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Content

Résumé

Ce document de travail étudie l'effet du passage du crédit d'impôt développement durable (CIDD) au crédit d'impôt pour la transition énergétique des logements (CITE) mis en place en France en septembre 2014, qui s'est traduit par une hausse du taux de crédit d'impôt entre 5 et 30 points de pourcentage (ppt) selon les revenus des ménages et le type de gestes de rénovation (mono-geste ou multigestes). Cette étude s'intéresse en particulier à l'effet de la hausse de 15 ppt (de 15 à 30 %) du taux de crédit d'impôt, pour les ménages modestes n'effectuant qu'un seul geste de rénovation, sur la décision de rénover d'une part, ainsi que sur les montants investis dans la rénovation thermique d'autre part. À l'aide d'une méthode de régression sur discontinuité (*Regression Discontinuity Design*, RDD), nous estimons que l'augmentation du taux de crédit d'impôt a eu un effet statistiquement significatif et positif sur la marge extensive (*i.e* la probabilité de rénover), qui augmente de 1,3 ppt après réforme (à comparer à un taux de recours au CIDD moyen avant réforme de 1,4 %). La hausse du taux du crédit d'impôt a eu un effet plus marqué sur la décision de rénover dans les maisons individuelles, les logements les plus grands et les plus anciens. Par ailleurs, les effets du changement de taux du crédit d'impôt augmentent avec les revenus du ménage (parmi les ménages à faible revenu). Par ailleurs, la hausse du taux de crédit d'impôt a eu un effet statistiquement significatif sur la marge intensive (*i.e*. le montant moyen des travaux) de +26 % entre 2014 et 2015 (+970 €). Ce résultat suggère que la réforme a encouragé les ménages modestes à investir dans des rénovations plus coûteuses et plus efficaces énergétiquement. Ce résultat est toutefois dépendant du groupe traité choisi : en restreignant l'échantillon aux seuls ménages modestes n'ayant effectué qu'un seul geste de rénovation avant et après la réforme, le passage du CIDD au CITE n'a pas d'effet sur le montant investi dans les travaux (l'effet sur la décision de rénover – la marge extensive – restant lui significatif et positif).

Au final, la réforme du passage du CIDD au CITE aurait encouragé les ménages modestes à effectuer plus de travaux de rénovations et à augmenter leur montant investi dans les rénovations, notamment en effectuant plusieurs gestes, mais ne les aurait pas orientés vers des rénovations mono-gestes plus coûteuses.

Abstract

This paper assesses the impact of the increase in tax credit rate implemented in France on September 1, 2014 on low-income households' renovation investments. The transition from the CIDD to the CITE increased the tax credit rate by 5 to 30 percentage points (ppt), depending on households' income and on the type and number of eligible renovations undertaken (i.e., a single renovation item or a combination of items from a schedule). In particular, this study focuses on the effect of the 15 ppt increase (from 15 to 30%) in the tax credit rate on low-income households' decision to renovate, on the one hand, and on the amounts they invested, on the other hand. Using a Regression Discontinuity Design model, the 15 ppt tax credit rate increase for low-income households was found to have a statistically significant and positive effect on the probability to renovate, which increases by 1.3 ppt (from an average renovation rate of 1.4% before the reform). We also investigate the potential heterogeneity in the treatment effect on this probability. We find that owners of single household dwelling units, larger dwellings and older dwellings are more sensitive to the tax credit rate increase. The impact of the reform also increases with income (among low-income households). Results on the intensive margin (*i.e* the additional amount spent by households on energy efficiency investments) show that the reform increases the level of investment by 26% (+€970). However, this result depends on the selected treatment group: when we restrict the sample to households undertaking only one renovation item (before and after the reform – as opposed to a combination of two or more after), the effect on the amount of renovation expenditures is no longer statistically significant, while the effect on the decision to renovate remains significant.

Overall, we show that the increase in tax credit rate for renovation investments in 2015 increased the probability for low-income households to undertake renovation work for two or more eligible items, thus increasing their average total amount of investment, but did not encourage them to carry out more costly single-item renovations.

Introduction

In 2019, buildings were the third largest emitter of greenhouse gases in France, accounting for 17% of French CO_2 emissions,[1] and represented nearly 45% of final energy consumption. The building sector therefore has a major role to play in achieving the national objective of carbon neutrality by 2050. In addition to environmental benefits, renovation to improve the energy efficiency of existing buildings can enhance occupants' comfort and reduce households' energy bill. In 2018,[2] 4.8 million primary residences, representing 16.7% of the housing stock, were classified as poorly insulated, i.e., identified as heat-leaking homes.[3] Further, 3 million households suffered from fuel poverty[4] in 2020, meaning that they had difficulties paying their energy bill, while about 20%[5] of their budget was allocated to housing expenses. In order to massively renovate housing, accelerate energy savings over the housing stock, reduce emissions, and tackle fuel poverty issues, multiple policy measures and financing instruments have been implemented. Energy-savings renovation of private housing and public buildings are priorities in the French recovery plan (*France Relance*) introduced in September 2020, which included €6.7 billion for energy renovation in buildings in the period from 2020 to 2022. These efforts are supplemented by legislative and regulatory measures.

A major challenge to public policy for renovation is that relatively few households actually invest in energy-saving renovation, even when renovation would be profitable for them in the long run. This phenomenon has been described as the "energy paradox" (Brown (2001), Van Soest and Bulte (2001)) or as "investment inefficiencies" (Allcott and Greenstone (2012)). Researchers have attributed the paradox mainly to market imperfections such as imperfect information. For instance, uncertainty surrounding future energy prices or energy savings following a renovation, when investment is irreversible, can encourage individuals to postpone investment as they wait to see if prices are actually increasing (Hassett and Metcalf (1993), Alberini et al. (2013)). To overcome these market imperfections and encourage households to undertake energy efficiency renovations in their homes, tax incentives have been introduced in many countries including the United States and European countries including Italy, Switzerland, and France. However, Jaffe and Stavins (1994) also emphasized that non-market failures, such as heterogeneity in consumer valuations of energy services and hidden costs (e.g., inconvenience caused by renovation work) may also prevent widespread adoption of energy efficiency investments. Unlike market failures, these non-market failures do not necessarily warrant financial intervention.

Considerable literature has been devoted to assessing whether fiscal instruments trigger investment by households. On the one hand, some studies find that tax credit schemes are effective. Using panel data from the U.S., Hassett and Metcalf (1995) found that a 10 percentage point increase in the tax price for energy investment would lead to a 24 percent increase in the probability of investing. Other studies found more ambiguous results. For instance, when Alberini et al. (2014) analyzed the effects of the Italian tax credit implemented in 2007, they found that the policy significantly raised the window replacement rate by 37 to 40% in colder regions, while they also identified a failure in tax credit scheme as it not have a significant effect on the replacement of heating systems. When studying the Weatherization Assistance Program[6] in the U.S., Fowlie et al. (2018) found that the extensive effort in the program (home visits, phone calls, follow-up appointments) managed to increase the participation rate by only 5 percentage points. The

[1] CITEPA, *Secten report 2022*. (The Secten report details greenhouse gas and air pollutant emissions in France.) The year 2020 is not representative due to COVID-19, and the 2021 data are preliminary.
[2] Source: 'Tableau de suivi de la rénovation énergétique dans le secteur résidentiel' (energy renovation in the residential sector), National Observatory for Energy Renovation, ONRE, March 17, 2022.
[3] A dwelling is officially considered an energy-leaking home (French: *passoire énergétique* or "energy sieve") if ranked in the lowest two classes for energy consumption (F or G on a scale from A to G), i.e., if consumption exceeds 330kWh per square meter per year.
[4] Law 2010-788 of July 12, 2010, on National Commitment for the Environment, also referred to as the "Grenelle II Law, defines fuel poverty as 'experiencing in difficulties in accessing the energy required one's dwelling to satisfy basic needs, due to inadequate resources or housing conditions.' The figure for households that suffer from fuel poverty comes from the General Commission for Sustainable Development (CGDD), for which energy insecurity (*précarité énergétique*) occurs when the dwelling's energy bill is equal to or greater than 8% of income and the household is in the lowest three deciles of total income.
(https://www.ecologie.gouv.fr/sites/default/files/thema_essentiel_15_precarite_energetique_en_2020_janvier2021.pdf).
[5] Insee, 'Household Budget Survey' (*Enquête budget de famille*, EBF), 2017.
[6] The Weatherization Assistance Program (WAP) is the United States' largest residential energy efficiency program; it has provided over 7 million low-income households with weatherization assistance since its inception in 1976.

authors explained the low take-up to numerous factors including time inconsistency, a high discount rate (myopia), and a rental market that does not value these investments properly.

Our study aims to provide new empirical evidence on the effect of an increase in tax credit rates, focusing specifically on a tax credit rate increase intended to benefit low-income households that are most likely to experience fuel poverty. To do so, we use a quasi-experiment that occurred with the French environmental tax credit enacted at the end of 2014 (and applied retroactively to September 1, 2014). This quasi-experiment consisted in an unanticipated 15 percentage point increase in the credit tax rate (from 15% to 30%) for low-income owner-occupiers, provided the home had been built at least two years before the renovation. To our knowledge, this discontinuity has not yet been studied in the literature. We use a Regression Discontinuity design (RDD) to assess the extent to which households responded to the policy, both at the extensive margin (*i.e.*, the probability to renovate) and at the intensive margin (*i.e.*, the change in average renovation expenditure). For the intensive margin, we identify a potential selection bias and therefore address the issue by using a two-step Heckman method combined with RD design.

Note that in our study, low-income households are selected combining both reference taxable income[7] and household size and structure (i.e., the number of "tax units,") following the definition of the National Agency for Housing Improvement (ANAH). The reference taxable income for these households should not exceed €24,043 for a household of two married or civilly partnered adults without dependent children, plus an additional €5,617 for the first dependent (child), and €4,421 for each additional dependent.[8]

The extensive literature on French tax incentives seeks to estimate the effect of an increase in tax credit rates. Mauroux (2014) was the first to undertake an econometric evaluation of the income tax credit introduced in 2005, the Sustainable Development Tax Credit (CIDD).[9] She evaluated the impact of the 2006 reform which marginally increased the tax credit rate from 25% to 40% for investments in buildings for which construction was completed before 1977. Using administrative tax data for the period 2006 to 2008 and a matching method combined with triple differences, the author found that the 15 percentage point increase in the tax credit rate had a significant and positive impact on the extensive margin: the proportion of households undertaking renovation increased by 0.7 percentage points. She also identified the presence of significant *free-riders*:[10] around two thirds of CIDD beneficiaries would have undertaken renovations even without the reform and the subsidy. Daussin-Benichou and Mauroux (2014) enriched the previous work by estimating the impact of the 2006 reform on the intensive margin, finding that households adjusted their average expenditure after the unexpected increase in tax credit rate. Combining a triple difference with a Tobit model and censored quantile regressions, the authors found that households increased their housing improvement expenditure, as each euro of additional public cost on average generated €1.5 of private investment. Evaluating the same tax credit change in 2006 with a difference-in-difference method, Tamokoué Kamga (2018) found a positive but not statistically significant effect of the tax credit rate increase on the extensive margin. However, he confirmed that the 15-point tax credit rate increase induced additional expenditure that averaged €1,650 (+49%) per household, for the investment items targeted specifically by the increased tax credit rate.

Nauleau (2014) studied the efficiency of the CIDD income tax credit system on decisions to invest (extensive margin) with a focus on insulation measures. A logit model with random individual effects determined that the tax credit had no significant effect the first two years, meaning that households probably failed to respond initially because of the complexity of the tax credit scheme. However, she also found a significant and positive effect of the tax credit on the probability of retrofitting between 2007 and 2010, suggesting a correlation with the level of subsidy. She estimated the average proportion of free-riders to

[7] The "reference taxable income" for a household (*revenu fiscal de référence*, RFR) is computed by the tax authorities and serves to determine certain tax benefits and eligibility for various social programs.
[8] The "family quotient" system is based on the size and composition of each household. A single-person household counts as one tax unit; a single person with a dependent child counts as 1.5 tax units; a married or civilly partnered household counts as two tax units if there are no dependent children, 2.5 tax units with one dependent child, three tax units with two dependent children, and a full additional tax unit is added for the third and for each subsequent child. Married and civilly partnered couples must file a joint tax return.
[9] Sustainable Development Tax Credit (*Crédit d'Impôt Développement Durable*, CIDD).
[10] The term 'free-rider' is commonly used in the energy efficiency literature, but 'windfall gain' would be more appropriate.

range between 40% and 85% after 2006. Finally, Risch (2020) exploited a sharp discontinuity with a RD design similar to the one in our study. This discontinuity was chosen at the introduction of the CIDD in 2005, in order to examine the policy's causal effect. She found significant and positive results for both the extensive margin (+1.09 percentage points) and intensive margin (+21.76%).

Our study contributes to the literature with an evaluation of the 2015 reform (the transition from CIDD to CITE[11]) that has not been previously investigated, with a focus only on the targeted tax credit rate increase on low-income households. Our results are statistically significant on both the extensive and intensive[12] margins and broadly consistent with the literature discussed above. More specifically, we find that the 15 percentage point increase in the tax credit rate for low-income households raises the probability of undertaking energy saving renovations by 1.3 percentage points (compared to an average renovation rate of 1.4% before tax credit change) and increases renovation expenditure by 22%-30%, depending on the period studied (+26% i.e., +€970 when focusing on the local effect between 2014 and 2015). These large magnitudes can be explained by the fact that our study focuses on low-income households, which are more likely to experience fuel poverty and face financial constraints. They therefore tend to respond strongly to subsidies that allow them to carry out thermal renovations and reduce their energy bills in the long run. Our findings thus provide evidence that CITE encouraged low-income households to undertake energy efficiency investments.

The rest of the paper is structured as follows. Section 1 discusses potential determinants of the renovation decision. Section 2 describes the tax credit schemes as well as the changes that occurred during the transition from CIDD to CITE. Section 3 then presents the data and descriptive statistics. Section 4 explains the identification strategy of the paper and Section 5 reports empirical results. We conclude in Section 6. The Appendix provides more detailed information on the households and renovation items eligible for tax credits before and after the cutoff.

[11] The Energy Transition Tax Credit (Crédit d'Impôt pour la Transition *Energétique*, CITE) has since been replaced by a system of grants called *MaPrimeRénov*.

[12] Note that results cease to be statistically significant when estimating the treatment effect on some alternative treated groups, meaning that those results should be interpreted with caution.

1. What factors determine households' decision to renovate?

Our study will try to analyze if and to what extent low-income households are sensitive to an increase in tax credit rates in deciding to carry out energy efficiency renovations. However, when estimating the average causal effect of an increase in tax credits, it must also be borne in mind that household investment decisions may also be influenced by a range of non-economic factors.

First, the Institute For Climate Economics (I4CE)[13] recently underlined that households may decline to undertake theoretically profitable renovations (i.e., those with a swift enough return on investment for energy savings to cover the initial outlay), because they fear the renovation work would fail to deliver expected energy savings or entail additional costs due to defective workmanship (asymmetric information). Such market failures are considered to contribute to the *energy efficiency gap* by altering the risk aversion curve and thus making some investments appear unprofitable (Newell et al. (2015)). To illustrate this feature, we compute the Net Present Value of energy efficiency investments carried out under CITE (i.e., after the change) by the low-income households selected in the ERFS database[14] as follows:

$$NPV_i = AEG_i \sum_{t=0}^{T} \frac{EP}{(1+d)^t} - I_i(1-s)$$

where NPV_i is the net present value[15] of the energy saving renovations for household *i* (€), AEG_i is the average energy gain (MWh/year) associated with the type of renovation,[16] *EP* is the energy price from 2014 to 2034[17] (€/MWh), *d* the discount rate,[18] I_i the expenditure reported in its tax return by the household for energy efficiency renovation (€), *T* the average lifespan of the renovation items performed(20 years[19]),and *s* the tax credit rate for low-income households (15% under CIDD and 30% under CITE).

Note that our calculation takes into account possible additional subsidies or other financial incentives that households may receive – e.g., under the White Certificates scheme (*Certificats d'Economies d'Energie, CEE)* – since households report their renovation expenditures net of those incentives.[20]

Further, because we seldom know the type of energy used by households to heat their dwellings,[21] we consider two scenarios, for either electricity or gas, and compute the net present value detailed above, for all households.

Note that our results should be interpreted with great caution due to uncertainties in several areas, including those related to estimated average energy gains, to energy prices actually paid by households, and to missing information regarding the initial energy used in the dwelling. In the absence of that information, and under the strong assumptions used for the calculation, we found that:

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[13] 'Quelles aides publiques pour la rénovation énergétique des logements?, PanelRénov': un outil pour analyser la viabilité économique des projets de rénovation,' February 2022.

[14] 'Tax and Social Incomes Survey' (Enquête Revenus *Fiscaux* et *Sociaux*, ERFS), INSEE.

[15] Net present value measures the profitability of an investment, i.e., the present value of future flows (both positive and negative) discounted over the lifetime of the investment.

[16] Average energy gains are the values computed by the Coeuré Committee in its October 2021 report. For missing information on some renovation items, we made assumptions that the average energy gains are the same as for similar renovation items. For instance, we give at gas boiler the same energy-savings as high-performance boiler. (*Comité d'Évaluation du Plan France Relance, Premier rapport*).

[17] We use the official regulated tariff (*tarif reglémenté de vente*, TRV, for residential customers, for both gas and electricity from 2014 to 2017 (soruce: open data from Energy Regulatory Commission, *Commission de régulation de l'énergie,* CRE), which we then hold constant over the next 20 years, at the level of the year of renovation. In the absence of more precise information on electricity and gas tariffs paid by households, we made the assumption that all households paid the official regulated tariff. Note that at the end of 2021, around 65% of households paid for electricity, and 30% for natural gas, at the official regulated tariff (source: '*Observatoire des marchés de détail'*, Energy Regulatory Commission, CRE).

[18]The discount rate used is 6%, that is, the rate identified by the Institute for Climate Economics, I4CE, for investments on the rental market. However, Giraudet et al. (2021) show that discount rates depend on the income decile and household composition (single-family unit or multiple-family units or dependents). Had we chosen those discount rates for our sample, we would have had a higher discount rate, 14.8% on average, for low-income households.

[19] The Coeuré Committee report (see note 17) estimated the average lifespan of the energy efficiency renovations at 20 years.

[20] For the "white certificates scheme" (or "energy efficiency certificates," CEE), companies typically handle the paperwork and deduct the corresponding subsidy from the amount blled the homeowner.

[21] The information is available neither before nor after the renovation, except in the case of a change in the heating system, for which the new energy source can be inferred.

- If households use *electricity*, 68% of the renovation work is profitable to low-income homeowners (within 20 years) with the 30-point tax credit rate under CITE, compared with 62% if the 15-point tax credit rate under CIDD had remained in place;
- If households use *gas*, 41% of the renovation work is profitable to low-income homeowners (within 20 years) with the 30-point tax credit rate under CITE, compared with 33% if the 15-point tax credit rate under CIDD had remained in place;
- A significant portion of the renovation work (32% for the *electricity* scenario and 59% for the *gas* scenario) will not be profitable to low-income homeowners after 20 years, even with a 30% tax credit.

These results suggest that financial profitability of energy efficiency investments is not the only determinant in the renovation decision, as households may also consider co-benefits. For instance, installing thermally efficient glazing may also improve noise insulation or the general comfort of dwellings that become quieter. Similarly, insulating the roof or walls can improve summer comfort by better resisting heat waves; and switching to a higher-performance heating system may improve the thermal comfort inside a dwelling. Such determinants can also explain why households undertake renovations with a negative NPV, as variables that are not observed in our database may also play a role in the investment decision.

I4CE identifies other non-market costs and obstacles to renovation that are more related to psychological or inconvenience costs. These include potential additional transaction costs if households must relocate during the renovation (and even longer if there are delays in the works). Camilier-Cortial et al. (2017) summarize other non-market factors in the literature that may explain failure to undertake investments with a positive NPV, such that irrational behavior or cognitive bias. For instance, the bounded rationality of agents, *i.e.*, that they lack the capacity or interest to explore all possibilities (the search for information being expensive), could reduce investment in renovation, if profitable investments require more information, which empirically seems to be confirmed (Gilligham and Palmer, 2014). Also, the bias in favor of the *status quo* can explain that certain renovations are not undertaken even if profitable (Brown et al., 2013). This suggests that an optimal approach to encourage households to undertake energy efficiency investments should involve not only financial incentives, but also service quality and support measures.

Overall, non-market costs seem as decisive as market costs when households decide whether or not to retrofit their dwelling. It is therefore important that energy efficiency renovation policies address more than only the financial aspect.

In this study, we estimate only the impact of financial incentives on renovation decisions and expenditures.

2. Tax credit schemes to promote residential energy efficiency

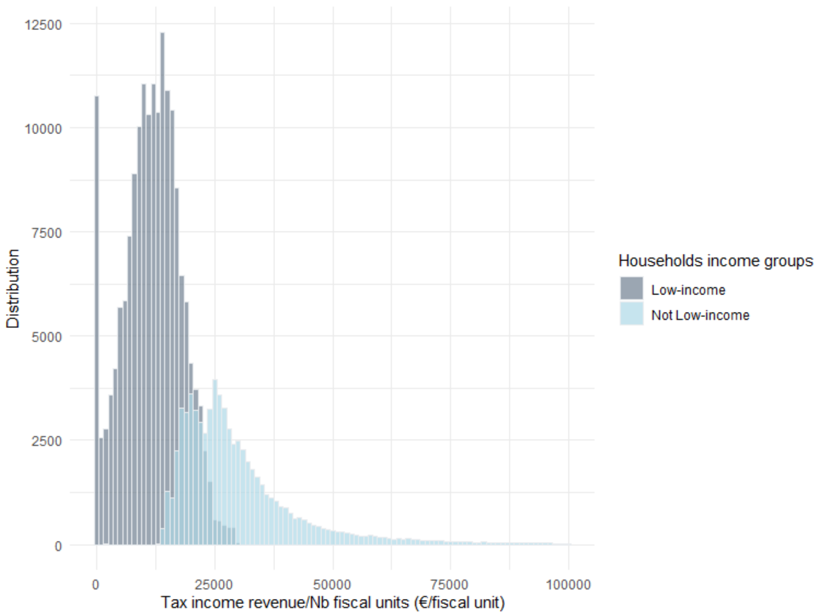
The Sustainable Development Tax Credit (*crédit d'impôt développement durable*, CIDD) was introduced in 2005 as an incentive for owners to carry out energy efficiency in a primary residence. (It was then replaced by the Energy Transition Tax Credit (*Crédit* d'impôt pour la transition énergétique, CITE) in 2015, with retroactive effect for renovation work undertaken from September 1, 2014. Eligible households could reduce their taxes by a percentage of the expenditure for items in a schedule of energy efficiency measures and renewable-energy equipment, in which the percentage deduction was specified for each type of item. Households with no income tax liability would receive either a bank transfer or a cheque from the French government. Eligibility criteria were adjusted over time and also varied depending on the type of renovation. Since 2013, only dwellings for which construction was completed over two years before the time of the renovation were eligible. Renovation work eligibility was based on formal energy efficiency criteria, which were also updated from time to time. For both the CIDD (pre-2015) and CITE (post-2015) schemes, three main categories of retrofitting projects were eligible for the tax credit:

- Heating system improvements (energy-efficient boilers, heating control system equipment) and heat pumps for space heating.
- Renewable energy equipment from sources such as hydropower, wind turbines, solar panels, solar water heating or geothermal energy).
- Insulation work and thermal insulation materials (such as double-glazed windows, shutters or doors).

When a household receives local or other national subsidies (from the regional council, department council, or National Agency for Housing Improvement) for the equipment purchased, the tax credit is calculated on the total expenditures net of the other public subsidies.

Our study aims to evaluate the 2014 reform which raised the tax credit as a percentage of expenditure, with variations depending on the number and types of renovation items and households income (see Box 1 for details on the reform). We restrict our examination to the impact on low-income households (identified on the basis of their reference taxable income, and household composition, i.e., the number of "tax units"[22]), which benefited from a 15 percentage point increase in the rate of the tax credit. Figure 1 depicts the distribution of reference taxable income per "tax unit" for low-income households compared to other households.

Figure 1: Distribution of reference taxable income per tax unit (€/tax unit) for households classified as low-income (grey) and not low-income (blue)



Source: ERFS database.

Note: Reference taxable income per tax unit for low-income households is in the range [€0, €29,655] while reference taxable income per tax unit for households that are not in the low-income group is in the range [€12,550, € 6,139,248]. Note that for clarity, households with reference taxable income per tax unit above €100,000 (1,067 observations among 246,847 observations) are not shown in the chart.

[22] As noted above, low-income households are identified of the basis of both reference taxable income and household composition (i.e., the number of "tax units," following the definition of the National Agency for Housing Improvement). Household reference taxable income should not exceed €24,043 for a couple without dependent children plus an additional €5,617 for the first child, and an additional €4,421 for the second and each subsequent child.

Box 1: the 2015 reform, from CIDD to CITE

When the CIDD was replaced by the CITE at the end of 2014, changes were made in eligibility criteria and in the tax credit rates.

Under the CIDD, households that had purchased in the past 2 years a primary residence constructed prior to 1977 could claim a tax credit equivalent to 15% to 25% of their energy efficiency expenditures, depending on the type of renovation and the number of renovation items reported. The 15% tax credit was intended for low-income households that undertook a single renovation, whereas the 25% tax credit was available to all households (regardless of income) that undertook two or more of the specified renovations. Accordingly, low-income households limited by their budget constraint to a single renovation item could benefit from a tax credit, unlike wealthier households that had to undertake two or more renovation "items."

Subsequently, under the CITE, all households owning a primary residence whose construction was completed over two years before renovation were eligible for a 30% tax credit on their energy efficiency investments, and there was no longer any requirements regarding the number of renovation "items" undertaken.

Under both schemes, eligible expenditure was capped, and the maximum tax credit would depend on the household composition.[23] The caps were set at €8,000 for a single-person household, €16,000 for a two-person household, plus an €400 per additional dependent person (usually children).

Overall, the transition from the CIDD to the CITE can be summarized as follows:

1) Tax credit increased by 15 percentage points (from 15% to 30%) for low-income households performing only one type of renovation before the reform.
2) Tax credit increased by 5 percentage points (from 25% to 30%) for households performing two or more types of renovation, regardless of income.
3) Tax credit increased by 30 percentage points (from 0% to 30%) for high-income households performing only one type of renovation after the reform.

3. Data

3.1 Source

We use the Insee Tax and Social Incomes Survey (ERFS) database that provides exhaustive tax files from 2005 to 2019 for a large sample of taxpayers. We focus on the period 2013-2019, for which our dataset contains on average 60,000 households per year; despite the term "survey," the tax data come directly from annual income tax returns. Each year, taxpayers can claim a tax credit when they report their total energy efficiency expenditures on their income tax returns. French households file tax returns in year N+1 for income earned in year N; we therefore follow home renovation investments undertaken between 2012 and 2018. The use of anonymized tax data guarantees a high level of reliability on energy efficiency expenditures.

Reliance on tax data nevertheless has drawbacks. First, this overlooks households that fail to report eligible energy efficiency investments on their returns, whether due to administrative burden, low awareness of the credit, or other reasons. Second, we fail to observe the total amount spent by households for energy efficiency or other home renovation work. Households only report the portion spent on items eligible for the tax credit that were installed by a registered professional. Moreover, as expenditures are self-reported, some households may have made mistakes in their returns. However, on average we are confident in the reliability of the reported renovation amounts, as households would be required to provide receipts in the event of a tax audit. Finally, unlike conventional panel survey databases, the tax data source provides few

[23] See *Bulletin Officiel des Finances publiques: IR - Crédit d'impôt pour la transition énergétique - Plafond de dépenses éligibles, BOI-IR-RICI-280-30-20*.

control variables, especially subjective and qualitative ones, such as information on agents' preferences regarding energy policy, or qualitative information on why households undertake energy efficiency investments.

Within the ERFS database, we use income tax return files already matched with the local residence tax dataset in order to obtain information on the characteristics of the household's dwelling (year of construction, size (in square meters), postcode, and whether an individual single-family house or an apartment). Local residence tax information is not available for both 2012 and 2013. We therefore merged the 2013 and 2014 datasets to find the one-sixth of households included in the survey in both years, which left only 16,837 observations for 2013. We were unable to do the same for 2012 as only a sixth of households are surveyed every quarter. Ultimately, for 2014 through 2017, there are an average of approximately 59,500 each year in our sample.

3.2 Descriptive statistics

3.2.1 The representativeness of the ERFS database

We first check that the ERFS database is representative of the overall French population as regards the use of CIDD and CITE over the period of interest. We use the 2017 IGF report[24] as a baseline, summing up statistics on various renovation policies computed by the DGFiP[25] in the form of an exhaustive review (CIDD and CITE tax credits, Habiter Mieux subsidies to owners, the "éco-PTZ" long-term zero-interest-rate loan for energy efficiency work, or the 5.5% reduced rate of Value Added Tax). Overall, from Table 1, we observe that the statistics from the total ERFS database are consistent with those from the IGF report relative to households and their dwellings that benefited from CIDD and CITE tax credit schemes.

Table 1: The representativeness of the ERFS database for households and dwellings that benefit from CIDD and CITE tax credit schemes

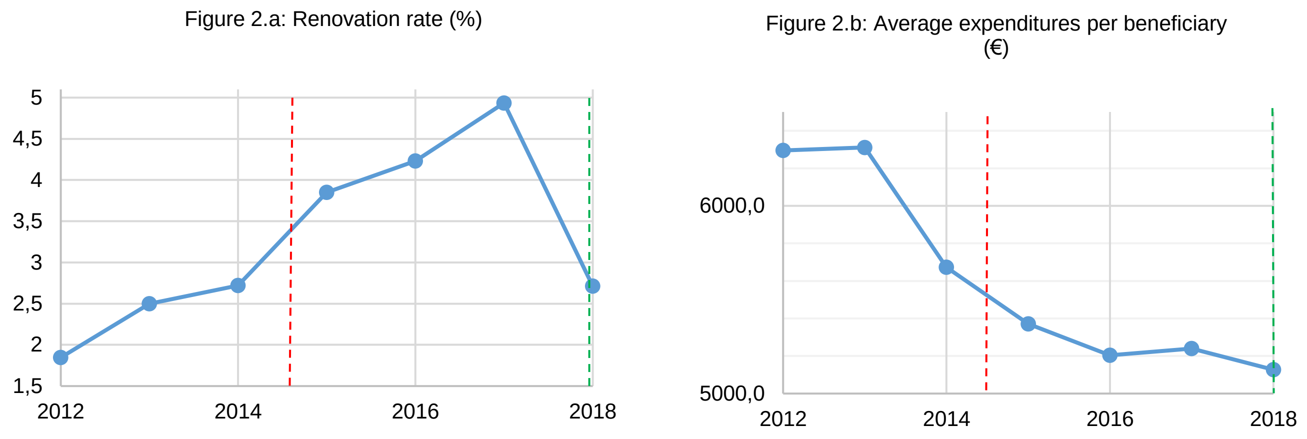
	IGF	ERFS Database
Renovation rate[26]	1.7% (2012-2014)	2.4% (2012-2014)
Wealthiest beneficiaries (5th quintile)	49-52% (2011-2015)	36-45% (2012-2018)
Poorest beneficiaries (1st quintile)	3-5% (2011-2015)	3-5% (2012-2018)
House[27]	87.9% (2015)	85% (2015)
Building completion date (share among beneficiaries)		
Before 1949	25.6%	28.4%
1949-1975	30.7%	26.4%
1975-1999	35.2%	35.3%
After 2000	8.5%	9.1%

Source: IGF and ERFS Database, DG Trésor computations.

[24] 'Aides à la rénovation énergétiques des logements privés', (Energy renovation aids for private dwellings), Inspection Générale des Finances, April 2017.
[25] Public Finances General Directorate, *Direction Générale des Finances Publiques* (DGFiP): https://www.economie.gouv.fr/dgfip.
[26] The "renovation rate" is the ratio of households that report renovations to the entire population in the database.
[27] In this paper, "house" refers to a single family house dwelling (detached, semi-detached, terraced house or bungalow), as opposed to an apartment.

Figures 2.a and 2.b highlight that the change in tax credit rate at the end of 2014 had two effects. On the one hand, there were more households making renovations (compared to the whole sample) after 2015 (the renovation rate increased from 2.7% in 2014 to 4.2% in 2016). But on the other hand, average expenditure per beneficiary household decreased continuously from €6,294 in 2012 to €5,127 in 2018, suggesting that households invested in less expensive renovations after the reform. It is likely that most beneficiaries undertook fewer renovation items in comparison to 2014 or earlier, as the new policy did not require at least two renovation items for high-income households to be eligible, unlike the earlier CIDD. Indeed, the share of "bouquets" of renovations (two or more items) decreases from 29.6% in 2014 to 24.1% in 2015.

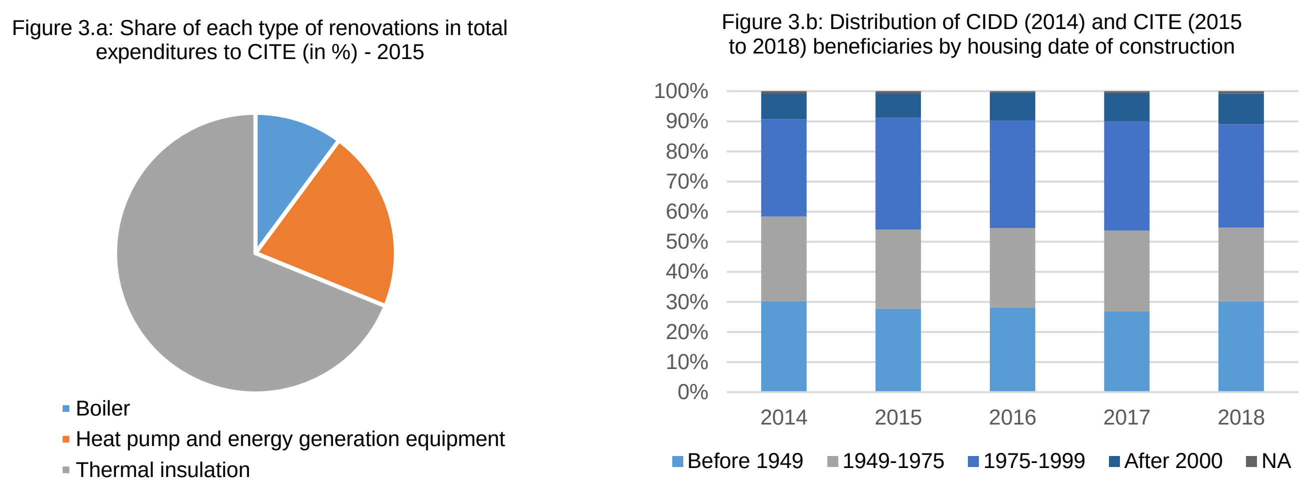
Figure 2: Change in extensive margin (left) and intensive margin (right) for total ERFS database



Source: ERFS Database, DG Trésor computations.

Figure 3.a displays the distribution of the tax credit with respect to type of renovation expenditure in 2015. Most expenditure went to thermal insulation (69%), with roughly half of that allocated specifically to windows; note however that from 2018 onward thermally efficient glazing was no longer eligible for the CITE tax credit. The year 2018 represents an important change in the renovation rate (green vertical line in Figures 2.a and 2.b), which decreased by 2.2 percentage points. We therefore remove the year 2018 from our sample, in order not to bias the effect of the tax credit change at the end of 2014 on the following years. As expected, Figure 3.b suggests that the oldest dwellings were most likely to attract renovation investment. Conversely, the most recent dwellings (those built after 2000) represent only 8.2% of total expenditures, because they do not require renovation and they represent a smaller share of the housing stock.

Figure 3: Type of renovation and housing under CIDD and CITE for total ERFS database



Source: ERFS Database, DG Trésor computations.

3.2.2 Our sample of interest: eligible low-income households

After validating the reliability of our database, we focus our study on a reduced sample, retaining only low-income households living in their primary residence built at least 2 years before undertaking renovation work, and performing at most one renovation item under CIDD (through 2014), or any number of renovation items under CITE (2015 and later). We choose to focus on this population because it is the only group eligible for all renovation items both before *and* after the reform, as wealthier households were previously eligible only if they undertook two or more renovations items. Thus, it would have been impossible to evaluate the effect of expanding eligibility of wealthy households to those undertaking just a single renovation item because we have no information about their “one item” renovation before the reform. If we had included this population in the estimate, the total effect would have been overestimated.

Table 2 shows the means and standard deviations for the dependent variables (see Tables 8 and 9 in the Appendix for control variable statistics). In our study, we are interested in both the extensive and intensive margins, i.e., changes in the decision to invest and in investment expenditures. The extensive margin describes how much the renovation rate varies, *i.e.*, the additional households that carry out energy efficiency renovation in response to the increase in tax credit rate. The average renovation rate in 2013-2014, before the tax credit change, was 1.4%, compared to 3.0% in 2015-2017, after the tax credit change (see Figure 4.a), suggesting that the change in policy indeed encouraged more low-income households to make renovations. Concerning the intensive margin, i.e., the additional expenditure in energy efficiency measures in response to the tax credit rate change, the average expenditure among low-income households that invest in eligible equipment also increases between the two periods, by 18.6%, from €4,088 on average before 2015 to €4,850 on average after 2015 (see Figure 4.b). However, because of the cap on the tax credit, for households undertaking energy-efficiency investments above the eligible amount, the credit covers less than the 15% or 30% (for CIDD or CITE, respectively) of total expenditure. Overall, under CIDD (through 2014), only 17 observations in our database reported renovation expenditures higher than the ceiling amount, whereas under CITE (2015 and later), 166 households reported investment expenditures higher than the cap and therefore had less than 30% of the expenditure covered by the tax credit.

Overall, these descriptive statistics identify a positive correlation between the increase in the tax credit rate, and both the decision to renovate and the increase in expenditure. Our study therefore seeks to determine whether or not there is a causal relationship induced by the tax credit rate change.

Table 2: Dependent variables – Descriptive statistics on low-income households in ERFS database

	All eligible low-income households (2013-2017)	Before tax credit change (2013-2014)	After tax credit change (2015-2017)
	Mean	Mean	Mean
Renovation rate using CIDD or CITE (%)	2.4	1.4	3.0
Observations	176,483	52,316	124,167
Average expenditure per beneficiary (Standard Deviation) [Min-Max]	4,644 (4,738) [26;69,425]	4,325 (4,277) [26;49,618]	4,856 (4,814) [42;69,425]
Number of beneficiaries	4459	721	3738

Source: ERFS Database, DG Trésor computations.

Figure 4: Change in extensive margin (left) and intensive margin (right), only for eligible low-income households in ERFS database

Figure 4.a: renovation rate (%)

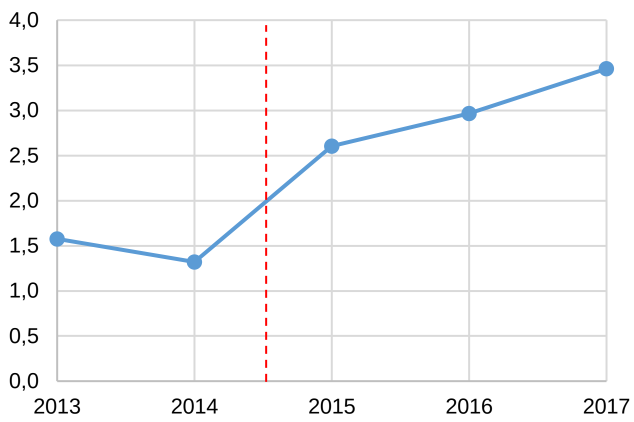
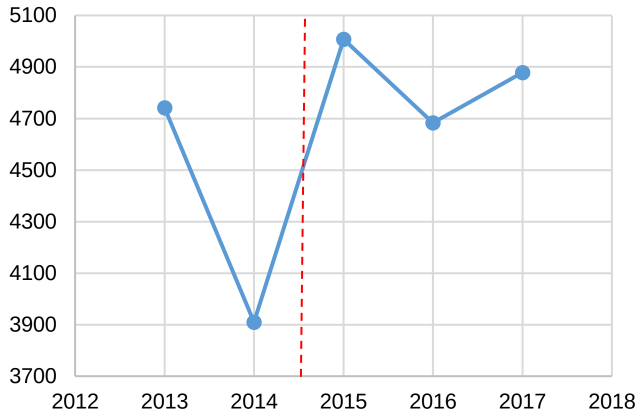


Figure 4.b: Average expenditures per beneficiary (€)



Source: ERFS Database, DG Trésor computations

4. Identification Strategy

4.1 Regression Discontinuity Design

Legislation to increase the tax credit rate for all households owning dwellings constructed at least two years previously was enacted in December 2014, to encourage them to undertake more energy-saving renovations. We aim to identify the average causal effect of the change on two dependent variables y_i (the renovation rate and expenditure) in order to validate whether the changes observed in Figures 4.a and 4.b are indeed caused by the increase in tax credit rate.

The tax credit rate increase was introduced in 2015[28] (denoted as $T = 1$); we therefore expect the average impact of this reform on households (denoted as Δ) to be the difference between the renovation rate (or renovation expenditures) *with the new policy* (y_1) and the renovation rate (or renovation expenditures) that would have been observed *without the new policy* (y_0) as in Rubin's model (Rubin, 1974):

$$\Delta = E[y_1 | T = 1, X = x] - E[y_0 | T = 1, X = x] \quad (1)$$

where T the denotes treatment dummy variable, y the dependent variable (renovation decision or expenditures) and X the control variables.

However, since we do not observe both states simultaneously, our approach aims at measuring the sharp discontinuity[29] in renovation rate and expenditures at the assignment threshold (t_0 = 2015). After t_0, observations are treated (T = 1), otherwise they are not (T = 0).

To assess the effect of this policy, we would have preferred to have observations before and after the policy for two groups, one subject to the increase in the tax credit rate and the other not affected by the change and thus serving as the control group. However, unlike Mauroux (2014) and Tamokoué Kamga (2018), we do not have a relevant control group to study the reform with a difference-in-differences method. Indeed,

[28] For the regression, we take the year 2015 rather than September 2014 as the cutoff threshold because households that carried out retrofitting in 2014 were not aware of the eligibility change on September 1, 2014 (see 4.2. Assumption 1).

[29] The implementation of CITE implies a *sharp* discontinuity in eligibility for the measure: after 2015, all observed households can benefit from the higher rate, while those observed up to 2015 are considered ineligible because the change was unanticipated and applied retroactively. Conversely, a *fuzzy* discontinuity could have been considered in the case of (i) imperfect compliance with the program that is not expected since the cost of the administrative burden (declaring only the renovation expenditures when filling the tax return) is likely to be much lower than the benefit due to a 30% credit rate on the expenditures, (ii) imperfect implementation that 'treated' some non-eligible units, or neglected to treat some eligible units (unlikely to happen here since the tax authorities are responsible for verifying eligibility), or (iii) manipulation of the eligibility that we exclude in our first identifying assumption.

there is no change in eligibility criteria that could provide a consistent control group. In particular, the most recent dwellings which were not eligible for the tax credit (neither before nor after the reform) cannot be considered a good counterfactual of the group of oldest dwellings since they are much less likely to undergo renovations. Moreover, we could have used non-eligible households slightly wealthier than low-income households eligible for the 15 percentage point tax credit rate increase as a control group. However, since non-eligible households have no reason to report their renovation expenditures, which could not benefit from any tax credit scheme, we would not have renovation data for that control group. As Lemieux and Milligan (2008) showed, a difference-in-difference estimator commonly used in quasi-experimental studies may perform poorly when control groups are inappropriately chosen. We therefore estimate the naive difference estimator of the average treatment effect (ATE) relying on time and policy-design change, as in Risch (2020), using a regression discontinuity design (RDD).

Our identification strategy relies on the comparison of observations just before the cutoff threshold year of 2015 with observations just after that threshold, using the regression discontinuity design (Thistlethwaite and Campbell (1960)):

$$y_i = \beta_0 + \beta_1 T_i + \delta(t_i) + \alpha x_i' + \epsilon_i \quad (2)$$

where T_i is the treatment dummy that captures the causal effect on the dependent variable y_i (renovation decision or expenditures) of the increase in the tax credit rate. The average causal effect of the policy change at the assignment threshold (t_0= 2015) is measured by β_1. We also denote ϵ_i the error term and x_i' the vector of observable households' and dwellings' characteristics. The latter are considered as control variables and include variables that may influence the renovation decision (see Tables 8 and 9 in Appendix). Finally, the effect of years (the assignment variable) on the outcome variable is captured by the function $\delta(t_i)$.

We first limit our analysis to a subset of observations that are sufficiently close to the cutoff year (t_0 = 2015), i.e., one year before the discontinuity (t_i= 2014), and the reform year itself (t_i= 2015). In that way, we restrict the observations so as to estimate a Local Average Treatment Effect (LATE) estimator by conducting the following local linear regression:

$$y_i = \beta_0 + \beta_1 T_i + \alpha x_i' + \epsilon_i \quad (3)$$

We also estimate a two-sided linear model (Risch (2020)) for both the extensive and intensive margins by introducing the distance to the discontinuity/shock in public policy with the assignment variable (t_i - 2015) and an interaction between the treatment and the assignment variable in order to assess whether there was a break in the trend at the threshold:

$$y_i = \beta_0 + \beta_1 T_i + \beta_2 (t_i - 2015) + \beta_3 T_i (t_i - 2015) + \alpha x_i' + \epsilon_i \quad (4)$$

where β_1 still measures the average causal effect of the policy change, β_2 captures the direct effects of the assignment variable (t_i) on the average dependent variables y_i and β_3 allows us to model a possible break in the trend after implementation of the CITE in 2015.

4.2 Identifying assumptions of the RD design

Before estimating the average causal effect, we have to validate four identifying assumptions to assess the *causal inference* of our econometric study, i.e., to ensure that any differences in renovation rate and expenditures (Figures 4.a and 4.b) between the two groups are solely and causally due to the treatment effect, without any confounders.[30]

Assumption 1: randomized treatment

[30] Confounders are variables/characteristics that differ between the treatment and control groups and that influence the dependent variables and bias the estimation of the causal effect of the treatment on these dependant variables.

First, we have to be sure that households cannot manipulate the assignment variable (t_0 = 2015). This implies that $\delta(t_i)$ is a smooth function, meaning that the treatment is the only source of discontinuity around the threshold. First, it is reasonable to suspect that some people could find ways to "cheat" by postponing their renovations if they were aware of the future policy change. If such manipulations had been possible, results from our RD design on the average causal effect of a 15 percentage point increase in the tax credit rate might lead to erroneous inferences. However, since there was a press release on August 29, 2014, to announce the tax credit change for renovations made from September 1, 2014, and since the policy was voted in December 2014 in the Finance Act for 2015,[31] the policy change was likely not anticipated by households, which did not have time to postpone their renovations. This explains why the year 2015 is taken as the assignment variable rather than September 2014, since we consider that households did not react to the new incentive before the beginning of 2015.

Assumptions 2 and 3: the characteristics of households (2) and dwellings (3) are similar around the threshold (i.e., no jump in those control variables)

Hahn et al. (2001) and Lee (2008) stressed that the identification is built upon the assumption that outcomes of individuals before the threshold t_0 = 2015 (*i.e.*, households just before the threshold that can benefit from a 15% tax credit) represent what would have been the outcomes for those marginally after the threshold in the absence of the treatment (*i.e.*, those just after the threshold who can benefit from a 30% tax credit). Therefore, the credibility of the RD design highly depends on the assumption of comparability of individuals marginally before and after the threshold. To guarantee such homogeneity between both groups, we compare households' (Assumption 2) and dwellings' (Assumption 3) characteristics that might also affect renovation decisions and expenditures, using a two sample t-test (see Table 10 in Appendix for details). Overall, our results set out in the Appendix validate these assumptions (see Appendix 6.1.2.).

Assumption 4: changes in other public policies around the threshold

Finally, we check that there were no major changes in other public renovation policies, so that we measure only the effect of the 15 percentage point increase in the tax credit. The IGF report (section 3.2.1 above and footnote 26) describes all existing renovation policies ('Habiter mieux', 'Eco-PTZ', and the 5.5% reduced rate of VAT, described in section 3.2.1 above) and does not mention any changes in 2015 other than the CIDD and CITE schemes and the white certificate obligation (*Certificats d'Economies d'Energie,* CEE)[32] policy. Indeed, to finance their renovations, households are allowed to combine CITE with subsidies paid by the "obligated" energy suppliers to households under the CEE schemes. If changes to the CEE system had occurred during the period studied (between 2014 and the end of 2015), that could bias our evaluation. We note that a new period of obligations under the CEE began on January 1, 2015, as “obligated” energy suppliers were assigned a more ambitious energy savings target over the 2015-2017 period,[33] encouraging them to accelerate their energy saving actions. However, the price of certificates on the market[34] barely fluctuated over the period, holding steady at around €3/MWh_{cumac}.[35] It is thus unlikely that the start of the new white certificate (CEE) period led to a significant change in the amounts paid as bonuses to households that could interfere with our results. Further, a specific CEE for households in a situation of fuel poverty (low-income households) was implemented on January 1, 2016. That date is far enough from the date chosen for the discontinuity (t_0 = 2015) that the new measure is also not likely to bias our results for the

[31] Article 3 of the Finance Act for 2015 (law 2014-1654 of December 29, 2014) refers to expenditure incurred from September 1, 2014.
[32] Under the white certificates (CEE) scheme, certain energy suppliers (the “obligated companies”) are required to ensure energy savings by their customers, particularly in the residential sector, which accounts for most of the energy-saving actions carried out under the scheme. (Subsidies in connection with these energy-saving actions can incentivize households to carry out thermal renovation work; in most cases the subsidies can be combined with other public aids, including the CITE.
[33] The energy savings target for 2015-2017 was set at 700 TWh_{cumac} over the period, compared to 447 TWh_{cumac} for the previous period (2011-2014). Energy savings are measured in TWh_{cumac}, i.e., terawatt hours over the lifetime of the improvement and discounted at 4 percent.
[34] The white certificates generated for energy suppliers are tradable on a secondary market, with the price set by supply and demand.
[35] The price of the white certificates (CEEs) (in €/MWh_{cumac}) is calculated as the ratio between the direct costs to the obligated companies ("bonuses" paid out and transaction costs) and the corresponding total energy savings in MWh_{cumac} (once again, over the lifetime of the improvement and discounted at 4 percent).

local average causal effect of the 15 percentage point increase in the tax credit rate between 2014 and 2015. However, when estimating the average causal effect over a longer timeline (2013-2017), we should bear in mind that this CEE reform on low-income households might also impact our estimates.

4.3 Heckman method to correct for self-selection bias at the intensive margin

At the intensive margin, the outcome variable y_i in Equation (3) is set as the logarithm[36] of reported expenditures. However, the only observations are of expenditures self-reported by households in their tax returns. Montgomery (1992) underlined that focusing only on a sample of households with nonzero improvement expenditure is not satisfactory. If the choice to improve the energy efficiency of their dwelling is correlated with the choice of the level of expenditure allocated to the improvement, the households included in our sample may not be randomly selected. It might bias our expenditure renovation results if treated and untreated groups differ in their probability to renovate for reasons other than the treatment.

To address this source of endogeneity, we use the two-stage method proposed by Heckman (1976) to estimate a model in which households first decide whether to undertake energy renovations (selection), and then, conditional upon that decision, they decide the amount of renovation expenditure (outcome). We then obtain a two-step estimator, assuming that the errors in the selection and outcome equations are jointly normally distributed. This assumption is sufficient for the identification by exploiting the non-linearity of the selection bias correction term, the so-called inverse Mill's ratio (IMR).

The first stage consists in estimating a qualitative choice model of the household's propensity to renovate as a function of a set of explanatory variables with a probit function. This is the so-called selection equation:

$$P(Renovation_i = 1) = \alpha_0 + \alpha_1 T_i + \alpha_2 Age_i + \alpha_3 Age_i^2 + \alpha_4 Marital\ status_i + \alpha_5 Tax\ reference\ income_i + \alpha_6 Surface\ area_i + \alpha_7 House_i + \alpha_8 Climate\ area_i + \alpha_9 Building\ completion\ date\ _i + \epsilon_i \quad (5)$$

Equation (5) generates the IMR[37] that is included in the second stage as an additional explanatory variable to correct the bias from non-randomly selected samples. To properly identify the parameters, the set of explanatory variables in the selection model has to include at least one variable which is not included in the outcome equation, the so-called exclusion restriction variable. Those variables that are excluded must affect the selection, *i.e.*, the decision to invest in renovations, without having a direct effect on outcome, *i.e.*, the amount of investment. For instance, a variable for the date the household moves into the dwelling would have been a good exclusion restriction as a recent change in occupancy might indicate a likely time to retrofit (Gans (2012) and Nauleau (2014)) without necessarily impacting the amount invested in renovation, which depends more on the dwelling's characteristics.

In our model, age, marital status of the owner filing for the tax credit and household size (specifically, the number of "tax units") are chosen as the exclusion restrictions since they do have a statistically significant impact on the decision to renovate (see Table 3) but probably not on the expenditure. Conversely, the cost of renovation highly depends on dwelling characteristics, so we cannot exclude that the dwelling characteristics influence both the extensive and intensive margins. It will be noted later, in Table 7, that the IMR is statistically significant, which suggests that there was self-selection.

The second stage consists in estimating the outcome equation only on the selected population estimated in the first stage, without the exclusion restrictions:

$$E(log(Expenditures_i)|Renovation_{it} = 1) = \beta_0 + \beta_1 T_i + \beta_2 Reference\ taxable\ income_i + \beta_3 Surface\ area_i + \beta_4 House_i + \beta_5 Climate\ area_i + \beta_6 Building\ completion\ date\ _i + \beta_7 IMR_i + \epsilon_i \quad (6)$$

[36] Because most values in our database are zero, due to the limited number of renovations carried out, we add €1 to all expenditures so that the logarithm of expenditures is always defined.

[37] The Inverse Mills Ratio is given from the estimation of a probit model (as it assumes that the error terms follow a standard normal distribution, a Logit cannot be used). Similarly to an instrumental variable, the IMR allows us to address the selection bias due to unobservable characteristics when adding it as a correction term in the second-stage outcome regression.

Where β_1 is the coefficient of interest that estimates the average causal treatment effect on the renovation expenditures and the IMR term generated by the first-stage allows us to address the selection bias.

Table 3: Heckman method – Selection Equation

	Dependent variable: Renovation rate	
	Coefficients	AMEs
T_i	0.349*** (0.017)	0.019*** (0.001)
Age	0.025*** (0.003)	0.0014*** (0.0001)
Age²	−0.0002*** (0.00002)	−0.000*** (0.000)
Number of "tax units" in household (Baseline: 1unit)		
1.5 to 3 units	0.072*** (0.019)	0.0039*** (0.010)
3.5 and 4 units	−0.044 (0.039)	−0.0021 (0.019)
More than 4 units	−0.221*** (0.069)	−0.0092*** (0.0024)
Marital Status (Baseline: Married or civilly partnered)		
Single	−0.009 (0.023)	−0.0005 (0.0012)
Divorced	0.049** (0.024)	0.0027** (0.0013)
Widowed	0.118*** (0.026)	0.0069*** (0.0016)
Surface area		
Surface area (m²)	0.001*** (0.0002)	0.0001*** (0.0000)
Type of dwelling (Baseline: Apartment)		
House	0.392*** (0.019)	0.0214*** (0.0011)
Building completion date (Baseline: Before 1949)		
1949-1975	0.108*** (0.018)	0.0063*** (0.0011)
1976-1982	0.103*** (0.023)	0.0060*** (0.0014)
1983-1989	0.114*** (0.025)	0.0067*** (0.0014)
1990-2000	−0.124*** (0.027)	−0.0059*** (0.0012)
2000-2009	−0.185*** (0.027)	−0.0083*** (0.0011)
After 2009	−0.341*** (0.062)	−0.0132*** (0.0018)
Climate area (Baseline: Climate area 1)[a]		
Climate area 2	0.062*** (0.015)	0.0034*** (0.0008)
Climate area 3	−0.0002 (0.025)	−0.0000 (0.0013)
Observations	175,838	175,838

*Note: *p<0.1; **p<0.05; ***p<0.01.*

[a] Climate Area 1 corresponds to the Mediterranean area, climate area 2 to western and southwestern France and climate area 3 northeastern and eastern France, excluding the Mediterranean area (colder, continental climate area), *cf.* Figure 5 below.

5. Results

5.1 Extensive margin

We first estimate the impact of the increase in tax credit on the rate of energy-saving renovations for all eligible renovations. Table 4 presents the results[38] of the RD design regression using a linear probability model.[39] Columns (1) to (4) illustrate results from the parametric model with and without control variables. More specifically, the first two columns estimate the impact of the treatment without the assignment variable (t_i - 2015) and without the interaction term $T_i(t_i$ - 2015). Columns (3) and (4) estimate the impact of the treatment with the assignment variable (t_i - 2015) and either without (3) or with (4) control variables. Then, columns (5) and (6) display results from the two-sided linear model (Equation 4) without and with control variables, respectively. Finally, the two last columns (7) and (8) show results from the local linear regression for the years 2014-2015 (Equation 3).

First, we notice that our results are not very sensitive to the inclusion of observed characteristics as control variables, suggesting that they are robust in that respect. Van der Klaauw (2008) assessed that this test can be interpreted as a test for an imbalance in relevant characteristics at the threshold (t_0 = 2015), which strengthens the validity of the continuity of the observable characteristics across the discontinuity mentioned in Assumption 2 and Assumption 3.

The increase in the tax credit rate is found to impact significantly and positively the decision to renovate, raising it by 0.8 and 1.3 percentage points depending on the specification chosen. Using the lowest Akaike Information Criterion (AIC)[40] we can identify which model has the most parsimonious fit. We conclude that the two-sided linear model with control variables (Column (6) from Table 4) is preferred. The effect of the increase in the tax credit rate is statistically significant on the extensive margin. It increases the rate of renovation by 1.3 percentage points, *ceteris paribus*. Also using a RD design, Risch (2020) found a similar effect in 2006, following a 15 percentage point increase in the tax credit under the recently introduced CIDD, which increased the probability to renovate by 1.09 percentage points.

Moreover, the result from the interaction term between the treatment and the distance to policy change $T_i(t_i$ - 2015) suggests that there is a statistically significant break in renovation trend after the increase in tax credit rate. More precisely, the further households are from the policy change, the more they declare renovations. The treatment effect is likely to increase with time as information spreads among households. More specifically, Mauroux (2014) suggested that the two main sources of information for households that wish to carry out renovations are companies in the building trades, and members of their families who have already benefited from tax credit schemes.

[38] Results on control variables can be provided upon request.
[39] The LPM is a special case of an OLS regression where the outcome variable is binary, either 0 (households do not report renovation under CIDD/CITE schemes) or 1 (households undertake renovation and benefit from a tax credit). The LPM is convenient to use as it is easier to estimate and interpret than a non-linear model (such as a Logit model). However, unlike in a Logit model, the predicted probabilities estimated with LPM can be lower than 0, which is meaningless. Accordingly, we also perform a Logit model for which the treatment increases the probability to renovate by 1.2 percentage point (see in Appendix), which confirms the order of magnitude found by the LPM.
[40] The AIC works to balance the trade-offs between the complexity of a given model and its goodness of fit, i.e., how well the model "fits" the data.

Table 4: RD design, OLS estimations – Effect of the treatment on the decision to renovate

	Dependent variable: Renovation rate							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ti	0.016*** (0.001)	0.017*** (0.001)	0.008*** (0.001)	0.008*** (0.001)	0.015*** (0.002)	0.013*** (0.002)	0.013*** (0.001)	0.013*** (0.001)
(ti – 2015)			0.004*** (0.001)	0.004*** (0.001)	−0.003 (0.002)	−0.0003 (0.002)		
Ti(ti – 2015)					0.007*** (0.002)	0.005*** (0.002)		
Constant	0.014*** (0.001)	−0.049*** (0.004)	0.018*** (0.001)	−0.045*** (0.004)	0.011*** (0.002)	−0.049*** (0.004)	0.013** (0.001)	−0.036*** (0.005)
Observations	175,838	175,838	175,838	175,838	175,838	175,838	81,939	81,632
Bandwith	(2013-2017)	(2013-2017)	(2013-2017)	(2013-2017)	(2013-2017)	(2013-2017)	(2014-2015)	(2014-2015)
R^2	0.002	0.020	0.003	0.020	0.003	0.020	0.002	0.016
AIC	−153,269	−155,561	−153,315	−155,617	−153,328	−155,622	−91,112	−91,744
Control variables	NO	YES	NO	YES	NO	YES	NO	YES

*Note: *p<0.1; **p<0.05; ***p<0.01.*

Using the two-sided linear model over 2013-2017, we also provide an estimation of the impact of the treatment on renovation items, which we split into two categories: insulation items include work involving thermal insulation materials, and heat and energy generation items. Although the difference is not statistically significant, the results in Table 5 suggest that the magnitude of the impact of the 15 percentage point increase in the tax credit rate is greater on the decision to undertake insulation renovation items (+0.77 percentage point) than for heat and energy generation items (+0.65 percentage point). This is consistent with the statistics of the CIDD/CITE schemes (see Figure 3.a) and raises a question as whether the CITE scheme accurately targets renovation that would generate the greatest energy savings. For instance, glazing accounted for over a third of insulation work performed over 2014-2017. These renovations did not significantly improve the energy efficiency of buildings,[41] and, as suggested by Risch (2020), they were highly subject to windfall effects (also called "free-riding" in the energy renovation literature). They were therefore inefficient in terms of both energy savings and public cost. This goes some way to explaining their removed from the list of eligible renovation work in 2018.

[41] Note that the average energy gain for glazing (windows and walls) is 0.62 MWh/year, compared to 4.30 MWh/year for insulating the roof (source: *Comité d'Évaluation du Plan France Relance*, known as the Coeuré Committee, October, 2021).

Table 5: RD design, OLS estimations – Effect of the treatment on the decision to renovate for subgroups of renovation items

	Dependent variable: Renovation rate	
	Insulation	**Heat and energy generation**
T_i	0.0077*** (0.002)	0.0065*** (0.001)
$(t_i – 2015)$	0.003*** (0.001)	−0.003*** (0.001)
$T_i(t_i – 2015)$	0.001 (0.001)	0.004*** (0.001)
Constant	−0.034*** (0.003)	−0.0016*** (0.002)
Observations	175,838	175,838
R^2	0.016	0.008
Control variables	YES	YES

*Note: *p<0.1; **p<0.05; ***p<0.01.*

5.2 Heterogeneous effects on the extensive margin

Depending on household and dwelling characteristics, the treatment effect might differ. To gain insight into the heterogeneity of the treatment effect, we make our treatment variable interact separately with dwelling and household characteristics. Table 6 reports the differential effects[42] of the treatment on the decision to renovate for those subgroups.

Concerning household characteristics, Douenne (2020) estimated households' responses to taxes by computing elasticities of energy demand conditional on certain characteristics. While those elasticities do not refer to households' responses to subsidy, they indicate that housing energy demand elasticities are decreasing with income. The mechanism behind this finding is energy accounts for a larger share of the budget for low-income households than for higher income households, and therefore respond more strongly to price increases to alleviate their budget constraint. Conversely, from Table 6 (Column (2)), we notice that for the low-income households investigated, the increase in the subsidy is more of an incentive for the wealthiest households (quintile 5) than the poorest ones (quintile 1).[43] For the former, the effect of the treatment increases their probability of renovating six times more than the latter (+3.6[44] percentage points vs. +0.6 percentage points, respectively). The intuition behind this result is that very low-income households are much more likely to lack both savings (to cover the initial investment costs) and access to credit; that barrier is likely to be less relevant for households at the higher end of the low-income spectrum.

[42] Note that to estimate the causal heterogeneous effect we need to compare categories with the same proportion so that results are not affected by size effect. We therefore create quintiles for each category of interest except for the climate area variable, which is already defined with respect to postcode.
[43] Note that low-income households are defined in our study with respect both to their reference taxable income and to household size and composition (i.e., the number of tax units), whereas the heterogeneous effect regarding income does not include the number of tax units.
[44]The treatment effect on Quintile 5 is given by adding coefficients from T_i and T_i*Quintile 5 terms.

Moreover, returns on renovation investment could be expected to be higher in homes built many decades ago, and especially before the introduction of the first thermal standards for residential construction in 1974. Table 6, (Column (4)) partially confirms those results: dwellings built after 1993 are subject to significantly fewer energy-efficiency renovations (-0.6 percentage point) than those built before1900. We also note that the larger the surface area, the stronger the treatment effect on the decision to renovate (Table 6, Column (3)). Similarly, Column (5) shows that the treatment increases the probability to renovate by 2.4 percentage points for houses (single family homes), which is 1.7 percentage points higher than for apartments. The intuition behind those results might be that the willingness to lower the energy bill is higher for larger dwellings, and for houses as opposed to apartments, as they consume more energy.

Finally, we observe (Column (1)) an unexpected heterogenous effect of the treatment on the renovation rate in favor of Climate Area 2 (mainly western and southwestern France – cf. Figure 5) in comparison to the colder, continental climate area (mainly northeastern and eastern France, excluding the Mediterranean area). However, this result is explained by a composition effect, as our sample contains a greater proportion of individual houses in Climate area 2 (95.7%) than in the Climate area 1 (72.3%), over the period studied (2013-2017). Reducing our sample to only houses, and thus excluding apartments, (Column (6)), there ceases to be any statistically significant heterogenous treatment effect with respect to the climate area, confirming the suspected composition effect.

Figure 5: French departments within one of the three climate area selected for the estimation

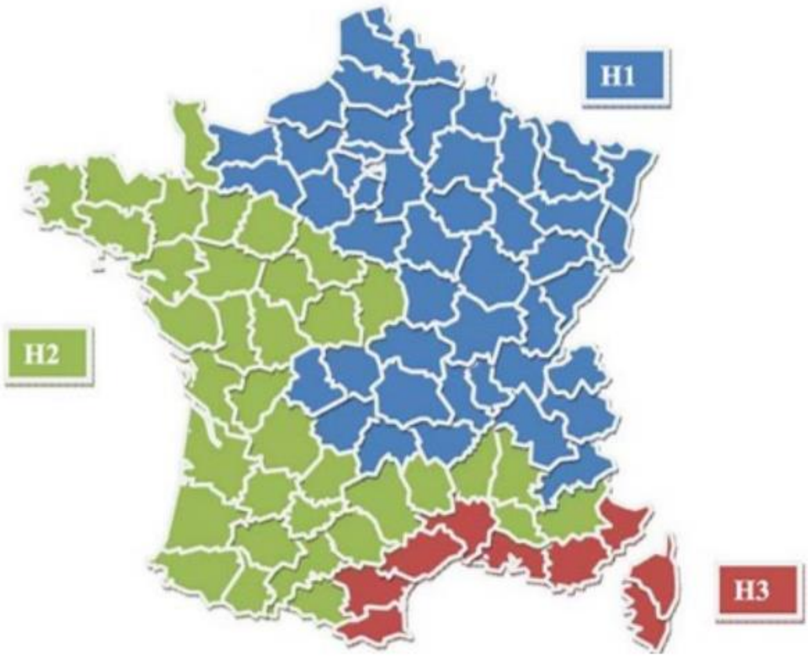


Table 6: OLS estimations – Heterogenous effects of the treatment on the extensive margin

	Dependent variable: Renovation rate					
	Total sample (houses and apartments)					Houses only
	(1)	(2)	(3)	(4)	(5)	(6)
T_i	0.015** (0.001)	0.006** (0.002)	0.003 (0.006)	0.016*** (0.001)	0.007*** (0.001)	0.022*** (0.002)
Climate area (Baseline: Climate area 1)						
T_i*Climate area 2	0.005*** (0.002)					0.0023 (0.003)
T_i*Climate area 3	−0.0001 (0.003)					0.004 (0.005)
Income (Baseline: Quintile 1)						
T_i*Quintile 2		0.006** (0.002)				
T_i*Quintile 3		0.015*** (0.002)				
T_i*Quintile 4		0.029*** (0.003)				
T_i*Quintile 5		0.030*** (0.006)				
Surface area (Baseline: Surface < 59m²)						
T_i* 59 - 73m²			0.003 (0.006)			
T_i*74 - 88m²			0.014** (0.006)			
T_i*89 - 108m²			0.021*** (0.006)			
T_i*Over 109m²			0.022*** (0.006)			
Building completion date (Baseline: Before 1900)						
T_i*1901-1963				−0.002 (0.003)		
T_i*1964-1976				0.0005 (0.003)		
T_i*1977-1992				0.009*** (0.003)		
T_i*After 1993				−0.006*** (0.003)		
T_i*House					0.017*** (0.003)	
Constant	−0.048*** (0.004)	−0.034*** (0.004)	−0.022*** (0.006)	−0.031*** (0.004)	−0.043*** (0.004)	−0.050*** (0.006)
Observations	175,838	175,838	175,838	175,838	175,838	106,645
R^2	0.020	0.021	0.016	0.016	0.021	0.017

*Note: *p<0.1; **p<0.05; ***p<0.01.*

5.3 Intensive margin

As noted above, results could be affected by self-selection bias when estimating the treatment effect on the intensive margin. In our study, this bias might arise when households decide whether or not to undertake energy efficiency renovations and, conditional upon that decision, the amount of renovation expenditure they report on their tax return. Households' propensity to undertake these investments may therefore be correlated with the level of expenditure, which we seek to estimate in this section.

Using the Heckman two-step procedure, we are able to account for sample-induced endogeneity and alleviate the self-selection bias. We first conduct a probit estimation referring to Equation (5). Table 3 reports the results of the probit estimation of the selection equation, as well as the average marginal effect. The results highlight that all variables are statistically significant and relevant in explaining the decision to carry out energy saving renovations. Then, using age, marital status and the number of "tax units" within the household as exclusion restrictions (as detailed in the previous section), we are able to estimate the effect of the policy change on the intensive margin without self-selection bias. Table 7 sets out the results for the outcome equation (Equation 6) corrected for self-selection that is statistically significant (see IMR coefficients in Table 7). The effect on the intensive margin is statistically significant and increases renovation expenditure by 21.7% to 30%, depending on the bandwidth used (Table 7). When focusing on the local linear regression between 2014 and 2015, the LATE estimates show an increase in renovation expenditure of 25.6%, which represents an additional €969 for total average expenditures per beneficiary household; this is consistent with our descriptive statistics illustrated in Figure 4.b (which reported an increase of €1,128 from 2014 to 2015).

Table 7: Heckman method – Outcome Equation

	Dependent variable: Expenditures (Log)				
	(2014-2015)	(2013-2016)		(2013-2017)	
	(1)	(2)	(3)	(4)	(5)
T_i	0.256*** (0.087)	0.217*** (0.067)	0.269** (0.122)	0.274*** (0.062)	0.303** (0.120)
$(t_i - 2015)$			−0.010 (0.080)		−0.008 (0.080)
$T_i(t_i - 2015)$			−0.067 (0.089)		−0.010 (0.082)
Control variables					
Reference taxable income	0.000** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Type of dwelling (Baseline: Apartment)					
House	0.559*** (0.114)	0.652*** (0.086)	0.649*** (0.086)	0.816*** (0.071)	0.815*** (0.071)
Surface area (m²)	0.004*** (0.001)	0.004*** (0.001)	0.004*** (0.001)	0.003*** (0.0005)	0.003*** (0.0005)
Building completion date (Baseline: Before 1949)					
1949-1975	0.092 (0.066)	0.053 (0.049)	0.051 (0.049)	0.048 (0.042)	0.048 (0.042)
1976-1982	0.197** (0.079)	0.139** (0.060)	0.137** (0.060)	0.159*** (0.051)	0.159*** (0.051)
1983-1989	0.177** (0.085)	0.178*** (0.065)	0.178*** (0.065)	0.182*** (0.055)	0.183*** (0.055)
1990-2000	0.123 (0.102)	0.042 (0.072)	0.045 (0.072)	−0.054 (0.061)	−0.053 (0.061)
2000-2009	−0.126 (0.115)	−0.120 (0.083)	−0.118 (0.083)	−0.152** (0.067)	−0.151** (0.068)
After 2009	−0.329 (0.263)	−0.317 (0.205)	−0.315 (0.205)	−0.264* (0.154)	−0.261* (0.154)
Climate area (Baseline: Climate area 1)					
Climate area 2	−0.037 (0.052)	−0.055 (0.040)	−0.056 (0.040)	−0.064** (0.033)	−0.065** (0.033)
Climate area 3	−0.047 (0.089)	−0.017 (0.065)	−0.017 (0.065)	−0.018 (0.055)	−0.019 (0.055)
Constant	5.598*** (0.941)	5.594*** (0.643)	5.618*** (0.650)	5.108*** (0.523)	5.103*** (0.532)
Observations	81,632	134,853	134,853	175,838	175,838
R^2	0.066	0.069	0.070	0.082	0.082
Inverse Mills Ratio	0.497* (0.283)	0.483*** (0.192)	0.472** (0.192)	0.618*** (0.156)	0.616*** (0.156)

*Note: *p<0.1; **p<0.05; ***p<0.01.*

These results should be interpreted with caution. Indeed, one of the most challenging points in the RD design method consists in finding the untreated group that is a good counterfactual for the treated group: the untreated group must properly reflect what the treated group would have done *in the absence of policy change*. Therefore, one should bear in mind that these results are highly dependent on our construction of the untreated and treated groups. In our core estimation, untreated households are low-income households that undertook only one renovation item before the tax credit rate increase (under CIDD, i.e., before 2015 when $T_i = 0$) whereas we observe all low-income households after the tax credit rate change, regardless of the number of renovation items undertaken.

In this way, we study both (i) the effect of an increase in the tax credit and (ii) the effect of the extension of eligibility to a set of multiple, more costly renovation items. However, the untreated group might be a poor counterfactual if we were to assume that households that undertake only one renovation item live, on average, in dwellings that are in better condition, and therefore which need less retrofitting than households that undertake multiple renovation items.

When we include low-income households that invest in only one renovation item both in the treated and the untreated groups, the 15 percentage point increase in the tax credit rate ceases to have a statistically significant effect on renovation expenditures[45], using the RD model. This suggests that the 2015 reform does not encourage households effecting only one renovation to direct their renovation investment toward more expensive renovations which could also be, on average, more energy efficient.l[46]

6. Conclusion

In this paper, we analyzed the effects of the 15 percentage point increase in the tax credit rate on energy-savings renovation implemented in September 2014 in France. We focused exclusively on low-income households. First, we estimate a significant effect on the extensive margin, that increases the probability of households' undertaking energy efficiency renovations, by 1.3 percentage points using the RD design model (1.2 percentage points using Logit model), compared to an average renovation rate of 1.4% before the reform. Second, using the Heckman method, we identify a significant effect on the level of renovation investments, that increase between 22% and 30% (26% when focusing on the local effect) following the tax credit rate increase. Both these results suggest that the studied reform encouraged (i) additional low-income households to retrofit their dwellings and (ii) low-income households to undertake more expensive renovations (through two or more renovations items), to further their dwelling's energy efficiency.

Although our results on the intensive margin vary when using alternative untreated and treated groups, they are still relevant in providing insight on designing efficient fiscal incentives. More specifically, our findings underline that there are heterogeneities in the treatment effect across categories of dwellings and categories of households, suggesting that larger houses, and houses in general as opposed to apartments, are particularly sensitive to an increase in tax credit rates. Similarly, among low-income households, those in the highest income quintile tend to be more responsive to the increase in the tax credit rate than those in the lowest income quintile, arguably as they are likely to be less financially constrained.

[45] Note that the effect on the extensive margin is still statistically significant but slightly lower when taking treated and untreated groups performing only one renovation item than in our core estimation (+0.7 vs. +1.3 percentage points, respectively).

[46] To illustrate the point, we use data from the National Agency for Housing Improvement regarding the average subsidy received per type of renovation work, and from the Coeuré Committee regarding the energy-savings when investing in a specific type of renovation work. For instance, households that invest in energy-efficient glazing benefit on average from a subsidy of €436 and energy savings average 0.62MWh per year, whereas households that invest in an air/water heat pump benefit on average from a subsidy of €3,060 and energy savings average of 14MWh per year.

For future work, it could be of interest to measure the energy efficiency of such reforms. We were unable to conduct this analysis due to lack of information on the initial energy vector used to heat each home, and on households' actual energy consumption. This information is required to accurately estimate the energy gains associated with each type of renovation, and the substitution elasticities of low-income households regarding more energy efficient heating systems or insulation. These data would allow assessment of the efficiency of those policies in terms of real energy savings and the rebound effect.[47] Moreover, the efficiency of a policy can also be measured by estimating the windfall effect it induces. It would be of interest to explore this aspect further, possibly with the use of panel survey data.

[47] Aydin et al. (2017) and Giraudet et al. (2012) found that the rebound effect is higher for low-income households that might consume more energy in order to reach a standard comfort level (the so called ‘income-induced rebound effect’).

7. Appendix

7.1 Tax credit rates on eligible renovation work from CIDD to CITE

	Tax credit rate (%)		
	Before tax credit change CIDD, through 2014)		After tax credit change (CITE, from 2015)
Eligibility	One renovation for low-income households	"Bouquet" of renovations[48] (at least 2 items)	Eligible without condition
Boiler			
Low temperature	15	25	30
Micro-CHP	15	25	30
Condensing	15	25	30
Heating system control equipment	15	Not eligible	30
Thermal insulation material			
Thermal insulation of outside walls	15	25	30
Thermal insulation of roof	15	25	30
Thermal insulation of floor	15	Not eligible	30
Thermally efficient glazing	15	25	30
Shutters	15	Not eligible	30
Front door	15	Not eligible	30
Heat pumps			
Air/water or geothermal heat pumps for space heating	15	25	30
Heat pump for domestic hot water	15	25	30
Energy generation equipment using renewable energy source			
Boiler/heating system with biomass fuel	15	25	30
Boiler/heating system with solar panels	15	25	30
Boiler/heating system with hydropower	15	25	30
Energy generation with hydropower	15	25	30
Energy generation with wind turbine	15	25	30
Energy performance certificate ("DPE")	15	Not eligible	30
Connection equipment to district heating network	15	Not eligible	30

[48] A "bouquet" of renovations is defined as at least two types of renovation work (either for the heating system or for insulation).

7.2 Control variables

7.2.1 Descriptive Statistics

Table 8: Control Variables – Eligible households characteristics (low-income households)

	All households among eligible (2013-2017)	Before tax credit change (2013-2014)	After tax credit change (2015-2017)
Reference taxable income: Mean (Standard Deviation)	16,637 (9,942)	17,008 (9,978)	16,986 (9,926)
Number of tax units: Mean (Standard Deviation)	2,38 (1,75)	2,41 (1,76)	2,36 (1,74)
	Pct	Pct	Pct
Married or civilly partnered (%)	31,29	31,88	31,04
Single (%)	39,21	39,08	39,27
Divorced (%)	16,48	15,66	16,83
Widowed (%)	13,01	13,37	12,86
Age: Median [Min-Max]	52 [17-106]	52 [18-103]	52 [17-106]
Observations	176,483	52,316	124,167

Table 9: Control Variables – Eligible households' dwelling characteristics

	All households among eligible (2013-2017)	Before tax credit change (2013-2014)	After tax credit change (2015-2017)
Surface area (m²): Mean (Standard Deviation)	84.91 (34.46)	85.24 (34.39)	84,77 (34.48)
Dwelling age Mean (Standard Deviation)	69.00 (72.35)	67.88 (74.08)	69.48 (71.60)
House (%)	60.6	61.1	60.3
Climate area 1 (%)	58.4	57.8	58.6
Climate area 2 (%)	31.2	31.2	31.0
Climate area 3 (%)	10.0	10.0	10.0
Observations	176,483	52,316	124,167

7.2.2 Testing for the identifying assumptions for RDD (Assumption 2 and 3)

Testing Assumptions 2 and 3

Based on the literature on household investment modeling in residential energy renovation, we check that, on average, every socio-demographic variable x_i likely to influence the investment decision, does not significantly differ between the treated group (T=1) and the untreated group (T=0). We therefore perform a two sample t-test:

$$x_i = \alpha + \beta T_i + \varepsilon_i$$

where T_i is the treatment variable, equal to 1 if households are observed after 2015 (treated group) and 0 (untreated group) otherwise. We use the following null (H_0) and alternative (H_A) hypotheses for the t-test:

- H_0: β = 0, the null hypothesis means that the difference between the averages of x_i for both the treated and untreated groups is not different from zero.
- H_A: β ≠ 0, the alternative hypothesis implies that the difference between the average of x_i in both groups is different from zero.

x_i are all available variables in our dataset that might influence the renovation decision:

- Annual income is a determinant of the renovation decision. The literature stresses that the probability of making home improvements is positively correlated with the income. Train (1985) showed that lower income households have less access to capital markets and less liquid capital to invest than higher income households. Consequently, they are less able to invest (for instance, in energy conservation) even if they anticipate a positive return on the investment. From Table 10, we fail to reject the null hypothesis for this control variable (significantly at the 5% level) except for the second quintile income group within low-income households.
- Age also influences the investment decision. According to the life cycle theory (Modigliani (1966)), age reflects households' financial status. Younger households are on average more financially constrained and less likely to be homeowners and thus we expect them to undertake fewer energy-efficient renovations. From Table 10, we fail to reject the null hypothesis for this control variable, meaning that we do not find any age differences among eligible households before and after the increase in tax credit.
- Family size may also reflect the constraints of the dwelling in relation to investment decisions. Giraudet et al. (2021) stressed that the observed discount rate is higher in multi-family units, than in single-family units suggesting that the former are risk-averse and have a stronger preference for the present. Households with several tax units might therefore decline supposedly profitable investment opportunities because of a high discount rate. From Table 10, we fail to reject the null hypothesis for this control variable so that untreated and treated groups do not significantly differ by their family size.

However, our database is not exhaustive; some variables that could determine the decision to renovate are missing. For instance, we do not have the status of occupation (whether the tax credit beneficiary is owner-occupier or landlord) while studies indicate that owner-occupiers are more likely to make home improvements than landlords (Phillips (2012)). According to INSEE,[49] in both 2013 and 2016, 57.7% of primary residences were occupied by their owners.

As for Assumption 2, a Two-Sample t-test is conducted in order to avoid ascribing the treatment effect to variations in time (across the treatment) of the dwelling characteristics control variables (Assumption 3). For instance, if there was a positive demand shock around the threshold (t_0 = 2015) on the housing market

[49]'Propriétaires – Locataires', INSEE Références, 26/03/2019 (for information on homeowners and tenants) https://www.insee.fr/fr/statistiques/3676698?sommaire=3696937.

for old dwelling that needed more renovations than recent ones, that might positively impact the renovation rate and/or expenditures around the increase in the tax credit rate. Indeed, Montgomery (1992) found that expenditures on improvements to the existing stock are statistically higher than expenditures on new housing. The results of Table 10 suggest that the share of housing built before 1949 was stable during the period studied, at around 31%. Similarly, variations in the shares of other groups of building completion dates before and after the policy change are not statistically different from zero. However, we do find a statistically significant non-zero variation for the most recent buildings (building completion date after 2009), but because these naturally increase in our sample with time, that variation is meaningless for our estimation. We also reject the null hypothesis for the mean surface area at the 5 percent significance level (85.24m² before the tax credit change vs. 84.77m² after the tax credit change). Finally, the share of houses (detached, semi-detached, terraced and bungalows) does not statistically differ between the untreated and treated groups, at around 60%.

Table 10: T-test for control variables used in RD design – Mean before and after the tax credit change

	Mean		p-value	t-test
	2013-2014	2015-2017		
Income quintile (share among eligible low-income households)				
Quintile 1	0.271	0.277	0.148	n.s.
Quintile 2	0.275	0.279	0.035	**
Quintile 3	0.260	0.260	0.909	n.s.
Quintile 4	0.172	0.165	0.157	n.s.
Quintile 5	0.021	0.017	0.157	n.s.
Age	53.06	52.94	0.23	n.s.
Number of tax units (share among eligible low-income households)				
1 unit	0.460	0.470	0.154	n.s.
1.5 - 3 units	0.488	0.481	0.197	n.s.
3.5 - 4 units	0.038	0.035	0.084	n.s.
Over 4 units	0.013	0.012	0.618	n.s.
Marital Status (in share)				
Married or civilly partnered	0.319	0.310	0.130	n.s.
Single	0.392	0.392	0.996	n.s.
Divorced	0.152	0.168	0.295	n.s.
Widowed	0.136	0.128	0.315	n.s.
Surface area (m²)	85.24	84.77	0.009	**
House	0.618	0.603	0.406	n.s.
Building completion date (among eligible low-income households)				
Before 1949	0.304	0.304	0.977	n.s.
1949-1975	0.284	0.292	0.137	n.s.
1976-1982	0.106	0.101	0.568	n.s.
1983-1989	0.079	0.074	0.365	n.s.
1990-2000	0.107	0.103	0.305	n.s.
2000-2009	0.111	0.104	0.193	n.s.
After 2009	0.007	0.022	0.025	**

*Note: *p<0.1; **p<0.05; ***p<0.01: n.s: not significant.*

7.3 Robustness checks

7.3.1 LPM vs. Logistic Regression

Concerning the extensive margin, we aim at estimating the effect of the treatment T_i using a linear probability model (LPM):

$$y_i = \beta_0 + \beta_1 T_i + \alpha x_i' + \epsilon_i$$

where the outcome variable y_i is binary, and equal to 1 if the household reports expenditures, i.e., undertakes renovation eligible for CIDD or CITE (y_i = 1), or 0 otherwise (y_i = 0).

However, as our dependent variable is a binary outcome, a non-linear model such as logit produces a better fit than LPM as it would properly estimate a probability Π_i of undertaking renovation:

$$\Pi_i = P(y_i = 1) = \beta_0 + \beta_1 T_i + \alpha x_i' + \epsilon_i$$

While (??) we run a regression on the observed binary outcome y_i with the LPM, the logit model is more relevant since it estimates the treatment effect on the *probability* of undertaking renovation Π_i. Therefore, even though a LPM is easier to estimate and interpret than a logit model, the predicted probabilities estimated with the LMM can be lower than 0, which is meaningless (see Table 11). We run a logistic regression to estimate if our LPM results are robust:

$$P(y_i = 1 | x_i, \epsilon_i) = \frac{e^{(\beta_0 + \beta_1 T_i + \alpha x_i' + \epsilon_i)}}{1 + e^{(\beta_0 + \beta_1 T_i + \alpha x_i' + \epsilon_i)}} = \Pi(\beta_0 + \beta_1 T_i + \alpha x_i' + \epsilon_i)$$

where Π denotes the logistic cumulative distribution function.

Table 11: Predicted probabilities of undertaking renovation – LPM vs. logit for each eligible household

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
LPM	175,838	0.025	0.022	-0.057	0.009	0.041	0.117
Logit	175,838	0.025	0.025	0.0003	0.008	0.034	0.364

Given the non-linearity of the logit model, we cannot directly derive the causal estimates from β_1 but from the average marginal effects of T_i on $P(y_i = 1 | x_i, \epsilon_i)$:

$$\frac{\partial P(y_i = 1 | x_i, \epsilon_i)}{\partial T_i} = \beta_1 \frac{1}{n} \sum_{i=1}^{n} \Pi'(\beta_1 T_i) = \beta_1 \big(1 - P(y_i = 1 | x_i, \epsilon_i)\big) P(y_i = 1 | x_i, \epsilon_i)$$

Table 12 gives the coefficients estimated by the logit model as well as the average marginal effects. From the latter, we conclude that the treatment has a significant and positive effect on the predicted probability of undertaking renovations. It increases by 1.24 percentage points (in comparison to +1.30 percentage points for the linear model) when introducing the trend (t_i-2015), suggesting that results from the linear model are consistent and robust.

Table 12: Logit model – Effect of the treatment on the decision to renovate over 2013-2017

	Dependent variable: Renovation Rate			
	Coefficients	AMEs	Coefficients	AMEs
Ti	0.831*** (0.042)	0.020*** (0.001)	0.515*** (0.0622)	0.0124*** (0.0015)
(t_i – 2015)			0.140*** (0.0203)	0.0034*** (0.0005)
Constant	−8.269*** (0.193)		−8.139*** (0.1938)	
Observations	175,838	175,838	175,838	175,838
Control variables	YES	YES	YES	YES

*Note: *p<0.1; **p<0.05; ***p<0.01*

7.3.2 Sensitivity analysis[50]

One approach for checking the robustness of our results involves estimating a linear model for an increasingly narrow window around the discontinuity. This arguably better captures the spirit of the regression discontinuity approach by relying only on observations that are increasingly close to the threshold. However, we face a trade-off between bias and variance when testing different bandwidths. Bias increases as one moves away from the threshold while variance increases when reducing the number of observations closer to the threshold. Therefore, a narrow window leads to lower bias, since more observations are near the threshold (and thus isolate the effect of the tax credit rate change), but also to greater variance because of the smaller sample.

Regarding the extensive margin, the treatment effect is statistically significant and increases the decision to renovate by 1.3 percentage points no matter how narrow the bandwidth used in the estimation is. Regarding the intensive margin, after correcting for selection bias, the effect of the increase in the tax credit rate is statistically significant and increases renovation expenditures whatever the bandwidth studied. Treatment increases expenditures by 25.6% between 2014-2015; by slightly less (+21.7%) over 2013-2016, as in our descriptive statistics (see Figure 4.b); and then to a larger extent (+27.4%) over 2013-2017. The results vary little with bandwidth and are consistent with descriptive statistics, suggesting that they are robust.

Another approach for testing the robustness of our results involves performing sensitivity tests, e.g., removing extreme values, to evaluate whether or not our results are sensitive to outliers. Removing the 5% largest expenditures (from €13,409 to €69,425), we exclude 264 observations from our sample of interest (low-income households over 2013-2017). Results for the extensive margin suggests that the effect of the treatment barely changes; it remains statistically significant and the effect decreases only by 0.2 points, increasing the renovation rate by 1.1 percentage points instead of 1.3 percentage points in our core analysis.

As expected, the intensive margin is more sensitive to outliers since it directly measures the effect on renovation expenditures. Therefore, removing the most expensive expenditures leads to causal average effects of the treatment that are lower and no more significant (or less significant). For instance, the local linear regression (between 2014 and 2015) suggests that tax credit rate change increases renovation expenditures by 13.6% at a 10% significance level, rather than 25.6% at a 1% significance level in the core analysis.

[50] Detailed results in this section can be provided upon request.

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