Participation in domestic energy retrofit programmes: key spatio-temporal drivers

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Participation in domestic energy retrofit programmes: key spatio-temporal drivers

RESEARCH

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ABSTRACT

The Canadian government created the EcoENEGY Retrofit for Homes programme (2007–12) to improve residential energy efficiency and reduce emissions produced through energy use. The uptake of retrofits varied both spatially and temporally. This research examines spatio-temporal patterns of retrofit adoption to understand the drivers behind participation in the grant programme and assess how future grant-based programmes might improve the uptake of efficiency measures. Temporal analysis demonstrated continued growth of programme participation over its original period of availability, and this accelerated once the programme was extended for an additional year after its original closure date. However, some spatial correlations weakened, which may be attributable to changes in programme design during the extension period. Seasonal variation was also observed, with spikes in retrofit activity occurring in winter. A regression analysis for conversion rates in Ontario and British Columbia displayed significant positive correlations for high shelter costs (>30% of household income) and households occupied by usual residents (regular occupants). Population density, median property value (only in Ontario) and units that were recently occupied demonstrated negative correlations. Spatial variation at both the city and neighbourhood levels suggests a greater degree of programme customisation is required to ensure uniform building stock improvement.

POLICY RELEVANCE

Domestic retrofit will be a crucial component of every developed nation's net zero strategy. For example, in Canada and the UK, houses account for 13% and 20% of energy-related greenhouse gas emissions, respectively. This paper explores trends in the most recently completed national retrofit programme in Canada, demonstrating rates of adoption across the programme, the effects of programme design modification, and the value of an understood programme brand and format for uptake. Further, when faced with tighter deadlines, there is a weakening of the relationship between adoption and spatially

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linked attributes such as population density, and duration of occupancy. Conversely, a strengthening of the relationship with levels of education and household costs was observed in some jurisdictions. The evidence in this paper strengthens the case for long-term, actively managed retrofit programmes to enable the skills base and consumer interest towards market transformation.

1 INTRODUCTION

Households accounted for nearly 13% of national greenhouse gas (GHG) emissions from energy use and about 17% of all secondary energy use in Canada in 2018, with over 80% of this used for space-conditioning and water heating (NRCan 2019b). Further, it is estimated that the average Canadian household spends about C$2000/year on domestic energy needs (NRCan 2016, 2019b). Mohareb & Kennedy (2014) estimate that even with complete grid decarbonisation and modest efficiency improvements to the entire housing stock, direct household fossil (*i.e.* natural gas and fuel oil) energy demand poses a substantial barrier to deep reductions in GHG emissions. This necessitates broad-based household-level action to shift individual end users to low-carbon heating alternatives and substantial reductions in heating requirements through improved building envelope performance. Hence, energy retrofit of the existing housing stock will be an important component of Canada's long-term GHG reduction goals (Government of Canada 2019).

The Canadian EcoENERGY Retrofit for Homes (ERfH) programme was created to address such ongoing challenges, and dramatically expanded in the wake of the 2007–08 financial crisis. It had the stated goals of:

> encourage the existing low-rise housing sector in Canada to become more energy-efficient, reduce emissions produced through energy use, and contribute to clean air, water, energy, and a healthy environment for Canadians.
>
> (NRCan 2010: 12)

However, uptake of this programme varied considerably nationwide; participation was not spatially uniform (nor was it temporally uniform, as will be discussed). The share of the existing single-family dwelling (SFD) stock that participated in the programme differed between cities, even within provinces (***Figure 1***). Insight from the US suggests unequal access to domestic low-carbon energy schemes (Carley & Konisky 2020; Sunter *et al.* 2019); if future deep retrofits of the building stock are to be achieved, previous policies and programmes need to be examined at spatially and temporally disaggregated scales to understand how to ensure rapid, universal adoption of low-carbon technology.

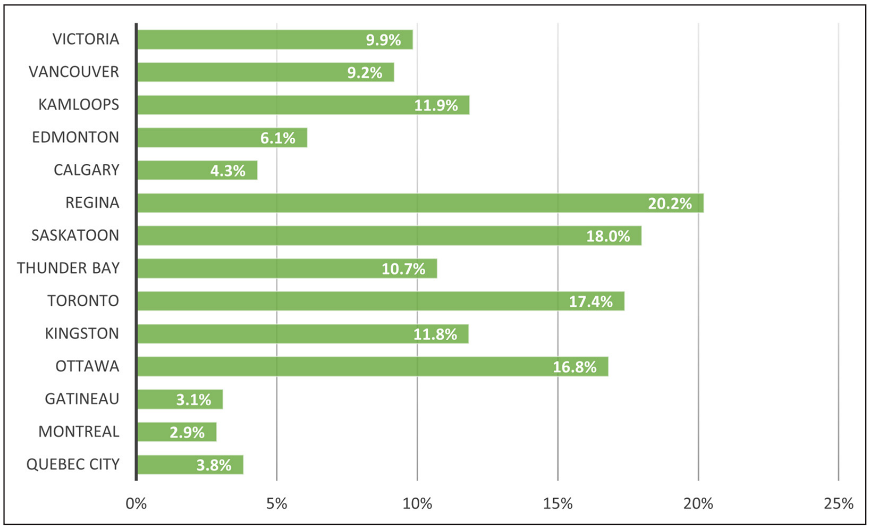

Figure 1: Percentage of occupied single-family dwelling stock retrofitted during the EcoENERGY Retrofit for Homes (ERfH) programme in selected Canadian urban areas.

Note: Estimated using programme data and 2011 Census data for urban forward sortation areas.

Source: Statistics Canada (2019a).

The ERfH rogramme was declared a success by the central government for having provided an estimated annual savings of C$400 million on energy bills, or 20% of the average participant's yearly costs, and stimulated C$8 billion in economic activity (NRCan 2013). However, the formal evaluation of this programme was carried out at an aggregated level, and no detailed breakdown of the programme's performance has been carried out to date to investigate how the results varied nationwide. Furthermore, the programme also sits within a wider policy landscape of retrofit market transformation efforts that are seeking to reduce emissions from Canadian homes. Evidence strongly suggests that such market transformation efforts require active programme strategies to address both cost and non-cost barriers. There is also a need to balance a national-level target and programme structure with flexibility to accommodate local delivery factors.

The paper will use this analysis to answer the following questions:

- How did the ERfH programme perform against its stated objectives? And how did the national-level headline statistics reported by the central government break down both spatially and temporally?
- Based on these findings, what lessons can be learned from ERfH about the balance between national programme frameworks and local programme delivery factors, with a focus on market transformation?

This will be done using spatio-temporal analysis, which is novel in its application for retrofit programmes. Further, it is the first disaggregated countrywide analysis of the ERfH programme, as well as the first detailed analysis of drivers across two major Canadian provinces (using multiple linear regression—MLR), which is useful when assessing the success of current retrofit programmes underway. Ultimately, this research endeavours to clarify where, when and why differences in retrofit adoption under the ERfH programme existed, how programme changes might have affected these and what this might signify for retrofit programmes towards a strategic approach for market transformation.

This paper is structured as follows. A literature review outlines the typical drivers/barriers to retrofitting seen in other programmes, the wider retrofit market transformation landscape within which it sits and the evaluations of the ERfH programme so far. The methods section will describe the data sources used to carry out a more granular temporal and spatial analysis of the ERfH performance data. Pre- and post-retrofit data are examined for all audits and retrofits carried out under the ERfH programme (April 2007–March 2012), including the original and extension periods in which it ran. The data are then analysed to determine the drivers of retrofit uptake in Ontario (ON) and British Columbia (BC) using regression analysis; drivers of adoption uncovered in previous studies were examined at the selected level of disaggregation (forward sortation areas—FSAs) for the ERfH programme using MLR, along with publicly available process evaluation reports to explore the reasons for the variations. The background description of the ERfH programme, its design and high-level outcomes are provided in the supplemental data online.

2 THEORY

2.1 CURRENT STATE OF RESIDENTIAL RETROFIT ADOPTION

Existing research generally suggests that the provision of financing and information is insufficient to drive the widespread uptake of domestic thermal retrofit (Fuller *et al.* 2010). Policies based on price signals and communication of the benefits of improved comfort have convinced early adopters in most markets to retrofit, but have failed to drive self-sustaining energy efficiency improvements at scale. For example, in 2011, only 12% of Canadian households had undertaken an energy audit in the past 10 years, and only 76% of those have adopted an energy-saving retrofit (NRCan 2011); this is underwhelming considering that this was during a period of funding availability from both federal and provincial programmes. The core barriers to domestic retrofit have not fundamentally changed in decades of study and governmental policy; these include the low priority of energy issues, information asymmetries, up-front cost and split incentives that have not fundamentally changed in decades of study and governmental policy (Sorrell *et al.* 2004; IEA 2007).

2.2 MARKET TRANSFORMATION

One notable change in retrofit programme design since the 1980s has been a gradual shift away from demand-side management (DSM) programmes towards market-based, whole-house approaches. Typically, DSM programmes have discrete objectives such as deploying energy-efficient lighting (Johnson 1997), boilers (Birner & Martinot 2005) or insulation (Ferguson *et al.* 1991b; Eto *et al.* 1996). Such programmes were very successful within these narrow definitions, but quite limited compared with what was technically feasible for overall domestic efficiency (Blumstein 2010).

The whole-house focus is often framed as part of a more comprehensive approach to transforming markets supporting retrofit delivery as opposed to the individual technologies themselves. 'Market transformation' is a strategic effort to target changes in a market causing structural improvements that lead to dramatic increases in energy-efficient technology adoption (Nadel *et al.* 2003). Due to the fragmented supply chains required to deliver a whole-house retrofit market, programmes incentivising this are required to be more comprehensive than the DSM programmes of the past. The concept of 'market transformation' has been characterised as a gradual reorientation towards the uptake of a given technology; it begins with an early research, development and testing phase for a new product or process, followed by a capacity-building phase in which information and rebates are used to reduce the price barrier, driving uptake among early adopters. These information and pricing mechanisms are used to build capacity in the market until the supply chain is sufficiently developed so that codes and regulations can be effectively implemented to convert the remaining adopters. The market transformation process typically requires a portfolio of programmes operating in a coordinated manner.

Domestic thermal retrofit programmes, such as ERfH, form part of the capacity-building phase, but have repeatedly failed to climb the steep part of the market transformation curve to create systems where thermal retrofit markets can operate successfully using regulations alone. It has repeatedly been shown that a retrofit programme whose design is solely based on the provision of grants will stimulate the market only as long as the grant remains (Gillich 2013). Once the grant is removed, the market effect is likely to disappear. Some retrofit markets have been maintained through programmes such as the Weatherisation Assistance Programme in the US or the Efficiency Obligation schemes across the European Union. However, these programmes largely target the social housing market, and many countries are reluctant to similarly support able-to-pay markets (Gillich *et al.* 2018).

Academics have noted that retrofit markets are by nature more diffuse and complex than single technologies, and it is uncertain how to effectively implement market transformation at scale (Killip 2011). There have been many notable efforts in advancing portions of markets over a particular time period (USDOE 2015), and academics have advanced frameworks for market transformation (Gillich *et al.* 2018). However, a recent review of international market transformation efforts found that no country has yet succeeded in transforming thermal retrofit markets to the scale needed (Greer *et al.* 2021).

Across the range of work done on retrofit market transformation there is now a strong consensus on several key ideas. First, cost is still the paramount barrier to retrofit at scale. Any market transformation effort should include a strategy to reduce the upfront cost barrier and grants are a cost-effective mechanism to drive demand (Gillich 2013). For many of the relatively simple-product market transformations referenced above, cost signals were sufficient to drive demand, and other supply chain factors such as installer skills were largely self-addressed through market forces in the presence of sustained demand. The retrofit service market, however, is more diffuse and fragmented, and there is strong evidence from past programmes across multiple countries that cost signals alone will not align the other elements of the supply chain to create a sustained change (Greer *et al.* 2021; Gillich 2013). Therefore, any programme targeting retrofit market transformation must include strategies to address both cost and non-cost barriers.

Furthermore, where the programme uses grants and rebates to reduce the upfront cost barrier, this should be done with care so as not to disrupt price signals in the longer term. There is again strong evidence from multiple programmes across multiple countries that 'stop–start' grants that offer short-term rebates lead to boom and bust cycles in the market (Gillich 2013). This is detrimental not only to the direct uptake of energy saving measures, but also damages the wider market effects, such as homeowner levels of knowledge and workforce skill levels, by creating an industry (and adopters) that chases subsidies.

It should be noted that many of the previously mentioned retrofit markets that have been maintained are ratepayer-funded programmes supported by small fees on utility bills, as opposed to public spending. Hence, these are easier to maintain in the longer term. Furthermore, most of such programmes typically only target portions of the market, such as low-income households. For Canada and other developed countries, owner-occupiers (or 'able-to-pay') are the largest segment of the market, and less likely to have costs supported by a grant programme on an ongoing basis. Most policies targeting the able-to-pay market are created as temporary subsidies (one to three years) with the aim of kickstarting self-sustaining changes (Middle Class Task Force 2009; NRCan 2010). Within these, several key factors have been identified which households engage with such programmes.

2.3 FACTORS IMPACTING RESIDENTIAL RETROFIT ADOPTION

Since the oil embargo era of the 1970s, and the associated programmes to improve energy efficiency across various sectors, many studies have attempted to understand how retrofit decisions are made. ***Table 1*** provides a summary from various literature sources that have attempted to explain the rationale behind retrofit in the residential sector (for more details on the data sources in these studies, see ***Table S2*** in the supplemental data online). The studies have evaluated external variables relevant to the decision-maker (*e.g.* climate, energy costs), but also include characteristics of the occupant (*e.g.* age, income) and the house itself (*e.g.* building age, size). Generally, these studies characterise domestic energy retrofit adopters as middle-income, working-age, single-family households, living in older SFDs, who are trying to reduce energy bills and/or take advantage of an economic subsidy (*i.e.* tax credits, grants).

There is limited research on temporal effects (*e.g.* seasons) and spatial effects (*e.g.* local networks) in driving the adoption of domestic energy efficiency measures. The potential of local networks to enable communication of retrofit decisions between peers (*e.g.* neighbours or cultural/religious groups) may accelerate retrofit adoption with a given spatial context. Wilson & Dowlatabadi (2007) describe psychological processes in energy decision-making, including the theory of planned behaviour, which are reliant on social norms and can help develop self-efficacy in energy behaviours (*i.e.* the ability to act on a perceived problem). The dataset used in the present study allows some exploration of these temporal and spatial aspects, in addition to confirming whether the findings of these previous studies are consistent with the ERfH programme.

Table 1: Drivers of home energy retrofit adoption from selected literature sources.

Notes: [a] Study focuses on renewable energy adoption.

DRIVER	EXPLANATION AND SOURCES
Climate	Adoption correlated with the number of cooling and/or heating degree-days (Walsh 1989)
Household attitudes	Beliefs that measures will save energy/money encourage adoption (Brown 1984; Tonn & Berry 1986; Pettifor *et al.* 2015; Trotta 2018); improve comfort (Brown 1984); improve property value (Tonn & Berry 1986); and create positive perceptions of retrofit adoption from family/friends (Sardianou & Genoudi 2013)[a]
Household income	Households with greater income levels have the means, information and/or degree of understanding to exploit energy saving opportunities. This is generally observed at middle- rather than high-income levels (Brown 1984; Ferguson *et al.* 1991a; Michelsen & Madlener 2012; Smiley 1979; Tonn & Berry 1986; Walsh 1989; Sardianou & Genoudi 2013)[a]. Those with medium and high incomes are more likely to invest in energy efficiency (Trotta 2018); very low incomes are less likely to invest (Ferguson *et al.* 1991a)
Improved information	Households with more information about their energy consumption will act to reduce their demand (Brown 1984; Allcott 2011); have knowledge of a subsidy programme (Tonn & Berry 1986); and are present during energy audit (Tonn & Berry 1986)

(Contd.)

DRIVER	EXPLANATION AND SOURCES
Subsidy programme design	Tax credit schemes may lead to lower engagement than grants (Walsh 1989); a robust energy efficiency 'ecosystem' builds a network of actors to drive participation (Gillich *et al.* 2018); tax deductions and subsidies are more appealing than increasing energy costs (Sardianou & Genoudi 2013)[a]; the availability of grants is more likely to drive retrofit than no grant (Das *et al.* 2018; Gamtessa 2013; Hoicka *et al.* 2014), with one suggesting these are nine times more likely (Das *et al.* 2018); and the availability of grants increased the number of recommendations made, as well as those taken (Hoicka & Parker 2018)
Household composition	Households with multiple families are less likely to retrofit (Ferguson *et al.* 1991b); households with older occupants are less likely to retrofit (Smiley 1979; Brown 1984; Walsh 1989; Michelsen & Madlener 2012; Sardianou & Genoudi 2013)[a]; households with children are less likely to retrofit (Das *et al.* 2018); households with more occupants are more likely to retrofit than those with a single occupant (Das *et al.* 2018); women are generally more likely to make energy-efficient retrofit investments (Trotta 2018); and respondents living with a partner more likely to invest (Trotta 2018)
Household age or relative efficiency	Older homes tend to be better candidates for retrofitting due to lack of recent energy efficiency measures; more efficient homes are less likely to insulate, less efficient homes are more likely (Ferguson *et al.* 1991b; Gamtessa 2013; Smiley 1979; Michelsen & Madlener 2012; Sardianou & Genoudi 2013[a]; Das *et al.* 2018)
Heating energy source	Inefficient households using expensive energy sources (fuel oil, electricity) for heat are more likely to retrofit (Ferguson *et al.* 1991a)
Larger dwellings	A greater conditioned area of a house may lead to greater costs, hence a greater incentive to retrofit (Ferguson *et al.* 1991a; Walsh 1989)
State of repair	Homeowners' perception of the need for general renovation beyond regular maintenance (Ferguson *et al.* 1991b); other renovations planned (Pettifor *et al.* 2015)
Type of dwelling	Single-family detached homes tend to be larger and have a greater proportion of exposed building envelope when compared with semi-detached houses and rowhouses (Ferguson *et al.* 1991b; Trotta 2018)
Mobility	Households not able to move (*e.g.* due to the presence of children or occupants' age) are more likely to complete retrofits (Ferguson *et al.* 1991b); renters are less likely to participate (Walsh 1989)
Education of maintainers	Greater awareness of energy efficiency cost and environmental benefits (potentially correlated with higher incomes) (Ferguson *et al.* 1991a; 1991b); better education of occupants resulted in less retrofitting (Das *et al.* 2018); better education is not correlated with energy-efficient investments (Trotta 2018)
Rural setting	Households in rural areas are more likely to retrofit heating equipment due to the relative prevalence of expensive heating fuels (*e.g.* fuel oil, wood, propane); as well, urban residence may also be correlated with lower mobility (Ferguson *et al.* 1991a)
Heating costs	Costs of heating were not found to be an indicator of retrofit activity (Smiley 1979); expected future cost rises were estimated to motivate adoption (Walsh 1989)
Community effects	Relatively low numbers of African American owners of solar installation and maintenance companies, limiting access by households in these communities to the services such businesses would provide. It is expected that this partially explains why solar adoption rates are lower in communities of colour in the US (Sunter *et al.* 2019)

Perhaps less easy to measure are the non-cost barriers, such as those related to information, local skills gaps and workforce engagement. The core principle of market transformation is the strategic use of public funds to fundamentally transform the market for residential retrofits, thus having a bigger payoff than traditional rebate-style interventions (Sebold *et al.* 2001: 228). Addressing the cost barrier is a key part of this, and in order for this to be done in a sustainable way, programmes should calibrate grant levels such that they maintain a predictable demand over time, then use that demand to drive changes in critical market effects such as levels of knowledge, workforce skills and data gaps (Gillich *et al.* 2017).

2.4 ENERGY-EFFICIENCY DRIVERS IN CANADIAN HOUSEHOLDS

Canada has a variable geography across its 10 million km^2 and 13 provinces/territories. Residential heating is derived from a variety of energy sources (*e.g.* 53%/33% electric/wood in Quebec, 89%

natural gas in Alberta, 40%/35% heating oil/wood in Nova Scotia; NRCan 2019a). These heating requirements vary across climate zones; comparing provincial capitals, heating degree-days range from 2900 in Victoria to 5700 in Edmonton (base 18°C; BizEE 2021). Ferguson *et al.* (1991a, 1991b) conducted a review of household level adoption across different Canadian provinces for the Canadian Home Insulation Program (CHIP). Amongst the general findings, Ferguson *et al.* found that larger SFDs (based on the number of rooms) were more likely to renovate equipment rather than the building envelope. However, variations were observed across provinces; *e.g.* provinces without access to (relatively lower cost) natural gas as a heating fuel were more likely to take up retrofits.

More recently, Gamtessa (2013) reviewed motivations for the uptake of retrofits across Canada during the precursor to the ERfH programme, the EnerGuide for Houses (EGH) programme. This programme reached 188,000 households and had a conversion rate of 19%. He found that homes that participated in the programme were less likely to complete retrofits if they registered before the availability of financial incentives. Further, houses built before 1990 were more likely to retrofit, as were relatively smaller houses, those with less efficient furnaces, higher incomes and those with larger potential cost savings (as observed from their pre-retrofit audit).

Looking at the urban and regional scale, Hoicka *et al.* (2014) and Hoicka & Parker (2018) examined the role that various iterations of home retrofit programmes supported across various level of government over a 12-year period (including the ERfH programme). Their work echoed findings of the improvement of conversion rates when financial incentives are provided, with a conversion rate of 77% (during the ERfH programme), and the scale and depth of retrofits were greater in grant-based programmes. Additionally, the adoption of a house-as-a-system retrofit approach was frequently not evident, with retrofit measures often selectively implemented and not in a combination that would achieve the greatest efficiency (*e.g.* building envelope with/before heating equipment). The authors attribute this to constraints of time-limited grants.

An analysis of the conversion data (signifying retrofit adoption) for the ERfH programme in Canada has yet to be undertaken in the academic literature on a provincial and national level. With such an analysis, the drivers of conversion can be understood, as well as how these may have been impacted by programme design, and where temporal and spatial differences are evident. The data presented below show how these were observed across Canada over the original and extension period of the programme.

3 CALCULATION

As mentioned above, households conducted pre- and post-retrofit audits to be eligible for ERfH grants. These audits were conducted by energy advisors certified by NRCan (2019c), who used energy demand modelling software (HOT2000) to estimate baseline and post-retrofit annual energy consumption, with results stored in a central database; this dataset then provides detailed information of household characteristics at the level of individual participants. The HOT2000 modelling software considered house characteristics such as floor area, volume and local climate, in addition to energy-related installations. Location data (forward sortation areas—FSAs; the first three characters of a Canadian postal code) were also provided by auditors, allowing the linking of spatial data with the audit data.

The percentage of homes that completed a retrofit after the initial audit is termed the conversion rate and serves as an indicator of the programmes' ability to convert initial interest into energy efficiency retrofits. The conversion rate (C) during a given stage of the programme for jurisdiction i is calculated as:

$$C_i = \frac{\sum E_i}{\sum D_i} \tag{1}$$

where E_i is the total number of post-retrofit audits; and D_i is the total number of pre-retrofit audits. The conversion rate is a useful indicator because it controls for endogenous factors and allows comparisons across programmes (Gillich *et al.* 2017). Also, it provides a measure of how interested households are in adopting retrofits, which is a critical early step in building a market.

Data are compiled on the total number of pre- and post-retrofit audits completed for each FSA between the starting and closing dates of the programme (1 April 2007–30 June 2012; here forth referred to as the 'entire programme'). This can be further subdivided in the 'original programme' 2007–11 and an 'extension period' (2011–12); these are assessed separately to determine the impact of the change in programme administration that occurred. The supplemental data online provide a graphical timeline (***Figure S1***) and a detailed description of the programme (under 'The EcoENERGY Retrofit for Homes'). The final date of pre-retrofit audit submissions used in this study was 31 January 2012, when it was (prematurely) closed to new applicants (McKie 2013).

It should be noted that there may be instances where retrofits completed were deemed ineligible for the grant programme (or, indeed, were completed without partaking in the rebate programme) and did not proceed with the second audit on that basis, but it is assumed that these instances are relatively few and randomly distributed. Further, retrofits occurring beyond the timeframe of the funding programme are not likely to be captured in this dataset as the motivation to engage with an energy auditor is reduced.

Population and household data on FSAs were obtained from the 2006 and 2011 censes and the 2011 National Household Survey (NHS) (Statistics Canada 2006, 2011a, 2011b). These were then matched with household pre- and post-retrofit data. Statistical analyses included linear regression modelling, using the native multiple linear regression (MLR) function in R (v. 3.6.1; scripts (will be) available on the Open Science Framework platform). MLR analysis was used to determine if correlations existed for selected demographic data for each FSA within two selected provinces— Ontario (ON) and British Columbia (BC)—obtained from the census and the NHS (***Table 2***). Panel methods were also considered but deemed unfeasible due to the temporal data limitations for the explanatory variables. The dependent variable tested for the MLR was conversion rate (*C*).

MLRs were conducted on two provinces with large populations of FSAs, as well as substantial retrofit adoption: ON and BC. Focusing on individual provinces avoided impacts from divergent programme designs across different provinces that resulted in differing auditing costs and rebate amounts (*i.e.* some provinces provided more support for audits and/or more generous rebates than others). It should be noted that a complementary programme of tax relief was provided nationally (the Home Renovation Tax Credit; up to C$1350 in tax relief; Government of Canada 2009) enabling households to claim against expenditures on durable improvements to a property (*e.g.* new furnaces, water heaters, insulation, windows, *etc.*). While this may have further boosted participation between 27 January 2009 and 01 February 2010, it is not expected that spatial impacts assessed in the MLR results will be affected as the credit applies uniformly across the provinces and for the same duration.

Table 2: Variables tested in the multiple linear regression (MLR) models for Ontario and British Columbia, and whether they were excluded by stepwise backward regression.

Note: [a] Properties occupied by usual residents are those where there is at least one occupant, and they are residing there on a permanent basis.

VARIABLE	DESCRIPTION	USED IN BRITISH COLUMBIA MODEL	USED IN ONTARIO MODEL
pop_dense	Population density	Yes	Yes
occ_usual_res	% Units occupied by usual residents[a], 2011	Yes	Yes
middle_class	% Households that are middle class (share of households with incomes of C$30,000–100,000)	Yes	No
stem_ps	% Population receiving a post-secondary education in a sciences, technology, engineering and mathematics (STEM) subject	Yes	Yes
participation	% Population participating in the workforce (*i.e.* share of the working-age population employed or seeking employment)	No	No

(Contd.)

VARIABLE	DESCRIPTION	USED IN BRITISH COLUMBIA MODEL	USED IN ONTARIO MODEL
new_occ1	% Newly occupied (within one year)	Yes	Yes
rel_prop_val	Median property value relative to the maximum national median property value in the National Household Survey (NHS) (C$1,900,384)	No	Yes
noncondo	% Properties that are not condominiums	No	No
olderhouse	% Properties built before 1970	Yes	Yes
mortgaged	% Properties that are mortgaged	No	No
housepoor	% Units with housing costs > 30% of income	Yes	Yes

Independent variable selection is based on drivers identified in the literature review above, including income, education and household mobility (*i.e.* how recently occupants have moved in), as well as some novel variables that are enabled through the socio-economic NHS dataset (*e.g.* workforce participation, housing affordability, population density). As some of the variables listed above are based on respondents answering a binary 'yes/no' condition (*e.g.* conversion rate, workforce participation, occupied within one year, *etc.*) to develop a probability (*p*), a logit transform (see equation 2) was applied to these variables to yield a log-odds form to enable them to be used within the regression model (Allison 1999). The only variables to which this was not applied were population density and relative median property value.

$$log\left(\frac{p}{1-p}\right) \tag{2}$$

Visual inspection and assessment of homoscedasticity of the fit with the modified set of variables was used to validate the transformation and the fit. While including variables such as climate severity (*e.g.* heating degree-days) or existing EnerGuide score may have improved the quality of the regression model produced (as these have been shown to have an influence on audit/retrofit adoption rates; Gamtessa 2013), these were assumed not to be correlated with the other independent variables assessed here. Hence, the regression analysis is still appropriate for estimating the effect of the selected variables (Allison 1999: 50).

The R package for ordinary least squares (OLS) regression modelling 'olsrr' was used for diagnostics and variable selection. A stepwise backward regression ('ols_step_backward_p') function was used to select the most relevant independent variables for this model, which excluded variables with $p > 0.3$ from each province's model (***Table 1***). Further, multicollinearity was tested through an assessment of variance inflation factors (VIFs) with 'ols_vif_tol'. No VIFs were > 4, hence no further variables were eliminated from the model.

Choropleth maps were developed in QGIS 3.0, using 2011 FSA boundary files from Statistics Canada (2018). These choropleths applied 10 equally sized intervals (deciles) from the conversion rate data throughout the entire ERfH programme period of 1 April 2007–31 March 2012.

Data entries from the pre- ($n = 917{,}762$) and post-retrofit ($n = 713{,}114$) audit data were cleaned in the following ways:

- Duplicate ID entries with the same submission date were deleted (pre-retrofit data: 28,250 entries; post-retrofit data: 55 entries).
- All FSAs that did not contain required data from the NHS were excluded ($n = 629$).
- Any FSAs that had completed more post- than pre-retrofit audits were examined for mistakes in FSA assignment of the property evaluation ID number in the post-retrofit list. These mistakes were corrected to match the FSA stated in the pre-audit list for a given evaluation ID number ($n = 11$ for 2007–11; $n = 56$ for 2011–12). It is worth noting that errors

in the FSA where $C > 1$ were identified, but generally those detected amounted to a relatively small number of the total entries (three incorrect entries).

- Any independent/explanatory variable data where the log odds conversion resulted in 0 or 1 were deleted (80 entries).

As a result of this data cleaning, the number of FSAs assessed decreased from 2230 to 1502.

A limitation of the method here is the reliance on secondary quantitative data, which restricts the extent to which causation can be understood. Hence, all inference discussed below must be treated as speculative, with only corresponding support from the literature where available. Finally, to reiterate, any retrofit activity that occurred without engagement in the ERfH programme will not be captured here, nor will associated motivations of this activity, though it is assumed during the funding period that these will be in the small minority.

4 RESULTS

4.1 ERFH PROGRAMME PERFORMANCE: SPATIAL AND TEMPORAL DISAGGREGATION

Retrofit conversion is examined across the entire programme in the first instance. Key summary data are presented in ***Table 3***. The first sets of data present the take-up of pre-retrofit audits nationally over the entire programme, as well as in the original programme compared with the extension period. The total number of occupied private households audited is in the same order of those estimated to have conducted an audit associated with an energy retrofit programme (843,079) based on responses from the 2011 Environment and Household Survey (conducted January–July 2011; NRCan 2012). The conversion rate of participants for the combined programme was 80%, which compares with 19% observed in the precursor programme EnerGuide for Houses, which had less generous subsidies (Gamtessa 2013; Hoicka *et al.* 2014). Surprisingly, despite the shortened timeframe, the conversion rate seems to have improved slightly during the extension period. The average number of monthly participants engaging with the programme also appears to have accelerated during this extension period, around 75% and 50% faster for audits and retrofits, respectively, than was observed over the duration of the original programme.

Table 3: Selected summary data from the entire EcoENERGY Retrofit for Homes programme, 2007–12.

Notes: [a] The National Household Survey (NHS) did not provide data on total dwellings (occupied plus unoccupied), while the census did not disaggregate by housing type (*e.g.* single-family dwellings—SFDs).

[b] SFDs, which are included within private dwellings along with units in multi-unit residential buildings.

Number of pre-retrofit audits—entire programme	889,549
Original programme (2007–11)	715,607
Extension period (2011–12)	174,182
Number of post-retrofit audits—entire programme	713,064
Original programme (2007–11)	570,040
Extension period (2011–12)	143,024
% of Occupied private dwellings audited	7.2%
% of Total private dwellings retrofitted[a]	4.8%
% of Occupied SFD[b] audited	10.6%
% of Occupied SFD retrofitted	8.5%
Conversion rate—entire programme	80.2%
Original programme (2007–11)	79.7%

(Contd.)

Extension period (2011–12)	82.1%
Average monthly pre-retrofit audit rate—entire programme (audits per occupied SFD/month)	1.90×10^{-3} (0.190%)
Original programme (2007–11) (48 months)	1.52×10^{-3} (0.152%)
Extension period (2011–12) (8 months)	2.61×10^{-3} (0.261%)
Average monthly post-retrofit audits—entire programme	1.52×10^{-3} (0.152%)
Original programme (2007–11) (48 months)	1.42×10^{-3} (0.142%)
Extension period (2011–12) (8 months)	2.14×10^{-3} (0.214%)

4.1.1 Post-retrofit temporal data

An examination of temporal adoption patterns shown in ***Figure 3*** presents the fraction of retrofit activity (*i.e.* conversions) relative to the peak observed in each jurisdiction. The overall national trend is presented in black. This representation of retrofit activity revealed that most retrofits occurred during winter months, with the peak occurring in most jurisdictions at the end of the initial funding period (this assumes that post-retrofit audits were completed soon after the retrofit was completed—it is also possible that retrofitting activity occurred just before the start of colder months and grants were claimed soon afterwards, as a greater proportion of winter exit audits were done in January). A two-sample *t*-test was conducted to determine whether there was an increase in monthly audit activity nationally between winter months (those occurring 1 January–31 March across all programme years; $\bar{x}$ = 20,368; n = 14, as the outlier of March 2011 has been removed) and all other months ($\bar{x}$ = 8483; n = 48), with the results suggesting that the participation during the winter is significantly greater (95% confidence interval (CI); one-tailed p = 0.0003). This variation could be attributable to several challenges, such as failure of equipment during the most intense operating seasons, greater awareness of indoor comfort issues during these months (triggering investigation of retrofits options), or availability of assessors/contractors. For the former two, this seasonality can pose challenges for energy advisors, as well as contractors relying on stable year-round income, as well as homeowners searching for capable energy retrofit specialists. Further, there could be challenges in aligning retrofit activity with budget availability, given that the federal fiscal year runs until the end of March.

The initial closure of the programme (31 March 2011) is evident in ***Figure 3***, along with the increased activity associated with the reopening of the programme (June 2011—June 2012). ***Figure 3*** presents the fraction of the post-retrofit audit peak in each jurisdiction, as well as nationally, reaching '1' when the greatest number of post-retrofit audits for that jurisdiction was reached (*i.e.* the peak). This increase immediately after the reopening during the extension period (June 2011) suggests a continued awareness and demand for the programme, suggesting the existing national brand was useful for driving awareness of the availability of funding. Data between 2012 and 2014 are presented to demonstrate the post-programme impact of engagement with these energy efficiency audits; based on the data provided in ***Figure 2*** on post-retrofit audits by licenced assessors, audits by assessors declined dramatically in the years following (2012–14), with implications for employment by assessors. It may be assumed that retrofits were simply no longer being captured by assessors (as there was no longer any need to conduct a post-retrofit audit); however, certain jurisdictions maintained funding programmes after the end of the ERfH that necessitated post-retrofit audits (*e.g.* BC; BC Hydro 2013). Engagement with post-retrofit audits also dropped after the conclusion of BC's programme.

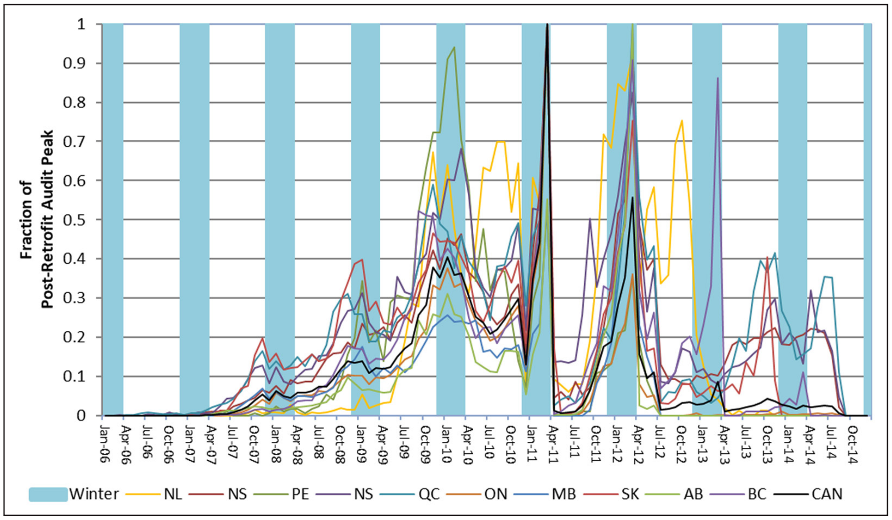

Figure 2: National and provincial monthly fraction of post-retrofit audit peak.

Note: The original programme start and end dates are April 2007–March 2011; the extension programme was from June 2011 to June 2012; and the British Columbia programme closed in April 2014.

4.1.2 Post-retrofit spatial data

Variation in the conversion rate nationwide are plotted in ***Figure 3***. At first glance, it may appear as though there is higher conversion rates (marked in green) in higher density areas, with lower density areas demonstrating lower rates (yellow to red). However, further examination of three major cities highlights non-uniform conversion within cities (***Figure 3b–d***). Toronto census metropolitan area (population 5,583,064), Vancouver (2,313,328) and Montreal (3,824,221) are selected due to their relatively high population (Statistics Canada 2019a), as well as their differences in observed adoption rate (***Figure 1***). In general, areas with extremely low conversion rates tended to have low participation either due to fewer households (*i.e.* all housing types, including those in single-family attached, SFDs or multi-unit residential buildings) or fewer SFDs specifically. For example, looking at FSAs with conversion rates below 50% (*n* = 89), the average number of occupied SFDs identified during the 2011 NHS was 2005 (compared with the average of 10,564 across all FSAs). Interestingly, the proportion of occupied SFDs conducting a pre-audit during the entire programme was higher for lower conversion FSAs (< 50%) than for the total (12.7% versus 11.2%). It can also be seen that of the three cities highlighted, Montreal had lower conversion rates, per findings by Gamtessa (2013).

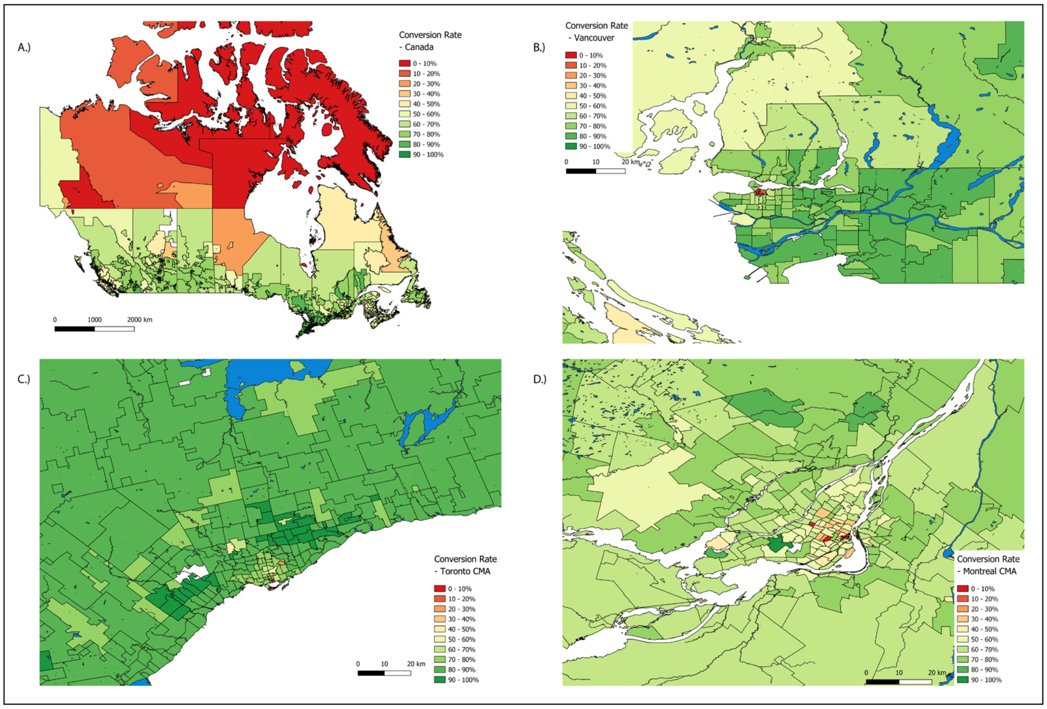

Figure 3: National and selected urban conversion rates for the EcoENERGY Retrofit for Homes (ERfH) programme: **(a)** Canada, **(b)** Vancouver, **(c)** Toronto and **(d)** Montreal.

Table 4 presents the results of the MLR analysis conducted to identify significant variables associated with the conversion rate (for complete regression results, see ***Tables S3*** and ***S4*** in the supplemental data online). Focusing on the entire programme, of the variables selected percentage middle class, older homes (built before 1970) and science, technology, engineering and mathematics (STEM) post-secondary education did not demonstrate a correlation with conversion rate (nor did they for initial programme or extension period, for that matter, with the exception of STEM education in ON). Households spending more than 30% of income on rent or mortgage costs demonstrated strong positive correlations in both provinces (> 99% CI). Meanwhile, population density, new occupants (less than one year in place) and relative property value (in ON) all demonstrated a strong negative correlation (mostly > 99.9% CI).

TERM	ENTIRE PROGRAMME, 2007–12		ORIGINAL PROGRAMME, 2007–11		EXTENSION PERIOD, 2011–12	
	ON	BC	ON	BC	ON	BC
Population density	*** (–ve)	*** (–ve)	*** (–ve)	*** (–ve)	** (–ve)	
% Occupied by usual residents	*** (+ve)	*** (+ve)	*** (+ve)	*** (+ve)	*** (+ve)	*** (+ve)
% Middle class (household income C$30,000–100,000)	n.a.		n.a.		n.a.	
% Moved within one year	*** (–ve)	** (–ve)	*** (–ve)	** (–ve)	** (–ve)	** (–ve)
% Built before 1970						
% Households with house costs > 30% of income	** (+ve)	** (+ve)	** (+ve)	** (+ve)	*** (+ve)	†
% With STEM post-secondary education					*** (+ve)	
Median property value (relative)	*** (–ve)	n.a.	*** (–ve)	n.a.	*** (–ve)	n.a.

Table 4: Multivariate regression summary data for degree of correlation selected explanatory variables related to the conversion rate for available Ontario (ON) and British Columbia (BC) forward sortation areas.

Notes: BC (*n* = 180); ON (*n* = 485).

STEM = science, technology, engineering and mathematics.

Significance: ***0.001, **0.01, *0.05, †0.1; not assessed (n.a.) values represent variables that were eliminated in the stepwise backward regression; while blank spaces indicate those that were not statistically significant at a > 90% confidence interval (CI). +ve = Positively correlated; –ve = negatively correlated.

5 DISCUSSION

5.1 OVERALL PROGRAMME PERFORMANCE AND UPTAKE

The analysis of conversion rate is generally consistent with findings from the existing literature with a few exceptions. These are discussed in greater detail below. One observation worth highlighting is the diminished strength in correlation observed in some household characteristics when compared with the initial programme; this may be due to a broader rush to participate given the perceived 'last chance' to avail of subsidised energy efficiency improvements.

5.1.1 Occupant characteristics

Areas that hosted a greater proportion of households occupied by usual residents (*i.e.* a property that is occupied by at least one person, residing at a property on a permanent basis; Statistics Canada 2019b) demonstrated a strong correlation with conversion rate, which serves as a good test of the validity of the data as they represent households that were occupied on the census date (10 May 2011); occupied housing would be a good indicator for participation in the programme and, coincidentally, aligns with the peak of programme participation in ON and BC (end of March 2011). It was found that households occupied by residents with stronger links to the physical dwelling tend to demonstrate a greater likelihood to retrofit, which was consistent with the findings here (Ferguson *et al.* 1991a; Walsh 1989).

Another result that is consistent with previous findings is the statistically significant relationship for FSAs with greater proportions of 'house poor' households (*i.e.* those with more than 30% of household income spent on housing). The regression coefficient is positive across all programme stages and was stronger during the original programme in BC, but weaker in ON during this stage.

This suggests a drive to retrofit amongst those with higher housing costs, potentially as a means to improve overall affordability. Further, in ON, relative median property value was strongly negatively correlated with conversion (*i.e.* less likely to complete a retrofit; > 99.9% CI), while no correlation was evident in BC. This may be explained by household space conditioning costs being relatively larger (along with associated relative benefits of retrofitting) when compared with property value in ON; the weighted average property value for FSAs in ON and BC in 2011 were about C$350,000 and C$540,000, respectively (Statistics Canada 2011b). Further, when evaluating the percentage of SFDs that received an initial (pre-retrofit) audit, there were positive statistically significant (> 95% CI) relationships with 'middle-class' households, similar to previous programmes (Walsh 1989; Brown 1984; Tonn & Berry 1986; Sardianou & Genoudi 2013; Ferguson *et al.* 1991a; Michelsen & Madlener 2012; Smiley 1979), though it is unclear as to why this relationship was not evident for conversions.

NRCan assessed household participation statistics within the programme, which is worth highlighting here (NRCan 2015). After implementing retrofits, the top benefit cited by respondent homeowners was increased home comfort (82%), followed by reduced energy costs (67%). This is further support for the idea that non-monetary benefits are important for retrofit decisions, suggesting a strict monetary cost–benefit analysis does not provide a complete picture of motivation.

5.1.2 Dwelling and spatial characteristics

An inconsistency with previous studies is a lack of relationship with older houses (built before 1970). While many others have found older houses more likely to adopt improvements (*e.g.* Gamtessa 2013; Ferguson *et al.* 1991a), this was not observed in the BC and ON cases. However, in both cases a significant relationship (> 99.9% and > 99% CI for ON and BC, respectively) was observed between older households and participation in the pre-retrofit audits. The weaker relationship with retrofit conversion could be attributable to diminished benefits from new retrofits to previously improved older stock, perhaps due to insufficient energy savings or more expensive outstanding retrofit measures.

5.2 LESSONS FROM PROGRAMME FRAMEWORKS AND LOCAL PROGRAMME DELIVERY: MARKET TRANSFORMATION

Having examined spatial and temporal trends, it is also valuable to review the programme-related design implications of adoption.

5.2.1 Implications of programme extension

A decline in the strength of correlations was observed for some variables in the extension period, relative to the original programme; this is potentially attributable to increased awareness within the general public due to the broader dissemination of the programme after the first four years of operation, coupled with the perceived time constraints to make use of the available grants. Further, when one considers the substantial increase in uptake during this extension period, the increase in the rate of retrofit speaks to improved word of mouth during the extension, a heightened need to act to avoid missing out on the extension and/or a good pre-existing awareness of the programme before its initial closure.

5.2.2 Localisation

Several factors fall under the theme of local programme design, but this section will focus primarily on how a programme found its local market niche and leveraged the support of surrounding networks. In this area there are several best practice principles to draw upon from the Better Buildings Neighborhood Program (BBNP) of the US (Gillich *et al.* 2017). Numerous programme demographic factors inherent to the location of the programme that cannot be fundamentally altered, but can critically impact how a programme performs, as has been discussed above. Given that these factors will vary subnationally, it can be difficult to craft a national-level policy with suitable relevance and fairness across the range of circumstances. The ERfH programme was uniformly available across the country, with grant set at the national level (NRCan 2015). As mentioned in Section 1.1 above, 12 of 13 provinces and territories offered a complementary incentive programmes that coincided with the ERfH programme (NRCan 2013).

Community-level synergy was generally not provided in the ERfH, other than through local energy assessors. In ERfH, the Federal Home Renovation Tax Credit (HRTC) was seen as having a positive impact on uptake of the ERfH programme (Bronson Consulting Group 2010). The credit essentially provided a double incentive to renovate. While there was confusion over the mixed branding of the offers, when ERfH administrators and energy advisors were questioned about HRTC, they were able to explain that both programmes could be used together. The HRTC thus served as an additional route to market for the ERfH programme and brought in homeowners that it otherwise may not have, whose participation could be supported by energy advisors.

5.3 PROGRAMME DELIVERY FACTORS

The above findings fit with an emerging pattern that grant programmes are simple and effective at delivering high volumes of savings but have a weak market impact in the post-funding period, evidenced by the loss of about 25% of energy advisors after the conclusion of the initial programme end date of March 2011 (NRCan 2012; see description in supplementary data for more details). There is a general movement away from 'rebate only' programmes towards more comprehensive 'market transformation' retrofit programmes (Gillich *et al.* 2018).

The ERfH programme included elements of the market transformation approach through the training of over 2000 energy advisors (NRCan 2013), with these inherently becoming locally embedded proponents of wider energy efficiency adoption. A key success factor for the ERfH programme was the presence of an energy assessor in the home to directly answer homeowner questions; 69% of respondents learned something new from their energy advisor and report, and 76% said that it helped them decide which retrofits to implement (NRCan 2015). However, an internal evaluation states that ERfH would have been more cost-effective if it had better engaged local partners. Once programme goals are suitably calibrated and the local networks are in place, success is generally driven by how well these networks identified and addressed the barriers at a local level (Gillich *et al.* 2018).

A key challenge in assessing the reasons for the temporal and spatial variability of the EcoENERGY programme is the lack of granularity in the programme evaluation document kept by NRCan. For example, an internal interim evaluation carried out in 2010 stated the EcoENERGY programme had successfully signed 23 collaborative agreements with provinces, territories, utilities and other stakeholders (NRCan 2010). However, there are few details on the nature of these collaborative agreements and how they impacted local delivery. The 23 collaborative agreements are credited in the evaluation as a successful achievement, exceeding the target of 14 collaborative agreements within that evaluation period. However, the same evaluation report also cites qualitative interviews with programme partners that state that while these partnerships were important to the cost-effectiveness of the programme, the lack of flexibility in the national framework of EcoENERGY meant that overall, these partnerships were not as successful as they set out to be:

> interviewees from NRCan, provinces and territories commented that more work should be done to accommodate the diverse regional needs (*e.g.* climate, main heating sources, *etc.*). These interviewees explained that the programme is unable to be entirely flexible because it is designed to be a national programme. Thus, there may be an opportunity to improve the cost-effectiveness of the ecoENERGY Retrofit—Homes Programme by expanding regional partnerships and identifying mechanisms to better respond to the needs of the various regions across Canada.
>
> (NRCan 2010, p. 76)

5.4 IMPLICATIONS FOR FUTURE PROGRAMMES

The main implication coming from the results assessed here is disruptiveness of short-term funding to the domestic energy efficiency ecosystem. As observed, engagement with energy advisors dropped off after the conclusion of the funding programmes (leading to loss of associated expertise and skills development), and the Canadian and subnational governments have needed to once again initiate similar programmes to kickstart activity after nearly a decade of lower retrofit activity (NRCan 2021; Better Homes BC 2021). This speaks to the requirement for longer term programmes that lead to market transformation, rather than market volatility (***Figure 3***).

Further, the time-limited final year of the programme seemed to encourage a broader spread of participants (weakening of *p*-values) and an acceleration of interest. Having regular deadlines (perhaps associated with progressively lower grant values) may assist in sustaining interest toward market transformation. These could be semi-annual or quarterly deadlines, which could help to even out the retrofit activity over the year rather than the observed winter activity spikes.

A final observation relevant for current and future programmes is the greater interest from households with relatively high expenditures on accommodation; given the cost-of-living crisis that is currently affecting nations globally (and its link with volatile energy costs), it will be important to engage with these potential participants as a priority in combating fuel poverty during the transition to a low carbon future.

6 CONCLUSIONS

This study evaluated the drivers evident in the EcoENERGY Retrofit for Homes (ERfH) programme, as well as spatial and temporal adoption patterns. Many findings are consistent with existing studies (relationships with tenure length, housing costs and education), demonstrating the importance of occupant characteristics, as well as the challenges in areas with greater population density which demonstrated lower participation rates. This validates the data analysis approach used here for future study on other aspects of the programme. Temporal analysis allowed an exploration of programme design (and the acceleration of adoption under time constraints), and highlighted the increase in activity during winter months, suggesting potential shortages of advisor and energy retrofit specialists during these times.

The level of participation and temporal engagement patterns reinforces the importance of the upfront cost barrier and consistent federal-level support. However, retrofit programme design may need to provide different grants in different jurisdictions to address specific community needs. Study is needed to use spatial and temporal disaggregation of selected technologies to help guide the next generation of Canadian retrofit programmes.

Finally, the spike observed at the end of the retrofit resulted in a boom-and-bust cycle, which is symptomatic of grant programmes, suggests labour market volatility in the energy retrofit sector. This is in place of an approach to build a stable market from the ground up, where installers, energy advisors and homeowners are all aware of energy retrofit benefits and where they are best applied. Ideally, policies and programmes should select incentive levels to create demand growth that can be supported by the market and avoid short-term market distortions and encourage long-term plans for keeping energy assessors and retrofit installers active. Businesses and homeowners should be encouraged to develop continual improvement strategies for their energy efficiency retrofits, discouraging subsidy expectations.

Overall, the national brand was useful for driving awareness with things such as the availability of funding, branding skills and programme dissemination, suggested by continued growth. But awareness cannot translate to delivery unless there is strong local engagement that made use of existing networks, trusted messengers, and local knowledge. National-scale retrofit programmes should acknowledge this and use their leverage to create a national brand for retrofit programmes but give local delivery bodies the autonomy to adapt that brand in the way they see fit, as was demonstrated with the Better Buildings Neighborhood Program (BBNP) in the US.

The literature on Canadian retrofit motivation focuses largely on cost barriers. However, the study of non-cost barriers in countries such as the UK and the US is rich in comparison and has repeatedly found that while cost is a dominant barrier in most markets, the remaining non-cost barriers still hinder the widespread uptake of thermal retrofit (Rosenow & Eyre 2016). A stronger research emphasis on non-cost barriers to retrofit within Canada would be useful in adapting international precedents to Canadian retrofit markets and beyond.

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COMPETING INTERESTS

The authors have no competing interests to declare.

DATA AVAILABILITY

All data used in this analysis are shared in the Fig Share project 'Retrofit Conversion in EcoENERGY 2007–2012', https://figshare.com/projects/Retrofit_conversion_in_EcoEnergy_2007-2012/68669/.

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SUPPLEMENTAL DATA

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