning renovations	
	RRR	*p*-value	RRR	*p*-value	RRR	*p*-value
Trig1	0.61	0.01*	1.04	0.88	1.19	0.48
Trig2	0.86	0.65	0.43	<0.01*	0.97	0.91
Trig3	0.58	<0.01*	0.97	0.88	0.81	0.32
Trig4	0.84	0.55	1.10	0.75	1.57	0.20
Trig5	0.64	0.04*	0.88	0.57	0.98	0.93
CDL1	0.98	0.95	1.08	0.73	1.20	0.46
CDL2	1.67	0.11	1.18	0.51	1.22	0.43
CDL3	1.23	0.47	1.67	0.08	1.18	0.51
CDL4	0.76	0.18	0.86	0.47	1.07	0.76
CDL5	0.52	<0.01*	0.75	0.17	0.99	0.97
IDM1	0.45	<0.01*	0.44	<0.01*	0.69	0.09
IDM2	1.20	0.55	1.44	0.23	1.57	0.17
IDM3	0.60	0.02*	0.78	0.29	0.58	0.01*
IDM4	1.24	0.49	1.30	0.38	1.13	0.66

The asterisk on *p*-value results highlights statistical significance different than 1 at 5% level or better.

Estimated regression included controls for property type, size and age, heating type, educational attainment, and income.

[a] Baseline category is stage 3, completed major renovations.

Table 6

Choice experiment econometric models.

Variable	MNL estimates	RPL means	RPL variances	CV
Attributes:				
Capital cost	−0.038***	−0.069***	(fixed)	
	(0.001)	(0.002)		
ASC	−0.492***	−1.109***	3.57***	1.79
	(0.053)	(0.153)	(0.172)	
Energy cost savings:				
30 percent	0.952***	2.107***	1.518***	0.85
	(0.055)	(0.117)	(0.139)	
50 percent	1.917***	3.622***	1.977***	0.74
	(0.058)	(0.139)	(0.138)	
70 percent	2.019***	4.031***	2.604***	0.80
	(0.060)	(0.164)	(0.141)	
Disruption:				
Minor	−0.375***	−0.619***	0.381***	0.78
	(0.049)	(0.076)	(0.111)	
Moderate	−0.485***	−0.887***	0.985***	1.05
	(0.051)	(0.083)	(0.142)	
Major	−0.942***	−1.697***	1.576***	0.96
	(0.053)	(0.111)	(0.129)	
LL	−7467.95	−5809.46		
AIC	14 952	11 691		
BIC	15 008	11 942		
Observations	8072	8072		
Respondents	1009	1009		

Standard errors in parenthesis.

*,**, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

Table 7

Average WTP estimates.

Attribute	WTP
Energy cost savings:	
30 percent	30.71***
	(1.654)
50 percent	52.81***
	(1.874)
70 percent	58.76***
	(2.012)
Disruption:	
Minor	−9.02***
	(1.078)
Moderate	−12.92***
	(1.183)
Major	−24.74***
	(1.501)
ASC (do not renovate)	−16.17***
	(2.177)

three levels of savings. This indicates that preferences for cost savings are more homogeneous across respondents, and that all respondents would be better off with a lower energy bill. In the case of disruption, the CV for the lower levels is .78, which indicates that the variation of preferences across the sample is relatively small, while the CVs are larger and close to 1 in the case of moderate and major disruption. This result indicates that respondents have a broader distribution of utility and reactions to moderate or major disruption levels.

Table 7 reports WTP estimates for the CE attributes estimated using the delta method. Such estimates indicate that respondents are willing to invest increasing amounts to obtain larger savings in their energy bill. However, disruption is a limiting factor to such investments being made, as increasing levels of disruption substantially reduce the net benefit of investment. For instance, average WTP associated with major disruption is €−24,740, which almost offsets WTP for 30% energy cost savings, or half of the WTP for 50% energy cost savings. In both these cases the net benefit of renovations is still positive and from a rational economic perspective the renovation investment would proceed. In practice we see many households undertaking energy efficiency renovations. However, the mean WTP values mask important variation across the distribution of WTP, which is discussed in the next section.

3.3. *Analysis of preference heterogeneity*

The RPL model allows estimating individual-level WTPs for energy cost savings and disruption levels. The distribution of WTP across the sample may be visually displayed by kernel density plots, which are reported below. In Fig. 2 the extent of WTP for energy cost reduction are displayed. Preferences for 30% energy cost savings are concentrated across the average value of almost €31,000, though right-skewed. What is interesting about preferences for 30% energy cost savings is that in the right tail there is relatively high support for WTP of €50,000 but beyond that support is effectively zero. In essence, €50,000 appears to be a hard ceiling of WTP for renovations yielding 30% energy cost savings. The WTP distributions for 50% and 70% energy cost savings have the more conventional bell-shape, though exhibiting fat tails. The three plotted distributions in Fig. 2 show the broad heterogeneity in preferences for energy efficiency renovations delivering energy cost savings. There is a substantial share of households willing to pay in excess of €80,000 for renovations that yield relatively high energy costs savings. However, on the other end of the spectrum, there are households willing to pay relatively small amounts (e.g., €20,000) for

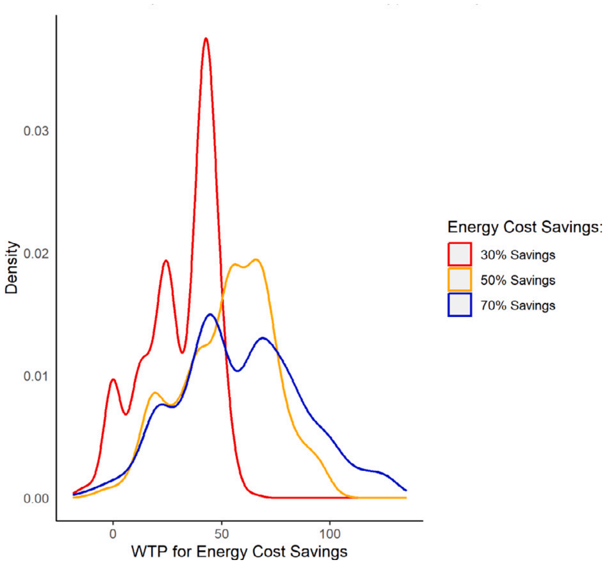

Fig. 2. WTP for energy savings.

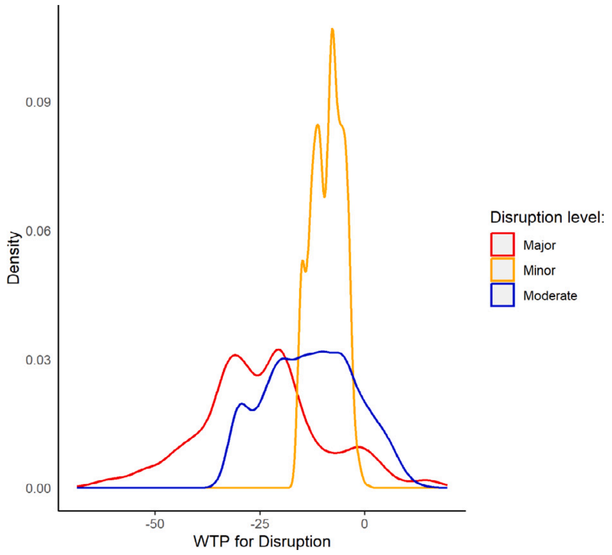

Fig. 3. WTP distribution for disruption.

Table 8
Present value of energy bill discounts of 30%, 50% and 70%.

Energy bill discount	Discount rate			WTP estimate (Table 7)
	4%	8%	12%	
70%	€37,815	€27,319	€20,784	€58,760
50%	€27,011	€19,514	€14,846	€52,810
30%	€16,206	€11,708	€8907	€30,710

similar levels of energy cost savings. This large distribution in WTP reflects both innate differences in preferences, and differences in ability to afford the underlying renovations.

We compare these WTP figures for energy cost savings to the present value of the savings based on average annual expenditure on energy bills in September 2023, the time the survey was carried out (CRU, 2023). The Commission for the Regulation of Utilites reports Estimated Annual Bills (EABs) for various tariffs. For our purposes, we use an average of all standard tariffs available for gas and electricity in 2023, weighted according to market share. We use standard compared to discounted tariffs, as the majority of energy consumers do not switch energy supplier on an annual basis. We assume the payback period is twenty years, and calculate the present value of the energy savings for discount rates of 4%, 8% and 12%. Table 8 displays the present value for the different energy bill discounts. Even at the very low discount rate of 4%, the willingness to pay for a reduction in energy bills far outweighs the present value of the actual energy bill savings. The gap between willingness to pay and present value of the energy savings is even higher at higher discount rates. While these savings were calculated on the basis of average energy usage, and we cannot match the stated willingness to pay with an estimate of the energy bills on a respondent-by-respondent basis, it is reasonable to infer the either that the majority of respondents see greater value in energy retrofits than the simple financial reduction in energy bills, or that they overestimate the value of energy bill reductions. Furthermore, energy bills have declined since September 2023 and are likely to continue to do so, which means the present value of energy savings will decline.

Fig. 3 plots the distributions for the various levels of renovation disruption. Recall that minor disruption was defined as "minor internal works, dust and materials affecting use of some rooms during renovation". As noted earlier in Table 7, mean WTP is €−9000, while the plot of the distribution clearly illustrates that the variation of preferences is relatively small. Thus, renovations with minimal levels of disruption still represent a disutility to households, and while there is some heterogeneity in preferences across households it is relatively modest. The distribution of preferences for higher levels of disruption is much wider. Similar to the energy cost savings estimates, the kernel estimates of the distribution of WTP exhibit fat tails. For moderate disruption, which is described as rendering some rooms unsuitable for use at times during renovations, a substantial share of households price that disruption in excess of €20,000. Where disruption means that the whole property is not suitable for use during renovations, the price of disruption is substantially higher for many households. On the other end of the spectrum, many households see the disutility of disruption as being relatively low. For either moderate or major levels of disruption, there is wide variability in preferences across households. Consequently, while the net financial benefits of renovation investment may be positive in many instances, disruption is usually not priced in those calculations. The rational decision from a financial perspective may be to proceed with the renovation, whereas from the perspective of the household that implicitly prices the disruption cost, the rational decision might be to decline proceeding with the renovation investment.

4. Discussion

Many countries, especially in the EU, have implemented policy measures to improve the energy efficiency of the residential housing stock. There is broad political support for such measures, especially in the aftermath of increasing energy costs associated with the war in Ukraine, and the wider cost of living crisis. Even with strong financial supports and a broad consensus on the need to improve energy efficiency, progress towards policy targets has been slow.

Policy supports for energy efficiency upgrades often take the form of a uniform grant and/or loan scheme, which applies equally to households and partially covers the cost of investment. Such policies exhibit two underlying assumptions: first, that most households are receptive to undertaking energy efficiency renovations, and second, that preferences for energy efficiency investment are homogeneous across households. Our results question both of these assumptions via several different angles. In particular, this research finds that only a minority of households are currently contemplating, or would contemplate, renovations, and therefore are potentially receptive to policy incentives. As noted in Table 4, just 26% of households are actively planning home renovations. A further 30% are potentially receptive to undertaking renovations but have not made any active decisions in that direction.

Therefore, approximately half of all households are currently receptive or potentially receptive in the future to undertaking renovation works to improve their homes' energy efficiency. With the survey results being a point-in-time assessment, these figures may change over time.

Regarding those who are not potentially receptive to renovation works, some 21% of households have undertaken prior energy retrofit works and are not open to additional retrofit measures. Prior research suggests that many of the households in this category may have only completed shallow retrofit measures (Collins and Curtis, 2016), which are substantially below current policy ambition. A further 23% of households "wouldn't dream of making any major changes" to their homes. In summary, at the point of the survey, just 1-in-4 households are actively receptive to policy supports to improve residential energy efficiency. A further 3-in-10 households are potentially receptive to policy incentives but have not taken any active steps to undertake home renovations. The balance, or roughly 1-in-2 households, are not receptive to policy measures to improve residential energy efficiency. These findings undermine the first assumption underlying retrofit policy, namely that most households are potentially open to retrofitting.

Our findings also undermine the second assumption, that of homogeneous preferences for retrofitting across households. Several data points support this claim. First, the large coefficient of variance associated with the ASC coefficient indicates that there is a relatively large degree of variability in homeowners' preferences for home refurbishment. Furthermore, there is considerable variation in the kernel density plots for WTP for energy cost savings and disruption avoidance. Regarding the latter in particular, 50% of homeowners place the cost of major disruption between approximately €17,000 and €33,000, with 25% placing a cost on major disruption at less than €17,000 and the final 25% placing a cost on major disruption at anything from €33,000 to €69,000. Given that grants in Ireland for external wall insulation and electric heat pumps combined come to between €7500 and €14,500, there is potential both for deadweight loss, where the grant is excessive for some homeowners, and also that the grant is insufficient to cover the cost of disruption as reported by the majority of homeowners. In other words, the flat rates of the grants available are too high for some households and too low for others.

Within the academic literature on residential energy efficiency, there is an argument that decisions on home renovations are not purely made as investment or financial decisions but occur in the context of everyday conditions of domestic life and intentional decision-making. These include decisions in the context of homes and families rather than property assets and financial returns. The premise of the argument, advocated by Wilson et al. (2018) amongst others, presents a plausible narrative to understand reticence in undertaking energy efficiency renovations. The current study attempted to find empirical support for the theory that decisions on renovations emerge from the conditions of everyday domestic life (CDL) and intentional decision-making (IDM), but failed to do so. The CDL and IDM concepts that Wilson et al. (2018) advocate are subtle and nuanced, making them difficult concepts to explicitly measure within the context of a survey. While the questions used within our survey to capture data on CDL and IDM were adopted from Wilson et al. (2018), fewer questions were used to reduce respondent burden within the survey. A case could be made that the 9 questions eliciting CDL and IDM data in the current study are insufficient to adequately capture the subtle complexity of CDL and IDM. A contrary point is that without relatively simple metrics to observe CDL and IDM, the concepts have limited practical benefit to inform public policy development.

Wilson et al. (2018) also argue that one-off, high salience events potentially act as triggers for undertaking home renovations, with the level of influence of the trigger event depending on family circumstances. The results from Table 5 provide empirical support for this hypothesis. While it is not surprising to find that a change in circumstances (e.g., windfall gain, retirement, family composition, illness, etc.) may trigger a decision to renovate a home, it is not immediately obvious that policy incentives can or should be specifically adopted for these specific types of events. However, families that find themselves in these situations might benefit from customised supports, such as tailored information and guidance, that could increase the likelihood of undertaking an energy efficiency renovation. Given that the State is typically informed via civil registration, taxation and/or social protection applications of many major life events, including purchasing a home, a birth, retirement or death, or a change of employment, there is potential to tailor supports and policies for households undergoing such a change.

The primary focus of the choice experiment was to estimate a price for disruption associated with residential energy renovations. A general result from the choice experiment is that overall, we find that opting-out of refurbishment options generally reduces respondents' utility, which indicates that there is a generally positive attitude towards energy retrofits. The second overall result from the choice experiment is that presenting results on homeowner preferences for energy retrofits as mean values masks the diversity of preferences across households. While Table 7 reported mean WTP values for both energy cost savings and disruption, the more relevant policy finding is that the WTP estimates span a wide range. This applies even in the case of attributes as simple as energy cost savings. In the case of minor disruption associated with dust and materials within the home, the distribution of WTP for that disruption was relatively tightly centred around €−9000. However, in the case of moderate or major disruption, which comprised either some rooms not being suitable for use during retrofit works, to the entire home not being available for use, the variance in the price of disruption is much greater. This large range in the distribution of the price of disruption illustrates why renovation decisions are not merely financial decisions.

Many non-financial barriers have been identified in the literature (Sorrell et al., 2004; Dolšak, 2023; Cattaneo, 2019), though the implicit value that homeowners place on disruption has not been prominently considered. The results here demonstrate this as a potential gap in understanding of retrofit barriers, as well as confirming results from several earlier studies (e.g., Scarpa and Willis, 2010; Meles et al., 2022; Schleich et al., 2022). Estimates of the price of disruption by Meles et al. (2022) also relate to Irish households but are substantially lower, being between €2600 and €8000 for 95% of households. Whereas Meles et al. (2022) considered a simple ordinal measure of installation hassle (i.e., low, moderate, high), the current study defined the disruption attribute in much more detail (see Table 3), so the estimates are not directly comparable. Current levels of grant supports for energy retrofits are generally designed to bridge the gap to make undertaking retrofit works financially rational. where households implicitly price disruption relatively modestly, the likelihood that renovations proceed may be slightly impacted, but where disruption has a high implicit price, the likelihood that renovations proceed may be substantially diminished.

The willingness to pay for a reduction in energy bills suggests that households either see greater value in energy retrofits than the value of energy bill reductions, or that they overestimate the value of energy bill reductions. It is not obvious the extent of either category. However, even when combining this over valuation/estimation (via a present value) with the available grants, the benefits of home retrofits are not great enough to bridge the gap with the capital and disruption costs of retrofitting for many households. This gap may render policy targets for retrofitting more challenging. Furthermore, communication of the benefits in terms of energy savings should be carefully designed: given that a significant number of consumers seem to overestimate the benefits of energy savings compared to the costs. More accurate communication of the benefits may undermine, rather than promote, retrofitting.

Quantifying the distribution of preferences and the implied price of disruption associated with residential energy renovations has direct relevance to policymakers seeking to improve energy efficiency and

Table 9
Cholesky decomposition coefficients.

	Energy cost savings			Disruption			ASC
	30%	50%	70%	Minor	Moderate	Major	
30%	1.518***	1.854***	2.133***	−0.119	0.033	0.19	2.665***
	(0.139)	(0.148)	(0.163)	(0.098)	(0.105)	(0.142)	(0.21)
50%		0.684***	1.464***	0.047	0.466***	0.48**	−1.894***
		(0.102)	(0.145)	(0.108)	(0.151)	(0.231)	(0.22)
70%			−0.293	−0.134	0.044	1.029***	0.987***
			(0.209)	(0.159)	(0.325)	(0.318)	(0.321)
Minor				−0.333***	−0.851***	−0.581	0.878***
				(0.116)	(0.191)	(0.412)	(0.301)
Moderate					−0.16	−0.874**	0.113
					(0.209)	(0.346)	(0.415)
Major						0.237	0.512
						(0.409)	(0.337)
ASC							0.187
							(0.351)

Standard errors in parenthesis.
*,**, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

reduce energy use in the residential sector. The immediate follow-on question is whether the heterogeneity of preferences can be associated with homeowner or other attributes that policymakers can leverage to more effectively design or target policy measures? The short answer is no. Whether in attempting to better understand the composition of retrofit decision stages, as outlined in Section 3.1, or the heterogeneity of preferences in Section 3.3, we fail to find empirical evidence of correlation with a wide range of socio-demographic and other variables. Variables considered include income, education, building type, age, heating type. This suggests that moving away from a flat-rate grant that applies equally to most households and towards a more targeted approach, where funds are directed towards households most likely to retrofit, faces significant challenges, and improving the current policy is not straightforward.

5. Conclusion and policy implications

Home renovation is a trade-off decision between monetary benefits (i.e. energy bill savings), investment costs, and non-monetary barriers that may refrain households from undertaking internal works. One of these non-monetary barriers is disruption. Without knowing household preferences for home renovation and disruption, the outcome of political support for energy efficiency measures, including grant schemes, is uncertain. This article utilised a choice modelling framework to determine whether households make trade-offs between expected energy savings and home disruption during the renovation timeframe. Results indicate that participants are willing to pay (i.e., undertake an investment), on average, in the range of €30–58k for energy cost saving of 30–70 percent. However, when home disruption is considered, investment levels decrease considerably with WTP declining by between €9–25k, on average, depending on the disruption level. The results further find that preferences are highly heterogeneous for both energy savings and disruption.

The results of this work are informative for future energy policy measures. Under the assumption that individuals are responsive to monetary incentives, several countries provide financial support to upgrade the energy efficiency of residential housing stock and achieve the EU's decarbonisation vision. In most cases, incentives are grants for which all households can apply for a fixed value amount to partially cover the investment costs of energy upgrades. This practice implicitly assumes that preferences are homogeneous across households but it does not consider that households may not necessarily respond to such incentives. One of the causes of such non-responsiveness might be the disutility associated with disruption. The results of this work support the hypothesis that disruption may be a relevant non-monetary barrier for home renovation. A further analysis on the socio-demographic determinants of preference heterogeneity did not allow outlining a clear profile of renovation takers and averters. This result complicates efforts to deploy more targeted approaches to grant schemes. The analysis of the attitudinal questions, personal triggers, and conditions of life suggests that the decision to renovate is often taken based on personal motivations, which are difficult to target with policy measures.

CRediT authorship contribution statement

John Curtis: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Gianluca Grilli:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Muireann Lynch:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: John Curtis, Muireann Lynch reports financial support was provided by MaREI the SFI Research Centre for Energy Climate and Marine [Grant No: 12/RC/2302_P2]; DCC plc; and the ESRI's Energy Policy Research Centre. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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