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Are environmental fiscal incentives effective in inducing energy-saving renovations? An econometric evaluation of the French energy tax credit

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1. Introduction

In its 2011 Energy Efficiency Plan, the European Commission states that the greatest energy-saving potential lies in building improvements in efficiency of insulation or appliances. The literature confirms that energy use in the residential sector is largely determined by building characteristics, whereas occupants' characteristics and behavior have more negligible effects on energy consumption (Santin et al., 2009; Risch and Salmon, 2017). However, few households invest in energy-saving measures even if they are profitable in the long run. Many authors refer to this phenomenon as the “energy paradox” (Brown, 2001; Jaffe and Stavins, 1994; Sanstad et al., 1995; Van Soest and Bulte, 2001). They explain this paradox essentially through market imperfections (i.e., uncertainty about energy prices or energy savings following a renovation and the irreversibility of the investment). To offset these market imperfections and encourage households to undertake energy-efficient renovations in their homes, fiscal incentives have been implemented in several countries (e.g., in the US and European countries such as Italy, Switzerland, and France). In this paper, our objective is to evaluate the effectiveness of an energy tax credit introduced in France in 2005. We use an econometric approach to assess the impact of an energy tax credit on renovation rate and expenditures.

The literature suggests that special attention should be given to fiscal incentives meant to induce energy-saving investments in the residential sector, because the effectiveness of such policies remains questionable. On the one hand, some studies show that a tax credit is effective. Hasset and Metcalf (1995) measure the impact of both US federal and state tax policies on the probability of making conservation-related investments. Using a discrete choice model on panel data, they show that conservation incentive programs have a statistically significant effect on investment, after controlling for individual fixed effects. More recently, subsidies have been introduced in Switzerland in the form of tax credits or deductions, and similar results are observed: The likelihood that homeowners will undertake energy-efficient renovations increases with the size of the subsidy (Alberini et al., 2013). On the other hand, some studies obtain more mixed results. Alberini and Bigano (2015) find that subsidies such as the Italian tax credit program are not cost-effective. Indeed, the cost per ton of CO₂ emissions avoided is relatively high, even under optimistic assumptions. Comparing homeowners' behavior before and after the 2007 implementation of this tax credit in Italy, Alberini et al. (2014) conclude that the policy had a significant and positive impact on the

replacement of windows but no significant effect on the replacement of heating systems. They explain this as free riding¹: the participating households would have made energy-efficiency investments even in the absence of public policy. Using a Tobit model on 1979 data, Dubin and Henson (1988) find no evidence that a US tax credit incentivized conservation expenditures. They also point out that this measure provided windfall gains to households that would have insulated their home anyway.

To appraise the effectiveness of the French tax credit, we estimate how the introduction of this fiscal measure impacts, first, the decision to renovate (i.e., the extensive effect) and, second, renovation expenditures (i.e., the intensive effect). Our first objective is to determine if households are sensitive to this measure or if the tax credit provides funding for households that would have undertaken a renovation anyway. A few papers assess the extent of the free-riding effect, with estimates ranging from 40% to 92%. Grösche and Vance (2009) use a cross-section of data from the 2005 German Residential Energy Consumption Survey and show that free riding occurs in 50% of the cases (they define free riding as a situation in which a household's willingness to pay for renovations exceeds their cost). Grösche et al. (2013) use revealed preference data on home renovations from Germany's residential sector to simulate the effect of grants on renovation choices. They conclude that 92% of the program expenses would be awarded to free riders if every eligible household behaved rationally and applied for the grant. Malm (1996) confirms the extent of free riding. He investigates the impact of subsidies on the purchase of high-efficiency heating systems and estimates free riding at 89%. More recently, Nauleau (2014) uses the same database as in this paper and studies the effect of the same tax credit on the decision to invest in opaque and glazed insulation, using a difference estimator. She estimates the share of free riders as between 61% and 85% a year according to the year considered. Contrary to her approach, this paper focuses on all renovations eligible for the tax credit (insulation and heating system changes) and we use a complementary methodology in order to contribute additional elements on the effectiveness of this measure. We also go further to assess the extent to which the tax credit increases renovation expenditures. To our knowledge, the impact of tax incentives on amounts invested has been rarely studied. However, if the subsidy provided windfall gains to households that would have renovated anyway, as suggested by some of the literature, we can

¹ This term, free riding or free riders, is commonly used in the energy efficiency literature (Alberini et al., 2014; Nauleau, 2014; Grösch and Vance, 2009 for example), even though the term windfall gains (as used by Dubin and Henson, 1988) is probably more appropriate in this case.

expect that the subsidy will be used to invest in more energy-efficient renovations. This is why our second objective is to investigate whether the tax credit incentivizes households to invest in more expensive and, we can assume, more energy-efficient renovations.

To study the effect of a French tax credit on household behaviour, we use French data from ADEME-SOFRES Maîtrise de l'Énergie surveys from 2001 to 2008. These data provide information on energy-saving renovations as well as on household and housing characteristics. As is true of any policy evaluations, we cannot observe what the renovation rate or expenditures would have been if the tax credit had not been introduced (Rubin, 1974). To overcome these problems and obtain an unbiased evaluation, we use regression discontinuity design (Thistlethwaite and Campbell, 1960; Lee and Lemieux, 2010). We exploit a sharp discontinuity corresponding to the introduction of the French tax credit in 2005. We identify the policy's effects by comparing observations just below the threshold year of 2005 with observations just above that threshold. To test the robustness of the results, we use also the matching method and propensity scores (Heckman, Ichimura and Todd, 1997, 1998; Rubin, 1977).

We find that the tax credit has a low impact on the decision to renovate: it increases renovations by 1.09 percentage point, *ceteris paribus*. This is explained by the presence of free riding. We find that around three-quarters of the households who received a tax credit would have made the renovation even in the absence of the public policy. Although some studies find no evidence that tax credits provide an incentive to renovate (Dubin and Henson, 1988), our result is low compared with other reported results. For example, Hassett and Metcalf (1995) find that an increase of 10 percentage points in US tax incentives leads to a 24% increase in the probability of performing energy-efficiency improvements in housing. However, our result is in the range of Nauleau (2014), who finds a low impact of the tax credit (from 0.8 point to 3.1 percentage points depending the years considered) after a three-year latency period with no significant effect of the policy. Finally, we find that the tax credit has a significant and positive effect on renovation expenditures. Indeed, it leads to an increase in renovation expenditures by 21.76% *ceteris paribus*. Our results suggest that this policy induces households that have already decided to undertake a renovation to make a more expensive and energy-efficient renovation.

We organize the remainder of this paper as follows: In section 2, we present the French tax credit and data; in section 3, we discuss the methodology used; in section 4, we present the results; we discuss the results and conclude in sections 5 and 6 respectively.

2. Context and data

2.1 The French tax credit

A tax credit has been in effect in France since 2005 to encourage households (owners or tenants) to undertake energy-efficient renovations (e.g., insulation or changes in heating equipment) and to adopt renewable energy systems in their main housing. This measure appears in the *General Tax Code* of December 29th, 2014.

The tax credit offers an income tax deduction for households that undertake an energy-saving renovation (from 10% to 50% of renovation expenditures, according to the type of renovation carried out and the equipment chosen). The maximum amount of expenses deducted depends on the number of people in the household (the maximum of expenses deducted is €8,000 for a household with one person and €16,000 for a couple). Households that do not pay income tax receive a reimbursement of a share of the renovation expenditures. The only condition to benefit from the tax credit is that a qualified building professional must be hired to perform the renovation work. There is no income ceiling (see Table 1 below).

This measure is very popular. From 2005 to 2008, 4.2 million French households received the tax credit (Clerc and Mauroux, 2010); this represents a significant cost for the government: The public cost reached €7.8 billion during this period and around €2 billion per year from 2009 to 2011 (Feuerstein, 2016). It seems important to compare this cost to the effectiveness of this policy, in order to provide further guidance to policymakers.

2.2 Data

We use *ADEME-SOFRES Maîtrise de l'Energie* surveys from 2001 and 2008. It is an unbalanced panel dataset. Each year, approximately 7,000 households are surveyed. Information is available about whether households undertook energy-saving renovations, the type of renovations undertaken (e.g., improvement of insulation, modification of heating system, adoption of renewable energy) and the renovation expenditures. In addition, we have information on household characteristics (e.g., income, occupational status, household size, age of reference person, occupancy status) and housing characteristics (type of dwelling [i.e.,

house or apartment], surface area, year of construction, type of heating system) as well as geographic area (climatic area, size of the urban area) and energy bills.

A zero-interest bank loan for energy-saving renovations was introduced in 2009. To avoid capturing the effect of this policy and isolate the impact of the tax credit, we do not take into account data after 2008. Therefore, we observe energy-saving renovations four years before and four years after the introduction of the tax credit in 2005. After accounting for missing observations, our final sample comprises 41,102 households.

Amongst renovations eligible for the tax credit, the survey considers renovations aiming at reducing heat loss (opaque and glazed surface insulation) and improving heating, hot water, or ventilation systems (installation or replacement of the boiler, adoption of renewable energy, and/or installation of a heating regulation or programming system)². Taking into account only these renovations, we observe a slightly higher renovation rate in the four years following the introduction of the tax credit (9.21% vs. 8.23%)³.

As a reminder, to benefit from the credit, households must hire a professional to do the renovation work. However, some households partially or completely carried out the renovation themselves. Considering only renovation work performed by the household itself, the renovation rate is low and constant during the period, averaging 2.9% each year (see Table 2). This suggests that the tax credit has no spillover effect on renovations carried out by the household itself (which are ineligible for the tax credit) or does not lead to a substitution effect from renovation performed by the households to renovation performed by a professional. However, to control for these spillover and substitution effects, which can respectively increase or decrease the impact of the tax credit, we study, in the following sections, the impact of the tax credit on the total renovation rate (including renovations performed by a professional and by the household itself).

We also focus on renovation expenditures, considering only energy-saving renovations performed by a qualified professional, and including the costs of labor and equipment. The

² We choose to study the impact of the tax credit on renovation rate and renovation expenditure for all these renovations to assess the effectiveness of this policy. It is also possible to estimate the impact on insulation on the one hand and heating system renovations on the other hand. When we do this, we note that the tax credit has a significant and positive effect on insulation renovations (rate and expenditures). However, the effect on renovations aiming at improving the installation of heating, hot water, or ventilation is not significant. Results are available upon request.

³ Note that several households may be both in the control and treatment groups. For example, we follow 404 households over the eight years. Among them, 122 households undertook at least one energy-saving renovation before the introduction of the tax credit. Their renovation rate after the tax credit implementation is significantly higher than those who did not renovate between 2001 and 2004 (respectively 12.7% and 7.1% on average over the 2005-2008 period).

difference in renovation expenditures (including only households that renovate) is significant, reaching an average of €5,058 after the introduction of the tax credit versus €3,919 before (see Table 2).

These observations suggest that the tax credit has a positive impact on renovation rate and on the amount spent by a household for a renovation. However, the effectiveness of these fiscal measures may be mitigated by free riding. The survey asks households for information on the effect that the tax credit had on their behavior. Among households that received or intended to receive the tax credit, only 8% on average each year carried out a renovation that they had not considered before the introduction of the measure (Figure 1). In contrast, 54.5% of these households declared that the tax credit had no effect on their behavior. Thus, more than half of the households receiving the tax credit would have renovated without this financial subsidy. Free riding seems to play a significant role.

Moreover, households that renovate are mainly owners who live in their house⁴ and belong to the wealthiest income group (Table A.1 in the Appendix). This trend becomes more pronounced after the introduction of the tax credit. Of households that renovated before 2005, 55.9% belong to the two wealthiest income groups (with an annual income higher than €23,000), compared with 68.9% after 2005 (Table A.2 in the Appendix). After 2005, the renovated units are slightly more recent: 35.5% are built after 1975 versus 31.1% before the introduction of the tax credit. This suggests that the tax credit is not enough to induce tenant or low-income households to undertake energy-saving renovations.

Finally, one particularity of the tax credit is that all households can potentially benefit from this measure. However, only 76.9% of households that undertake an eligible renovation intended to request the tax credit. Households that renovate are not all aware of the existence of the tax credit.

In the following sections, we take our analysis a step further and assess the effectiveness of the tax credit, *ceteris paribus*. Our objective is to study the impact of the tax credit on the rate and expenditures of energy-saving renovations. We explore two questions: Does the tax credit

⁴ Our results from econometric analysis are similar if we only consider homeowners and remove tenants from the sample. Indeed, renters could be excluded from this analysis because they are often considered to be unable to make significant decisions about renovations. But (i) rented housing represents a significant portion of housing stock and (ii) the tax credit could have an impact on tenants' behaviour, so we keep them in the analysis. However, results for homeowners only are available upon request.

encourage households to renovate? Does this measure provide an incentive for households to spend more money on energy-saving renovations?

3. Methodology

The tax credit was introduced in 2005 ($T = 1$) to induce households to undertake energy-saving renovations. The likelihood of renovating and requesting the tax credit is correlated with household characteristics x (e.g., income or occupancy status, for example). Consequently, the impact of the tax credit is the difference between the renovation rate (or renovation expenditures) with the policy (y_1) and the renovation rate (or renovation expenditures) that would have been observed without the policy (y_0) (Rubin, 1974). Thus, we can express the impact of the tax credit as follows:

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

As such, the impact is unobservable because it is impossible to simultaneously observe both situations, and it is specific to each individual. We must therefore estimate what *would have happened* without the tax credit—that is, the counterfactual renovation rate (or expenditures) given by $E[y_0 | T = 1, X = x]$. We use regression discontinuity design to estimate the counterfactual situation. The identification and estimation strategy is presented in sub-section 3.2. As a robustness check, the appendix includes an estimation of the counterfactual situation using the matching method and propensity scores (Appendix B). The results from both approaches are similar.

Regression discontinuity design (Thistlethwaite and Campbell, 1960) allows us to identify the average causal effect of the tax credit. The objective of this approach is to measure the discontinuity in renovation rate and expenditures at the assignment threshold ($S_0 = 2005$). The implementation of the energy tax credit implies a sharp discontinuity in eligibility for the measure: After 2005, all observed households can benefit from the tax credit, while those observed up to 2004 are not eligible. The impact of the fiscal incentive on renovation rate and expenditures is obtained comparing observations below the threshold year of 2005 with observations above that threshold.

3.1 Graphical analysis

Figures 2 and 3 present the fit of linear regression – the first one concerning the renovation rate and the second representing renovation expenditures. In both figures, we observe a

discontinuity between 2004 and 2005. Both renovation rate and expenditures tend to decrease between 2001 and 2004. After the implementation of the tax credit, we observe a reverse trend: they both increase quickly between 2005 and 2008. The renovation rate increases after 2005, except for a small decline in 2006. The average amount spent for housing renovations continually increases after the introduction of the tax credit. This seems to indicate a significant effect of the tax credit⁵.

3.2 Identification and estimation strategy

Our objective is to analyse whether the discontinuities we observe on Figures 2 and 3 are caused by the introduction of the tax credit. In other words, we have to be sure that around the threshold of 2005, non-treated households (this means households observed before the introduction of the tax credit) are a good counterfactual of treated households (households that benefit from the tax credit). Therefore, the identification strategy requires that first, households cannot manipulate the assignment variable, and second, changes in renovation rate and expenditures do not occur for reasons other than the implementation of the policy. The first point is not a concern in our case since the assignment variable is the year ($S_0=2005$ is exogenous). Moreover, it seems difficult to anticipate a measure that appeared in the *General Tax Code* on December 29th, 2014. In consequence, a variation in the treatment in the neighbourhood of the threshold is as good as randomized (Lee and Lemieux, 2010; Cook, Shadish and Wong, 2008).

The second point means that the household and dwelling characteristics must be similar around the threshold, or that all other factors determining renovation rate and expenditures must evolve smoothly, with no jumps around the threshold. Several variables may be playing a role in the decision to renovate. Studies stress that owner-occupiers are more likely to undertake an energy-saving investment (Philips, 2012). The share of homeowners in our sample is stable before and after the introduction of the tax credit (representing around 71.74% of households before 2005 and 71.86% in 2005 and after) (see Table A.2 in the Appendix). Other important variables are (i) income, which is a determinant of home improvement decisions (Cameron, 1985; Potepan, 1989; Mendelsohn, 1977). Statistics suggest that the share of low-income households (belonging to income groups 1 and 2) decreases over the years in favor of households belonging to the fifth and sixth groups (Table

⁵ As a reminder, the average renovation rate before 2005 is 8.23% as opposed to 9.21% after the implementation of the tax credit, and renovation expenditures are, similarly, €3,919 before 2005 and €5,058 after.

A.2 in the Appendix). (ii) The year of construction can be considered as a proxy for insulation quality and is likely an explanation for renovation decisions. Indeed, Montgomery (1992) shows that the age of the building has a positive impact on renovation expenditures. The share of housing built before 1948 is stable during the period studied, at around 25%. However, the share of dwellings built after 1989 increased from 15.98% (average of the 2001-2004 period) to 19.94% (average of the 2005-2008 period). (iii) Finally, energy expenditures slightly increase before and after the introduction of the tax credit (Table A.2 in the Appendix). This may induce households to invest in energy-efficient renovations in order to reduce their energy bill (Cameron, 1985). We study how these variables vary with the years in Figures 4, 5, and 6 below. It is important to note that there is no discontinuity at the threshold.

These descriptive statistics suggest that an estimation strategy that measures discontinuity at the threshold identifies the causal effect of the tax credit implementation on renovation rate and expenditures. Therefore, we estimate the effect of the tax credit using the following model:

$$y_i = \beta_0 + \beta_1 T_i + f(S_i) + \delta x_i' + \varepsilon_i \quad (2)$$

where y is the outcome—the decision to renovate (y is in this case a binary variable equal to 1 if the household i decided to renovate or equal to 0 otherwise) or renovation expenditures (in logarithm); S is the assignment variable (the year, from 2001 to 2008). T_i is a dummy variable equal to 1 if the households can benefit from the tax credit (this means households observed in 2005 and after) or equal to 0 otherwise. The average causal effect of the tax credit on renovation rate (or expenditures) at the assignment threshold S_0 (i.e. $S_0=2005$) is measured by β_1 . We add exogenous covariates to the model to improve precision, even though they are not required to obtain consistent estimates. x_i is a vector of observable households and housing characteristics, and ε is the error term. The control variables are presented in Table A.1 in the Appendix and include variables that may explain the renovation decision. We first consider household socio-demographic characteristics such as income, age, occupancy status, number of people in the household⁶, years spent in the dwelling, and a proxy for environmental sensitivity. We use a proxy for environmental sensitivity assuming that households that use energy-saving bulbs (compared with standard bulbs) and know about the existence of “Energy info areas” are more sensitive to environmental issues. Energy info areas are places where

⁶ We add the number of people in the household to control for the tax credit ceiling. As a reminder, the more people in the household, the higher the maximum amount of expenses that can be deducted.

households can find all the information they need about energy consumption, renewable energies, and energy-saving renovations. This program was initiated in 2001 to alert and inform households; there are currently 250 energy info areas in France. Second, we introduce variables on housing characteristics, such as year of construction, type of housing (house or apartment), and surface area. Third, we take into account information on energy bills, the type of heating system (collective or individual), and the energy used, as well as a dummy equal to 1 if the heating energy price increases more than 4% in the year. We arbitrarily chose this number, which is approximately two times higher than average annual inflation (approximately 1.8% on average over the period) and slightly higher than the average annual growth rate of the energy price index (approximately 3.5% on average over the period) (see Figure A.1 in the Appendix). The energy price information comes from the French National Institute of Statistics and Economic Studies (INSEE). A period of rising prices might induce households to decrease energy consumption with energy-efficiency renovations (Cameron, 1985). Fourth, we introduce variables in geographic area, such as climate area, and a dummy equal to 1 if the households are in a rural area. This enables us to control for regional differences⁷.

The challenge in estimating the impact of the tax credit is that the functional form of $f(S_i)$, representing the relationship between the assignment variable and the outcome, is specified correctly. We use several specifications of the correlation between assignment variable S and outcome y in order to find the best model.

We first conduct a parametric model without including the assignment variable and estimate the following model:

$$y_i = \beta_0 + \beta_1 T_i + \delta x'_i + \varepsilon_i \quad (3)$$

Second, we estimate a two-sided linear model introducing to the model a normalized assignment variable and an interaction between the assignment variable and the treatment.

$$y_i = \beta_0 + \beta_1 T_i + \beta_2 (S_i - S_0) + \beta_3 T_i (S_i - S_0) + \delta x'_i + \varepsilon_i \quad (4)$$

S_0 is the assignment threshold (i.e. $S_0=2005$). The average causal effect of the tax credit on renovation rate (or expenditures) at threshold S_0 is still measured by β_1 . β_2 and β_3 capture the direct effects of the assignment variable S on the average y_i . Including an interaction between

⁷ As a robustness check, we also consider the unemployment rate as a control variable in the regression discontinuity designs, in order to capture the economic situation. This has no impact on the results, since exogenous covariates are not required to obtain consistent estimates. Indeed, the discontinuity identified the average causal effect for the threshold population.

the assignment variable and the treatment can account for the fact that the treatment may impact not only the intercept but also the slope of the regression line. This seems appropriate in our case since we have a negative trend in renovation rate and expenditures before 2005 and a positive trend after the introduction of the tax credit (Figures 2 and 3).

Then, to test the robustness of our results, we augment the regression with quadratic terms, and we estimate the following model:

$$y_i = \beta_0 + \beta_1 T_i + \beta_2 (S_i - S_0) + \beta_3 T_i (S_i - S_0) + \beta_4 (S_i - S_0)^2 + \beta_5 T_i (S_i - S_0)^2 + \delta x_i' + \varepsilon_i \quad (5)$$

Finally, we conduct local linear regressions (Hahn, Todd, and Van der Klaauw, 2001). This nonparametric approach limits the analysis to a subset of observations that are sufficiently close to the cut-off point (in order to more accurately specify the functional form). We estimate the following models (equations (6) and (7) without and with controls respectively) on a subset of the data within a chosen bandwidth h to the left and right of the cut-off point. The bandwidth choice is based on cross-validation methods (Imbens and Kalyanaraman, 2012).

$$y_i = \beta_0 + \beta_1 T_i + \beta_3 T_i (S_i - S_0) + \varepsilon_i \quad (6)$$

$$y_i = \beta_0 + \beta_1 T_i + \beta_3 T_i (S_i - S_0) + \delta x_i' + \varepsilon_i \quad (7)$$

To choose among these various specifications, we use an AIC indicator: the preferred specification is indicated by the smallest AIC (Van der Klaauw, 2008; Cook, 2008).

4. Results

4.1. Renovation rate

Our first objective is to estimate the impact of the tax credit on the rate of energy-saving renovations⁸. The results from the discontinuity design regression are presented in Table 3⁹. Columns (1) to (3) present results from the parametric model. Column (1) shows results from the model with neither normalized assignment variable ($S_i - S_0$) nor interaction term $T_i(S_i - S_0)$ (equation (3)). Column (2) shows the estimation of the two-sided linear model (equation (4)), and column (3) presents the model with the quadratic term (equation (5)). Finally, results from the local linear regression are presented in columns (4) (equation (6))

⁸ As a reminder, we take into account all eligible renovations, i.e., opaque surface insulation, glazed surface insulation, installation/replacement of the boiler, adoption of renewable energy, and installation of a heating regulation or programming system.

⁹ The effect of control variables is available upon request

and (5) (equation (7)). Using cross-validation methods (Imbens and Kalyanaraman, 2012), the bandwidth retained combines the observations from 2004 to 2006. The results suggest that the effect of the tax credit is between zero and 2.88% depending on the specification chosen. The smaller AIC indicator indicated the better model (Van der Klaauw, 2008; Cook, 2008). The preferred specification is the local linear model with control variables (presented in column 5 of Table 3). We conclude that the effect of the tax credit is significant. This policy increases the renovation rate by 1.09 percentage point¹⁰, *ceteris paribus*.

To test the robustness of this result, we conduct an assessment of this tax credit using the matching method and propensity score. This approach is presented in the Appendix. The results are similar. Using a matching model, we find that the tax credit increases the renovation rate by 0.92 percentage point, *ceteris paribus* (Table B.3.1 in the Appendix).

4.2. Free riding

We find that 1.09% of the dwellings were renovated as a result of the tax credit, *ceteris paribus*. If we apply this share to the number of dwellings in France (according to INSEE), this result means that around 1,141,873 dwellings were renovated specifically as a result of the introduction of the tax credit between 2005 and 2008 (table 4). However, 4.2 million French households received a tax credit at least one time between 2005 and 2008 (Clerc and Mauroux, 2010). By taking the difference between the number of households who benefited from the tax credit and the number of households who renovated as a result of the tax credit, we obtain the number of free riders. Consequently, we find that more than 3 million households (or 72.8% of households who benefit from the tax credit) are free riders: They benefit from the tax credit for an energy-saving renovation that they would have made even in the absence of the public policy.

Given these results, we can conclude that the tax credit does not really encourage households to renovate. However, we can expect that free riders will use the subsidy to invest in more expensive, and we assume, more energy-efficient renovations. We investigate this point in the next subsection, exploring the impact of the tax credit on renovation expenditures.

¹⁰ As robustness check, we estimate the impact of the tax credit only on the renovations realized by a building professional (this means we exclude renovations realized by the households themselves from the treatment group). In this case, we find that the tax credit increases the renovation rate by 1.07 percentage point, *ceteris paribus*

4.3. Renovation expenditures

To estimate the impact of the tax credit on renovation expenditures, we consider only households undertaking an energy-saving renovation eligible for the tax credit. This represents a sample of 2,277 households. This means that we consider only renovations performed by qualified professionals (we exclude renovations performed by the household itself because they are not eligible for the tax credit). This allows us to have comparable costs, including labor and equipment. Moreover, we estimate that 72.8% of households who benefit from the public policy over the period are free riders, and we want to see if benefitting from the tax credit to undertake a renovation that would have been made even in the absence of the public policy induces households to spend more than originally planned. We estimate the impact of the tax credit on current prices (i.e., amounts declared by households in the survey).¹¹

Our results are presented in Table 5¹². The preferred specification according the AIC indicator is the local linear model with control variables (presented in column 5). The bandwidth retained for the local linear model combines the observations from 2004 to 2008. The tax credit has a significant and positive impact on total renovation expenditures. More precisely, the tax credit leads to an increase of renovation expenditures by 21.76%, *ceteris paribus*.

As a robustness check, we present results from the matching method in the Appendix. Using the matching model, we find that the tax credit increases renovation expenditures by 24.38%, *ceteris paribus* (Table B.3.2 in the Appendix).

5. Discussion

5.1. Renovation rate and public cost

We find a low impact of the tax credit on the renovation rate, increasing renovations rate by only 1.09 percentage point. Although some studies find no evidence that tax credits have an

¹¹ We are aware that the cost of renovation may increase due to inflation in the standard of living over the period (see figure A.1 in the Appendix). As a robustness check, we estimate the effect of the tax credit on renovation expenditures at a constant price. To do this, we use the annual price index for housing maintenance and improvements to deflate renovation expenditures and convert them into 2001 prices. This price index comes from INSEE (figure A1 in the appendix). We use regression discontinuity design. The preferred specification according to the AIC indicator is the local linear model with control variables and a bandwidth from 2004 to 2006. We obtain a slightly lower result than our result at the current price. We find that the tax credit increases the renovation expenditures at the constant price by 19.60% *ceteris paribus*. This result corresponds to the impact of the tax credit at the assignment threshold. We cannot extrapolate the impact of the tax credit on renovation prices over the long run. Detailed results are available upon request.

¹² The effect of control variables is available upon request.

impact on the number of renovations (Pon and Alberini, 2012), other studies report a more significant impact. An increase of 10 percentage points in US tax incentives leads to a 24% increase in the probability of performing energy-efficiency improvements in housing (Hassett and Metcalf, 1995). More recently, the current US federal home energy-efficiency tax credit program reportedly has encouraged 2%–12% of homeowners to invest in energy-saving equipment (Zhao et al., 2012). In France, our result is in the range of what Nauleau (2014) finds. Considering only opaque and glazed surface insulations, she finds a three-year latency period with no significant effect of the policy. Then from 2008, she obtains a significant and positive effect of the tax credit on renovation decisions, from 0.8 point to 3.1 percentage points depending on the years considered.

This result seems to be particularly low compared to the public cost of the measure (i.e. the cost to the government) which reached €7.8 billion over the period (Feuerstein, 2016). Based on the number of dwellings in France, and given that 1.09% of these dwellings were renovated as a result of the tax credit, all things being equal, we can deduce that 1,141,873 were renovated specifically as a result of this credit over the period 2005-2008 (Table 4). We can compare this number of renovated dwellings to the public cost of the measure: The public cost reaches €6,830.88 per dwelling that would not have been renovated without the tax credit. This is significant, given that the average expenditure on the period is €4,579.4 in our sample (Figure 3). The impact of the tax credit is low compared with the public cost of the measure. This finding can be explained by free riding. Indeed, we estimate that 72.8% of households who benefit from the tax credit are free riders. This free riding is in the range of what is commonly estimated in the literature. Taking into account opaque and glazed surface insulation, Nauleau (2014) estimates the share of free riders as between 61% and 85% a year according to the year considered.

5.2. Renovation expenditures and leverage effect

Although the effect of the tax credit on renovation decisions is low, the tax credit significantly increases the renovation expenditures: by 21.76%, *ceteris paribus*. This value is much larger than the result in Dubin and Henson (1988), who find no evidence that tax credits have an impact on renovation expenditures. However, our results remain in line with those of Pon and Alberini (2012), who show that US tax incentives are not significant in encouraging households to invest in energy-saving equipment but are effective in encouraging homeowners who are already looking to replace appliances with more energy-efficient ones.

Based on this result, we can estimate the leverage effect of the tax credit. According to the *French working group on housing energy improvement* (OPEN), total expenditures (excluding VAT) on energy-saving renovations reached €12.78 billion in 2006 and €15.10 billion in 2008. We assume that expenditures in 2005 and 2007 were similar; therefore total expenditures on energy-saving renovations reached 55.76 billion over the period 2005-2008 (table 6). We estimate that 21.76% of these expenditures are related to the tax credit; that is to say, the credit led to a total expenditure of around €12.13 billion during the period¹³. Of this €12.13 billion, €7.8 billion came from the government (the public cost of the measure) (Feuerstein, 2016) and the remainder from households. This means that households invested 4.33 billion euros in energy-saving renovations. In other words, for every €1 spent by the government, the tax credit led households to spend around €0.56. The leverage of this credit is low.

6. Conclusion

In this paper, we evaluate the impact of a French tax credit on renovation rate and expenditures. We use French household-level databases on energy conservation from 2001 to 2008 and econometric approaches. We estimate the tax credit effect with regression discontinuity design; in order to ensure the robustness of the results, results from matching method are presented in the Appendix.

The effectiveness of the tax credit is mixed. The measure has a significant and positive effect on renovation rate and expenditures. However, the effect on renovation rate is low: We find that 1.09% of the dwellings were renovated as a results to the tax credit, according to regression discontinuity design, *ceteris paribus*. The impact on renovation expenditures is much higher, leading to an increase of expenditures of 21.76%, all things being equal.

The results suggest the presence of free riding in up to 72.8% of households receiving the tax credit. The introduction of the tax credit does not seem to encourage renovation for households that are not prone to renovate in the first place. However, this policy does induce households that are already determined to renovate to choose a more expensive – and, we can assume, a more efficient – energy-saving renovation.

To improve the efficiency of this policy, a solution could be to reduce free-riding by limiting access to the tax credit to households that would not renovate without the measure (like low-

¹³ We estimate that of the 55.76 billion euros of investment on energy-saving renovations, 12.13 billion euros are due to the tax credit and the other 43.63 billion euros would have been spent even without the tax credit.

income households, tenants, and households living in an apartment, given the low renovation rate in these groups of households before the introduction of the tax credit). In addition, it seems appropriate to increase the incentives to renovate for these same households, such as through an increase in the deduction rates, as the current measure is not a sufficient incentive for these households. Further research could study the impact of the tax credit on energy savings. For this, however, data on energy consumption is needed.

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Appendix

Appendix A: Descriptive statistics

Table A1

Table A2

Figure A1

Appendix B: Matching method

B.1. Control and treatment groups

The matching method involves matching each household that can benefit from the tax credit (the treatment group) with a household that cannot benefit from it (the control group), with the same observable characteristics x being equal. One particularity of the tax credit is that all households have been eligible for the measure since 2005. Consequently, in our case, all households observed between 2005 and 2008 form the treatment group. By definition, households observed between 2001 and 2004 are ineligible for the credit, and thus we consider them the control group (Figures B.1.1 and B.1.2).

The matching method must respect the conditional independence assumption (CIA), which means that households in the control and treatment groups must be similar in terms of not only observable characteristics but also unobservable characteristics. This assumption can hold because our database contains a rich set of variables used to explain renovations, including socio-demographic variables and information on housing, energy used, and energy bills. However, in our case, it is important to pay attention to this assumption, especially because the control group is in a different time period from the treatment group. We carefully test the sensitivity of the results relative to this assumption using Ichino et al.'s (2007) approach. The results are presented below in Appendix B.4.

B.2. Propensity score matching

An important step is to match treated households with similar households from the control group. A common way of matching households from treatment and control groups is propensity score matching (Rosenbaum and Rubin, 1983). This matching is based on a single propensity score reflecting the probability of being eligible for the tax credit (or the probability of belonging to the treatment group), conditional on observed characteristics x

(Heckman, Ichimura, and Todd, 1998; Rubin, 1977). We estimate the probability of being eligible for the tax credit with a Logit model.

We use (1) the full sample to estimate the impact of the tax credit on the renovation rate and (2) a subsample including only households that hired qualified professionals to renovate to estimate the impact of the measure on renovation expenditures. We use the same control variables as for RD design (controls are presented in Appendix A). Results are presented in Table B.2.1. We use this to match households from the treatment and control groups.

The idea of the method is to match an eligible household with an equivalent ineligible household. The balancing assumption between characteristics of treatment and control groups is valid for both the full sample and the subsample (Figures B.2.1 and B.2.2). Figures B.2.3 and B.2.4 show the deviation of the household characteristics of the control group from those of the treatment group, before and after matching. The deviation is largely reduced after matching. Moreover, to verify that the household characteristics of the treatment and control groups are similar after matching, we use two indicators: the standardized percentage bias and overall explanatory power of the propensity score estimations (Table B.2.2). The standardized percentage bias is the percentage difference of the sample means in the treatment and control groups as a percentage of the square root of the average of the sample variances in both groups (Rosenbaum and Rubin, 1983). The overall bias decreases significantly after matching. We study the overall explanatory power of the propensity score estimations using the likelihood ratio (LR) chi-square test. This test enables us to conclude that before matching, at least one of the regression coefficients in the model is not equal to zero. In contrast, all regression coefficients are simultaneously equal to zero after matching. Considering these results, we can use the matched sample to estimate the effect of the tax credit.

B.3. Results

Once households are matched on the basis of their propensity score, we use what we observed in matched households to estimate the counterfactual situation and then the effect of the tax credit. The magnitude of the effect of the tax credit on renovation rate is estimated as the difference between the proportions of households that undertake a renovation in the treatment and control groups belonging to the matched sample (Brodaty et al., 2001). For continuous variables such as renovation expenditures, the effect of the tax credit can be estimated as the difference between the mean expenditures for the treatment group and the mean expenditures

for the control group in the matched sample (Rosenbaum and Rubin, 1983). These differentials can be estimated using different matching estimators (e.g., nearest-neighbor estimator, stratification matching, kernel matching). We use kernel matching to estimate the impact of the measure on renovation rates and expenditures. This estimator, proposed by Heckman, Ichimura, and Todd (1998), is a nonparametric estimator in which weighted averages of all ineligible households are used to construct each participant's counterfactual. Smith and Todd (2005); Heckman, Ichimura, Smith, and Todd (1998); and Heckman, Ichimura, and Todd (1997, 1998) argue for the advantages of kernel matching. It offers the most robust estimates in large samples (Heckman, Ichimura, and Todd 1997, 1998).

Results from the matching method are presented in Tables B.3.1 and B.3.2. They are consistent with RD design results. The estimated effect of the tax credit is significantly positive and equal to 0.92%, *ceteris paribus*. We also find with this method that the tax credit led to a 24.38% increase in expenditures during the 2005–2008 period.

B.4. Sensitivity analysis

Matching is based on the CIA: Given the observable characteristics, the renovation rate (or expenditures) is independent of the probability of being eligible for the tax credit. This assumption is not satisfied when unobserved characteristics of the treatment group differ from unobserved characteristics of the control group, and the results may thus be biased. In this section, we observe the sensitivity of the results to a deviation from this assumption.

The control group is in a different time period than the treatment group, and we are not able to take into account time information because we pooled the database. An unobserved factor (e.g., renovation prices, household preferences) could have an impact on the decision to renovate and may change over the period. Consequently, it can differ between the treatment and control groups. A sensitivity analysis enables us to appraise the extent to which the results can be altered by unobserved factors.

We use Ichino et al.'s (2007) approach, which is appropriate following a nonparametric model for the outcome equation. We test the impact of an unobserved binary variable u that affects the potential outcome Y (renovation rate or renovation expenditures) and eligibility for the tax credit ($T = 1$). Conditional independence, given the set of variables x , is not valid, but this assumption holds given x and u . In other words,

$$Pr(T = 1|Y_0, Y_1, x) \neq Pr(T = 1|x) \quad (8)$$

and

$$Pr(T = 1|Y_0, Y_1, x, u) = Pr(T = 1|x, u), \quad (9)$$

where u is assumed to be binary.

First, we must characterize the distribution of u , which depends on the choice of four parameters. In the case of a binary outcome (renovation rate), the distribution of u is defined by:

$$Pr(u = 1|T = i, Y = j, x) = Pr(u = 1|T = i, Y = j) \equiv P_{ij} \quad (10)$$

where $i, j \in \{0,1\}$, which gives the probability that $u = 1$ in each of the four groups defined by the treatment status ($i = 0$ or 1) and the outcome value ($j = 0$ or 1).

In the case of a continuous outcome (renovation expenditures), we apply to Y a binary transformation, and we define P_{ij} as follows:

$$Pr(u = 1|T = i, I(Y > y^*) = j) \equiv P_{ij}, \quad (11)$$

where $i, j \in \{0,1\}$, I is the indicator function, Y is the renovation expenditures, and y^* is the mean of Y .

We can assign arbitrary values to the parameter P_{ij} . We consider the neutral confounder $P_{ij} = 0.5$, and then we can let u mimic the behavior of some important covariates. We choose variables that we assume to have an effect on the outcome, such as owner-occupied, above-average energy expenditures per square meter, income corresponding to the wealthiest groups, and knowledge of energy info area (i.e. *Espaces Info-Energie*).

Second, we simulate u , which is considered like any other variable and is used to estimate the propensity score and the kernel-matching estimates.

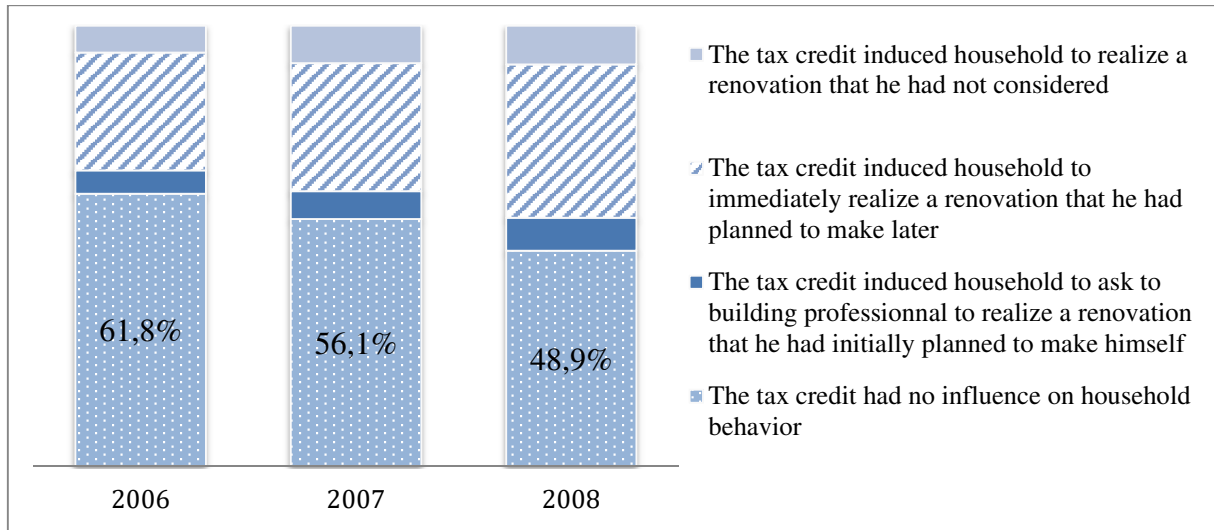
We present the results in Table B.4.1. The first four columns contain probabilities P_{ij} . For each value we give at u , the next two columns present, respectively, the outcome effect (i.e., the effect of u on the untreated outcome, controlling for observables x) and the selection effect (i.e., the effect of u on eligibility for the tax credit, controlling for observables x). The two last columns provide the marginal effect of the tax credit effect and the standard error, controlling for observables x and unobservable u . Here, we comment on the sensitivity analysis of the results on the renovation rate. We assume that u follows the same distribution as the variable “owner.” P_{11} is 0.93—that is, 93% of households that are eligible for the tax credit and renovate their housing are owner-occupied. We observe that u has a positive effect on the probability to renovate, given that households are ineligible for the tax credit (the outcome

effect is higher than 1), but u has almost no effect on the probability of being eligible (selection effect almost equal to 1). The effect of the tax credit on the renovation rate, controlling for x and u , is close to the situation without a confounder (0.0091 vs. 0.0092), and the effect is still significant. If u mimics the distribution of the “knowledge of energy info area” variable, the outcome and selection effects are both higher than 1. Therefore, u has a positive effect on the probability to renovate, given that households are ineligible for the tax credit, and a positive effect on the probability of being eligible. In this case, the impact of a tax credit is significant but lower than the situation without a confounder by 0.0011 points.

Regarding renovation expenditures, the impact of the tax credit with a confounder remains significant and close to the initial situation. When u follows the distribution of the “knowledge of energy info area” variable, the effect of the tax credit increases by 0.0057 points. All these simulations confirm that the measure has a significant and positive impact on renovation rate and expenditures.

FIGURES

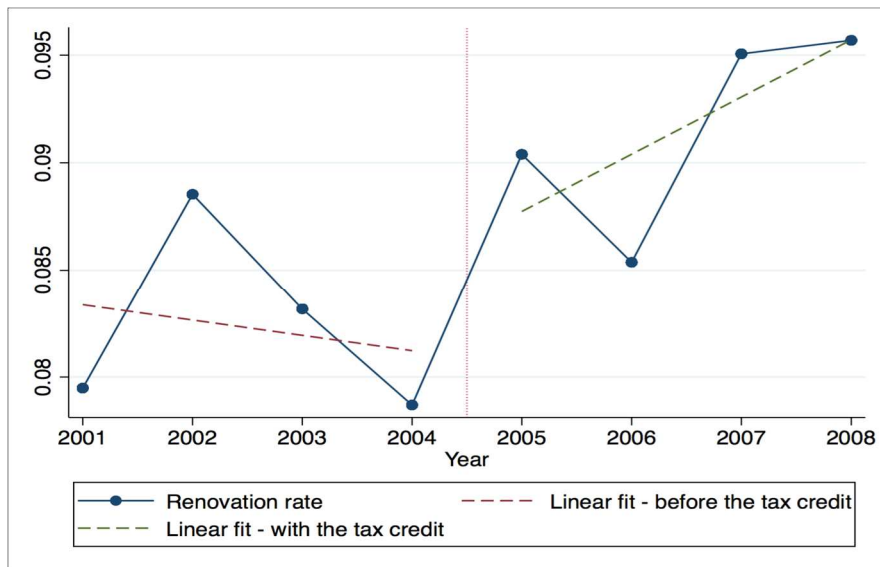
Figure 1: Impact of tax credit on household behavior



Note: This figure is based on 1,128 households that received or intended to receive the tax credit between 2006 and 2008.

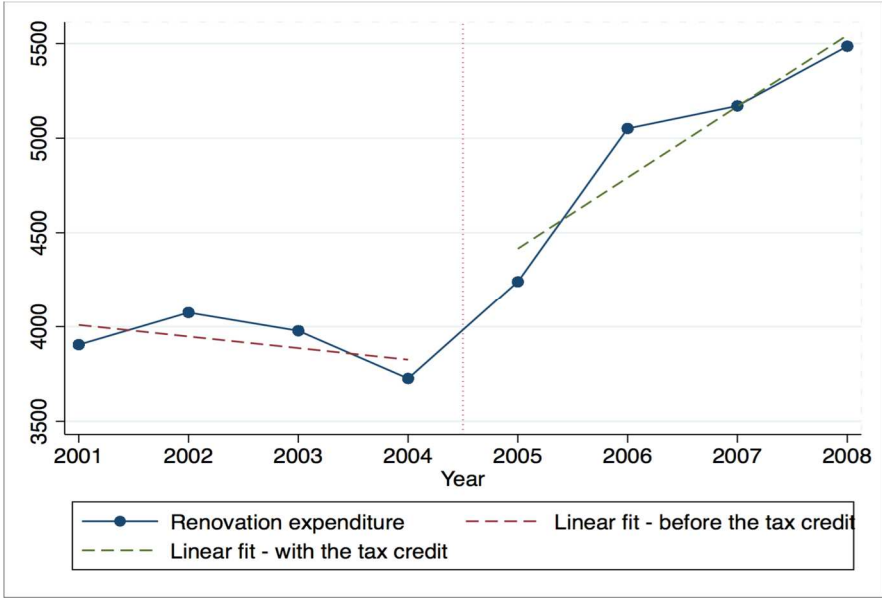
Source: ADEME-SOFRES *Maîtrise de l'Energie* surveys—Final sample.

Figure 2: Renovation rate and linear fit before and after the introduction of the tax credit



Note: This figure is based on 41,102 observations, including 22,001 households observed in 2005 and after (and therefore eligible for the tax credit).

Figure 3: Renovation expenditures and linear fit before and after the introduction of the tax credit



Note: This figure is based on 2,277 observations, including 1,320 households eligible for the tax credit (i.e. observed in 2005 and after).

Figure 4: The distribution of income groups around the threshold of 2005

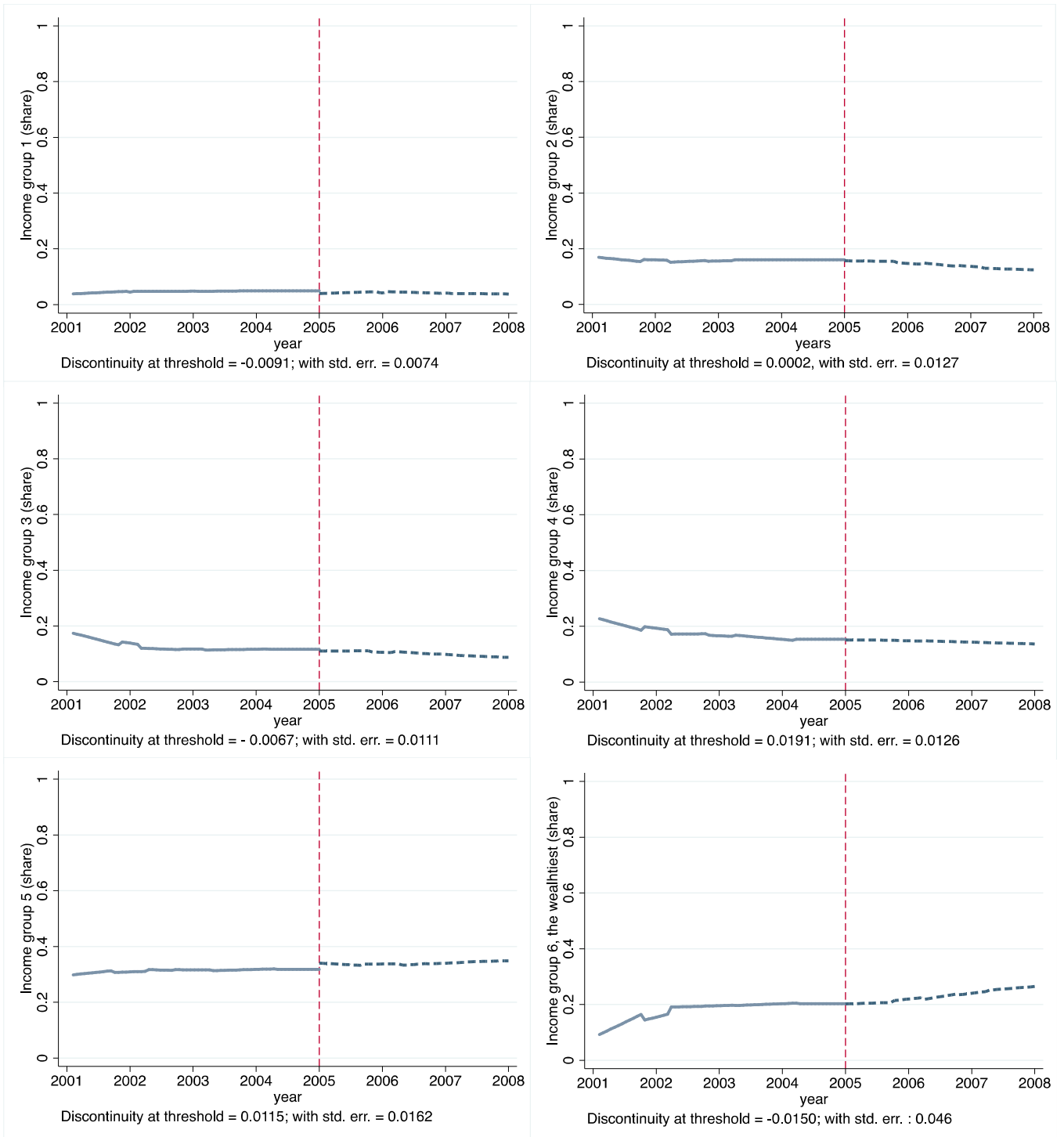


Figure 5: The distribution of housing by year of construction around the threshold of 2005

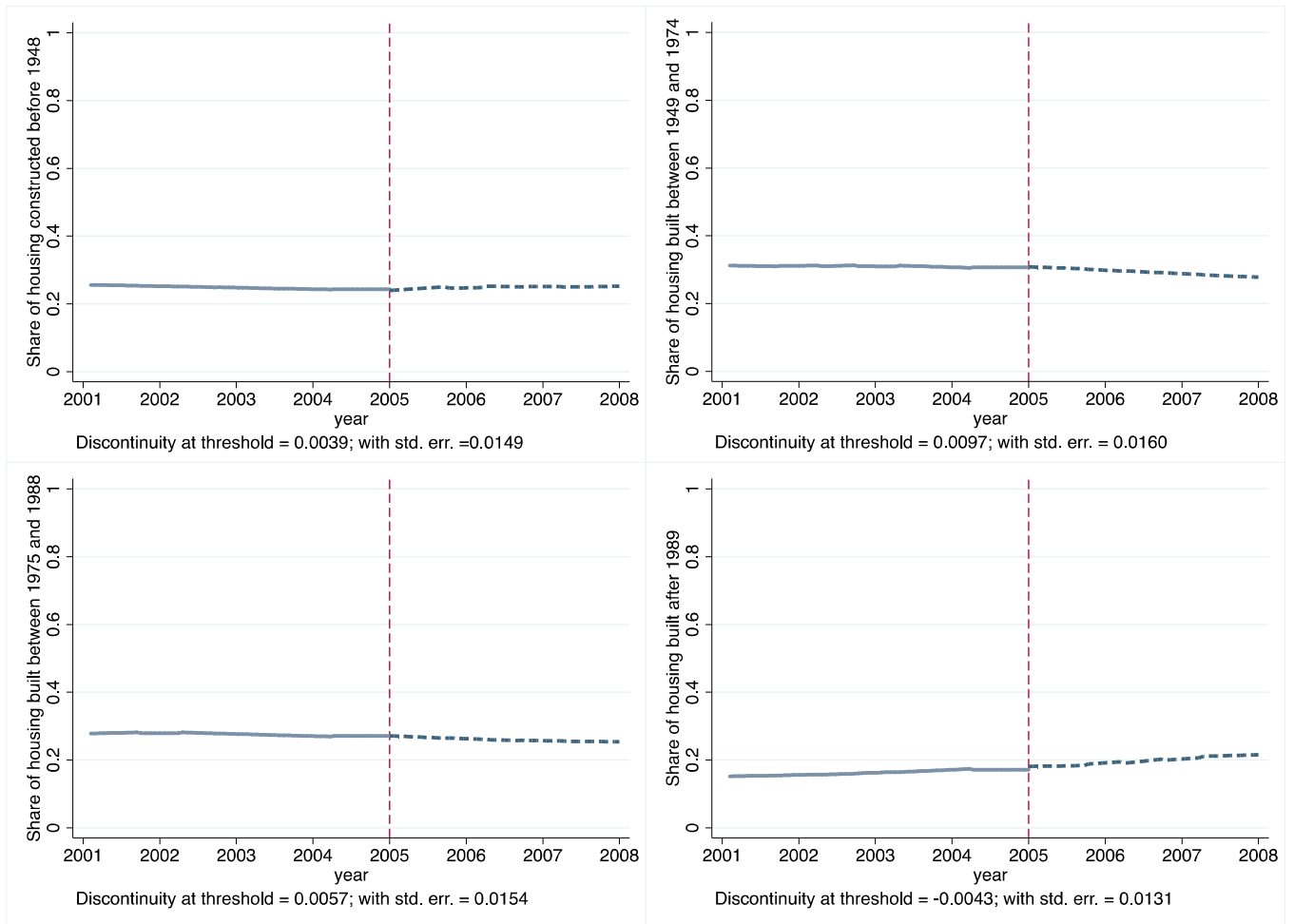
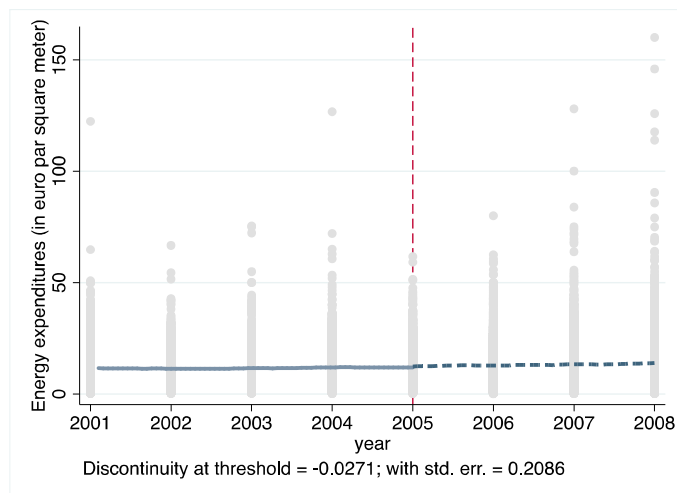
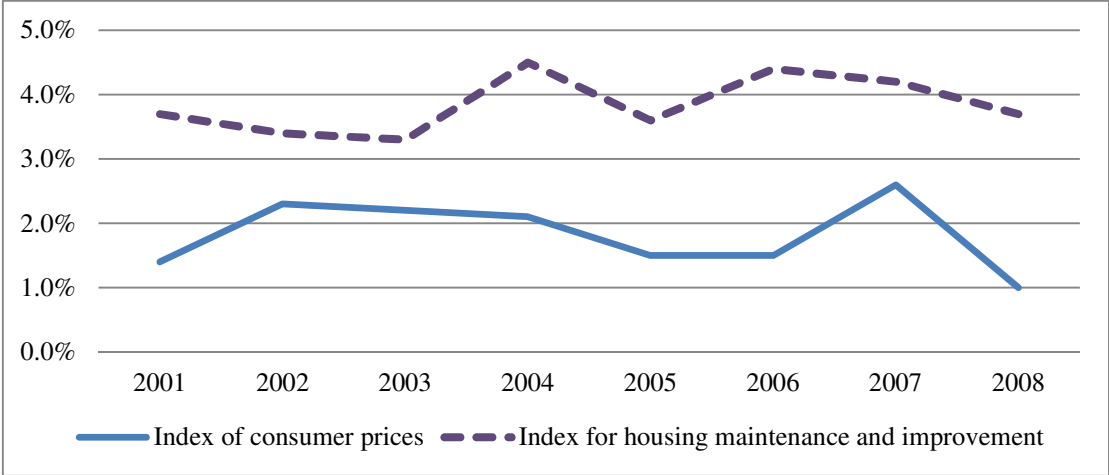


Figure 6: The distribution of energy expenditures around the threshold of 2005



Appendix

Figure A1: Evolution of prices for maintenance and improvement compared with the general inflation rate



Source: INSEE.

Figure B.1.1: Impact of the tax credit on renovation rate—matching method

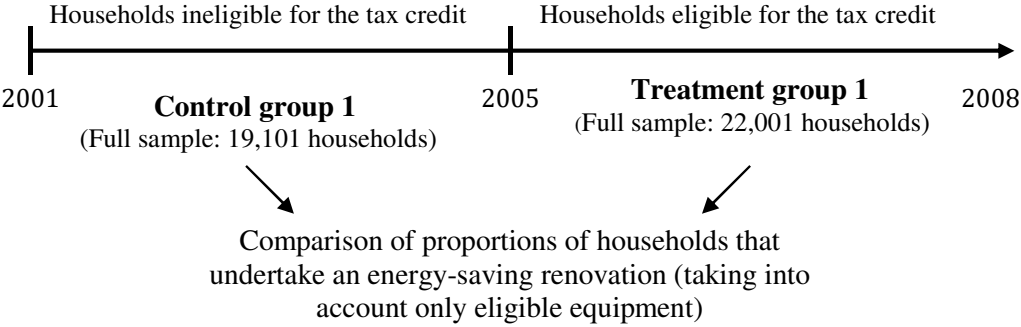


Figure B.1.2: Impact of the tax credit on renovation expenditures—matching method

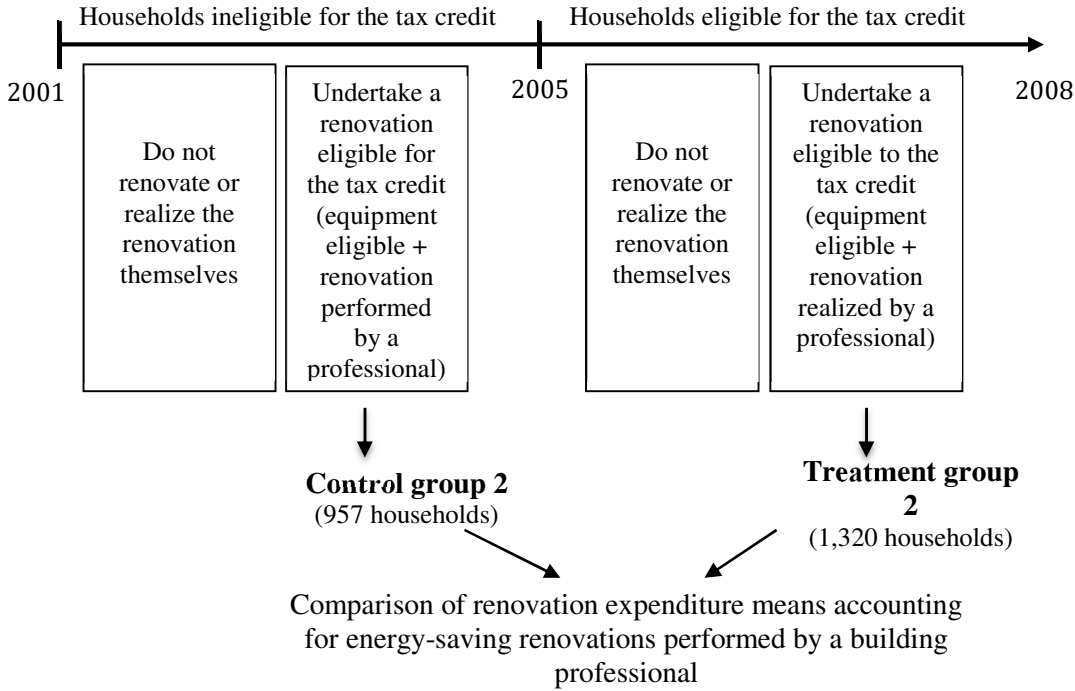


Figure B.2.1: Propensity score distribution by treatment status—renovation rate

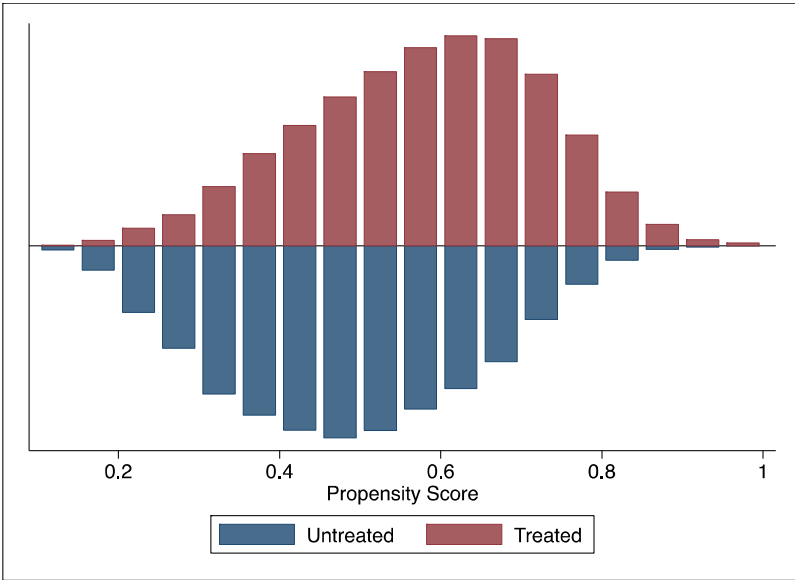


Figure B.2.2: Propensity score distribution by treatment status—renovation expenditures

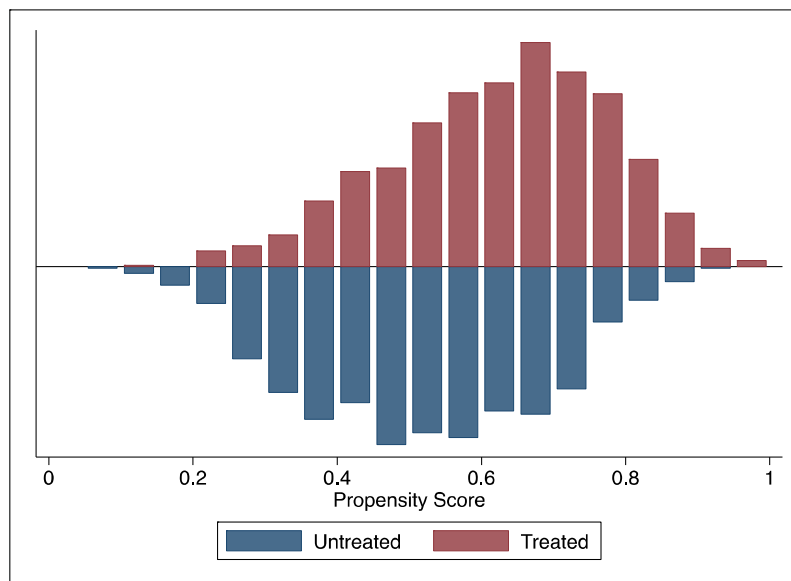


Figure B.2.3: Comparison of characteristics of the control group versus the treatment group, before and after matching—renovation rate

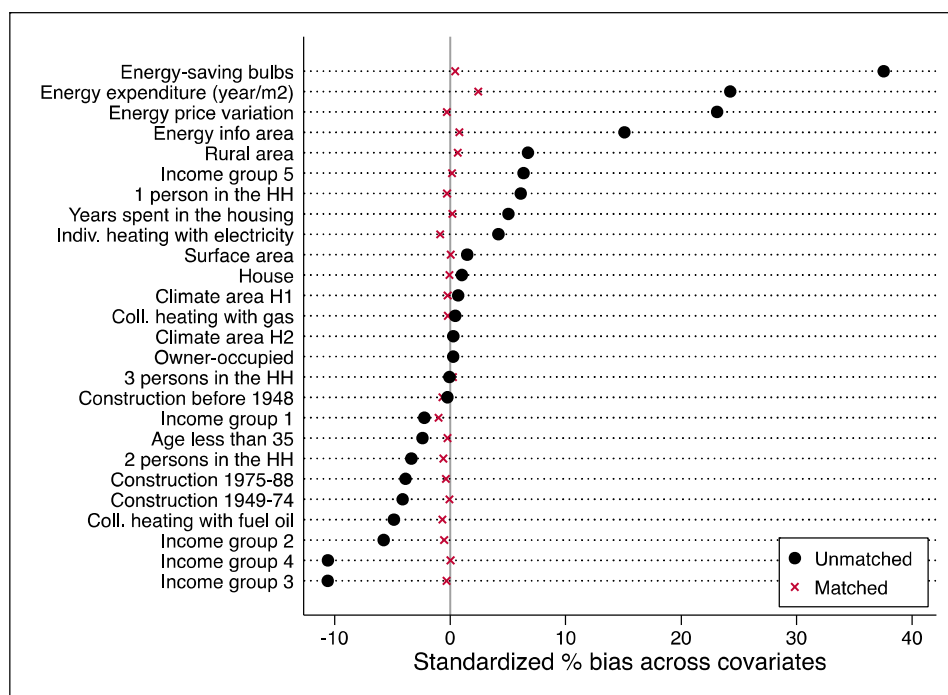
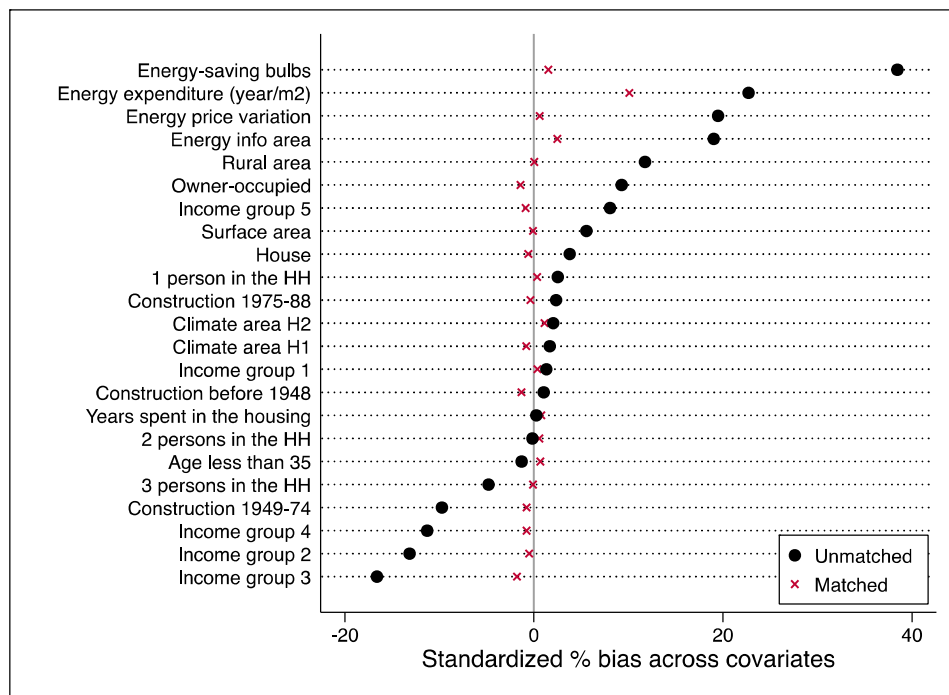


Figure B.2.4: Comparison of characteristics of the control group versus the treatment group, before and after matching—renovation expenditures



TABLES

Table 1: Presentation of the tax credit (from 2005 to 2008)

Beneficiaries of the tax credit	Conditions to receive the measure	Main equipment concerned	Deduction rate	Changes in the measure
-Owners and tenants (fiscally domiciled in France) -Primary domicile	-Energy-saving renovations -Renovation performed by a building professional	-Heating systems -Insulation materials -Renewable energies investment	From 10% to 50% depending on the kind of renovation	2006: increase in the deduction rate for some renovations

Note: An energy tax credit is still offered to households that undertake an energy-efficiency renovation. However, the deduction rate and eligibility conditions have changed since 2008.

Table 2: Comparison of renovation rate and expenditures before and after the introduction of the tax credit

	Before introduction of the tax credit (2001-2004)	After introduction of the tax credit (2005-2008)	T-test
Renovation rate ¹	8.23% (27.48)	9.21% (28.92)	***
Renovation rate performed by building professional ²	6.02% (0.172)	6.95% (0.171)	***
Renovation rate performed by household ²	2.79% (0.119)	3.02% (0.115)	n.s.
Number of observations		41,102	
Renovation expenditures, including only households that renovate and renovations performed by building professionals	3,919.15 € (105.98)	5,058.06 € (120.00)	***
Number of observations ³		2,277	

Notes: ***difference significant at 1%; n.s.: not significant. Standard deviations appear in parentheses.

¹ We account only for equipment eligible for the tax credit.

² These statistics are based on 41,078 since 24 households included in our sample did not indicate if the renovation was carried out by a building professional or by the household itself.

³ We consider only households undertaking an energy-saving renovation eligible for the tax credit.

Source: ADEME-SOFRES *Maîtrise de l'Energie* surveys-Final sample. Author's calculation.

Table 3: Impact of the tax credit on the decision to renovate—RD design results, OLS estimations

Explained variable: the renovation decision

	(1)	(2)	(3)	(4)	(5)
Tax credit effect	0.0090*** (0.0028)	0.0053 (0.0058)	0.0288** (0.0118)	0.0117** (0.0057)	0.0109* (0.0056)
$(S_i - S_0)$		-0.0002 (0.0017)	-0.0242** (0.0107)		
$T_i(S_i - S_0)$		0.0028 (0.0024)	0.0261** (0.0128)	-0.0050 (0.0059)	-0.0030 (0.0057)
$(S_i - S_0)^2$			-0.0048** (0.0021)		
$T_i \cdot (S_i - S_0)^2$			0.0051* (0.0028)		
Bandwidth	∞	∞	∞	[2004 ; 2006]	[2004 ; 2006]
Polynomial order	0	1	2	1	1
Control variables	yes	yes	yes	no	yes
Observations	41,102	41,102	41,102	14,411	14,411
R2	0.0432	0.0433	0.0434	0.0003	0.0466
AIC	11,049.1	11,050.8	11,049.8	4,040.8	3,440.9

Note: Bootstrapped standard errors, obtained after 5000 replications, appear in parentheses.

For estimations (4) and (5), bandwidth choice is determined by the cross-validation method.

Column (1) shows results from a parametric model without normalized assignment variable $(S_i - S_0)$ or interaction term $T_i(S_i - S_0)$ (equation 3). Column (2) shows the estimation of a two-sided linear model (equation 4). We augment the regression with quadratic terms in column (3) (equation 5). Results from local linear regressions are presented in columns (4) (equation 6) and (5) (equation 7).

Table 4: Number of energy-saving renovations and free-rider estimates

	2005	2006	2007	2008	TOTAL
Number of dwellings (from INSEE)	25,743,000	26,047,000	26,353,000	26,616,000	-
Rate of energy-saving renovations in ADEME-SOFRES survey	8.81%	8.55%	9.43%	9.50%	-
Estimated rate of renovations undertaken as a result of the tax credit			1.09% [0.00%-2.19%]		
Number of renovations as a result of the tax credit	280,599 [0; 563,772]	283,912 [0; 570,429]	287,248 [0; 577,131]	290,114 [0; 582,890]	1,141,873 [0; 2,294,222]
Number of households benefitting from the tax credit at least one time over the period (in million) (from INSEE)	1.0	1.1	1.0	1.1	4.2
Number of free riders ¹	719,401	816,088	712,752	809,886	3,058,127
Percentage of free rider²	71.9% [43.6%; 100%]	74.2% [48.1%; 100%]	71.3% [42.3%; 100%]	73.6% [47.0%; 100%]	72.8% [45.4%; 100%]
Public cost of tax credit (in billion euros) (from INSEE)	1.0	1.9	2.1	2.8	7.8
Public cost per dwelling (in euros) ³	3,563.8	6,692.2	7,310.8	9,651.4	6,830.88

Source: INSEE and ADEME-SOFRES Survey.

Note: Lines in grey are estimated or calculated figures. The values in brackets correspond to the 95% confidence interval.

¹ As a difference between number of households that benefit from the tax credit and the number of households that renovate as a result of the tax credit.

² We divided the number of free riders by the number of households that benefit from the tax credit.

³ We divided the total public cost by the number of renovations as a result of the tax credit.

Table 5: Impact of the tax credit on renovation expenditures—RD design results, OLS estimations

Explained variable: the renovation expenditures in logarithm

	(1)	(2)	(3)	(4)	(5)
Tax credit effect	0.2453*** (0.0451)	0.1699* (0.0926)	0.3685* (0.1964)	0.2531*** (0.0808)	0.2176*** (0.0805)
$(S_i - S_0)$		-0.0023 (0.0297)	-0.2149 (0.1806)		
$T_i(S_i - S_0)$		0.0517 (0.0383)	0.2909 (0.2104)	0.0676*** (0.0232)	0.0468* (0.0248)
$(S_i - S_0)^2$			-0.0422 (0.0355)		
$T_i \cdot (S_i - S_0)^2$			0.0344 (0.0421)		
Bandwidth	∞	∞	∞	[2004 ; 2008]	[2004 ; 2008]
Polynomial order	0	1	2	1	1
Control variables	yes	yes	yes	no	yes
Observations	2,277	2,277	2,277	1,558	1,558
R ²	0.0834	0.0850	0.0856	0.0232	0.0919
AIC	6,359.6	6,359.8	6,362.1	4,331.0	4,289.4

Note 1: Bootstrapped standard errors, obtained after 5000 replications, appear in parentheses.

Note 2: For estimations (4) and (5), bandwidth choice is determined by the cross-validation method.

Column (1) shows results from a parametric model without normalized assignment variable $(S_i - S_0)$ or interaction term $T_i(S_i - S_0)$ (equation 3). Column (2) shows the estimation of a two-sided linear model (equation 4). We augment the regression with quadratic terms in column (3) (equation 5). Results from local linear regressions are presented in columns (4) (equation 6) and (5) (equation 7).

Table 6: Leverage effect of the tax credit

	2005	2006	2007	2008	Total
Expenditures in energy-saving renovations (source OPEN) ¹	12.78	12.78	15.10	15.10	55.76
Estimation of renovation expenditures as a result of the tax credit (confidence interval in brackets)		21.76% [0.0598 - 0.3753]			-
Estimation of expenditures as a result of the tax credit in billion euros (confidence interval in brackets)	2.78 [0.764; 4.796]	2.78 [0.764; 4.796]	3.29 [0.903; 5.667]	3.29 [0.903; 5.667]	12.13 [3.33; 20.93]
Public cost of tax credit in billion euros (from INSEE)	1.0	1.9	2.1	2.8	7.8
Investment from households ²	1.78 [0; 3.796]	0.88 [0; 2.896]	1.19 [0; 3.567]	0.49 [0; 2.867]	4.33 [0; 13.13]
Euros spent by households for each euro spent by the government ³	1.78 [0; 3.796]	0.46 [0; 1.524]	0.57 [0; 1.699]	0.18 [0; 1.024]	0.56 [0; 1.68]

Source: INSEE, OPEN and ADEME-SOFRES Survey.

Note: In grey, estimated or calculated figures.

¹ Renovation expenditures in 2006 and 2008 are found in the OPEN survey. We have no data for renovation expenditures in 2005 and 2007. We assume that in 2005 and 2007 renovation expenditures are the same as in 2006 and 2008, respectively.

² We obtain the investment from households by subtracting the public cost of renovation expenditures due to the tax credit.

³ We divided the investment in energy-saving renovation from households by the public cost related to the tax credit.

Appendix

Table A1: Descriptive statistics of control variables used in RD design and matching models – Mean and standard deviation in parentheses

Variables	Full sample	Households that renovate ¹	Households that do not renovate	T-test
Household characteristics				
owners	0.7181 (0.4499)	0.9697 (0.1715)	0.7033 (0.4568)	***
age of reference person less than 35	0.1442 (0.3513)	0.1001 (0.3002)	0.1468 (0.3539)	***
1 person in the household	0.2470 (0.4313)	0.1823 (0.3861)	0.2508 (0.4335)	***
2 persons in the household	0.3990 (0.4897)	0.4708 (0.4993)	0.3948 (0.4888)	***
3 persons in the household	0.1389 (0.3459)	0.1489 (0.3560)	0.1383 (0.3453)	n.s.
4 persons or more in the household	0.2151 (0.4109)	0.1981 (0.3986)	0.2160 (0.4116)	**
income group 1 (the poorest)	0.0432 (0.2033)	0.0145 (0.1195)	0.0449 (0.2071)	***
group 2	0.1493 (0.3564)	0.1001 (0.3002)	0.1522 (0.3592)	***
group 3	0.1155 (0.3196)	0.0984 (0.2979)	0.1165 (0.3208)	***
group 4	0.1625 (0.3690)	0.1528 (0.3599)	0.1631 (0.3695)	n.s.
group 5	0.3270 (0.4691)	0.3821 (0.4860)	0.3238 (0.4679)	***
group 6 (the wealthiest)	0.2025 (0.4018)	0.2521 (0.4343)	0.1996 (0.3997)	***
energy sensitivity: energy-saving bulbs	0.5979 (0.4903)	0.6596 (0.4739)	0.5943 (0.4910)	***
knowledge of energy info area ²	0.1596 (0.3662)	0.2161 (0.4117)	0.1563 (0.3631)	***
no. years spent in the housing	15.4356 (13.1473)	17.7123 (13.9203)	15.3021 (13.0884)	***
Building characteristics				
house	0.6689 (0.4706)	0.8296 (0.3761)	0.6595 (0.4739)	***
surface area in m ²	101.915 (46.407)	115.483 (51.630)	101.1195 (45.9586)	***
year of construction: before 1948	0.2493 (0.4326)	0.2942 (0.4558)	0.2467 (0.4311)	***
1949–1974	0.3004 (0.4585)	0.3698 (0.4829)	0.2964 (0.4567)	***
1975–1988	0.2676 (0.4427)	0.2819 (0.4500)	0.2668 (0.4423)	n.s.
after 1989	0.1810 (0.3851)	0.0540 (0.2261)	0.1885 (0.3911)	***
collective heating system with fuel oil	0.0403 (0.1966)	0.0268 (0.1615)	0.0411 (0.1985)	***
collective heating system with gas	0.0781 (0.2684)	0.0474 (0.2126)	0.0799 (0.2712)	***
individual heating system with electricity	0.3125 (0.4635)	0.2336 (0.4232)	0.3172 (0.4654)	***

Energy price information				
annual energy expenditure in euros by m ²	12.369 (6.554)	12.557 (6.169)	12.3582 (6.5755)	n.s.
energy price variation (=1 if heating energy price increased more than 4% during the year observed)	0.3956 (0.4890)	0.4572 (0.4983)	0.3920 (0.4882)	***
Geographic area				
rural area	0.2426 (0.4287)	0.2574 (0.4373)	0.2418 (0.4282)	*
climate area H1 (the coldest. in the northeast)	0.5967 (0.4906)	0.3074 (0.4615)	0.5969 (0.4905)	n.s.
climate area H2	0.2943 (0.4557)	0.5920 (0.4916)	0.2935 (0.4554)	n.s.
climate area H3 (the warmest. in the south)	0.1090 (0.3117)	0.1006 (0.3008)	0.1095 (0.3123)	n.s.
Observations	41,102	2,277	38,825	

Note: ***difference significant at 1%; **difference significant at 5%; *difference significant at 10%; n.s.: not significant. Standard deviations appear in parentheses.

¹We consider only renovations performed by a professional and eligible for the tax credit

² Energy info areas are places where households can find all the information they need about energy consumption, renewable energies, and energy-saving renovations. This program was initiated in 2001 to alert and inform households; there are currently 250 energy info areas in France.

Table A2: Descriptive statistics of control variables used in RD design and matching models – Before and after the tax credit introduction

Variables	Full sample			Households that renovate		
	Mean		T-test	Mean		T-test
	Before 2005	2005 and after		Before 2005	2005 and after	
Household characteristics						
owners	0.7174 (0.4503)	0.7186 (0.4497)	n.s.	0.9603 (0.1954)	0.9765 (0.1515)	**
age of reference person less than 35	0.1487 (0.3558)	0.1403 (0.3473)	**	0.1024 (0.3033)	0.0985 (0.2981)	n.s.
1 person in the household	0.2329 (0.4227)	0.2592 (0.4382)	***	0.1766 (0.3815)	0.1864 (0.3895)	n.s.
2 persons in the household	0.4078 (0.4914)	0.3914 (0.4881)	***	0.4713 (0.4994)	0.4705 (0.4993)	n.s.
3 persons in the household	0.1391 (0.3460)	0.1388 (0.3458)	n.s.	0.1588 (0.3657)	0.1417 (0.3488)	n.s.
4 persons or more in the household	0.2202 (0.4144)	0.2106 (0.4077)	**	0.1933 (0.3951)	0.2015 (0.4013)	n.s.
income group 1 (the poorest)	0.0457 (0.2087)	0.0411 (0.1985)	**	0.0136 (0.1158)	0.0152 (0.1222)	n.s.
group 2	0.1603 (0.3669)	0.1397 (0.3467)	***	0.1233 (0.3290)	0.0833 (0.2765)	***
group 3	0.1337 (0.3403)	0.0997 (0.2996)	***	0.1275 (0.3337)	0.0773 (0.2671)	***
group 4	0.1835 (0.3871)	0.1444 (0.3515)	***	0.1766 (0.3815)	0.1356 (0.3425)	***
group 5	0.3111 (0.4629)	0.3408 (0.4740)	***	0.3595 (0.4801)	0.3985 (0.4898)	*
group 6 (the wealthiest)	0.1658 (0.3719)	0.2343 (0.4236)	***	0.1996 (0.3999)	0.2902 (0.4540)	***
energy sensitivity: energy-saving bulbs	0.5008 (0.5000)	0.6822 (0.4656)	***	0.5549 (0.4972)	0.7356 (0.4412)	***
knowledge of energy info area	0.1303	0.1851	***	0.1714	0.2485	***

energy sensitivity: energy-saving bulbs	0,1899	0,0052	***	0,1937	0,0233	***
knowledge of energy info area	0,0803	0,0070	***	0,0745	0,0266	***
no. years spent in the housing	0,0024	0,0003	***	0,0017	0,0010	*
Building characteristics						
house	-0,0366	0,0080	***	-0,0040	0,0332	
surface area in m ²	0,0003	0,0001	***	0,0002	0,0003	
year of construction: before 1948 (ref. after 1989)	-0,0465	0,0213	**	-0,0581	0,1488	
1949–1974 (ref. after 1989)	-0,1014	0,0218	***	-0,2013	0,1457	
1975–1988 (ref. after 1989)	-0,0494	0,0212	**	-0,0296	0,1496	
collective heating system with fuel oil	-0,0270	0,0299				
collective heating system with gas	0,1003	0,0201	***			
individual heating system with electricity	0,1837	0,0134	***			
individual heating system with gas, fuel oil and other	ref					
Energy price information						
annual energy expenditure by m ²	0,0203	0,0023	***	0,0217	0,0146	
energy price variation (=1 if heating energy price increase more than 4% during the year observed)	0,1635	0,0059	***	0,1080	0,0219	***
income group 1 * annual energy expenditure	-0,0084	0,0020	***	-0,0107	0,0153	
income group 2 * annual energy expenditure	-0,0044	0,0016	***	-0,0181	0,0068	***
income group 3 * annual energy expenditure	-0,0045	0,0017	***	-0,0149	0,0064	**
income group 4 * annual energy expenditure	-0,0022	0,0018		0,0024	0,0068	
income group 5 * annual energy expenditure	-0,0005	0,0014		-0,0034	0,0053	
1 pers in the HH * annual energy expenditure	-0,0034	0,0014	**	-0,0105	0,0069	
2 pers in the HH * annual energy expenditure	-0,0016	0,0013		-0,0108	0,0057	*
3 pers in the HH * annual energy expenditure	-0,0017	0,0016		-0,0134	0,0065	**
construction before 1948 * annual energy expenditure	-0,0037	0,0017	**	-0,0107	0,0128	
construction 1949–1974 * annual energy expenditure	-0,0006	0,0018		-0,0022	0,0129	
construction 1975–1988 * annual energy expenditure	-0,0035	0,0018	*	-0,0116	0,0130	
collective heating with fuel * annual energy expenditure	-0,0029	0,0020				
collective heating with gas * annual energy expenditure	-0,0084	0,0015	***			
individual heating with electricity * annual energy expenditure	-0,0083	0,0011	***			
Geographic area						
climate area H1 (the coldest, in the northeast)	-0,0205	0,0186		-0,1218	0,0767	
climate area H2	-0,0537	0,0206	***	-0,1657	0,0893	*
climate area H3 (the warmest, in the south)				ref		
annual energy expenditure * climatic area H1	0,0005	0,0015		0,0118	0,0062	*
annual energy expenditure * climatic area H2	0,0052	0,0017	***	0,0180	0,0071	**
rural area	0,0613	0,0066	***	0,0843	0,0260	***
Log-likelihood		-26,294.87			-1417.77	
Number of observations		41,102			2,277	
Correct prediction rate		63.36%			65.70%	

Note: ***significant at 1%, **significant at 5%, *significant at 10%.

We introduced multiplicative variables to correct collinearity in the model.

Table B.2.2: Matching quality

	Renovation rate		Renovation expenditures	
	Standardized percentage bias	LR χ^2	Standardized percentage bias	LR χ^2
Before matching	6.4%	4,175.78	8.3%	262.89
		$p > \chi^2 = 0.0000$		$p > \chi^2 = 0.000$
After matching	0.5%	40.16	1.6%	21.51
		$p > \chi^2 = 0.552$		$p > \chi^2 = 0.973$

Table B.3.1: Impact of the tax credit on renovation rate—kernel-matching estimates

Renovation rate	
Effect of the tax credit	0.0092
Standard error	(0.0031)***
Number of observations	41,102
Number in treatment group	22,001

Note 1: Bootstrapped standard errors, obtained after 1000 replications, appear in parentheses.

Note 2: ***significant at 1%; **significant at 5%; *significant at 10%.

Table B.3.2: Impact of the tax credit on renovation expenditures—kernel-matching estimates

Renovation rate	
Effect of the tax credit	0.2438
Standard error	(0.0457)***
Number of observations	2,277
Number in treatment group	1,320

Note 1: Bootstrapped standard errors, obtained after 1000 replications, appear in parentheses.

Note 2: ***significant at 1%; **significant at 5%; *significant at 10%.

Table B.4.1: Sensitivity analysis—impact of the tax credit on renovation expenditures

	Fraction $u = 1$ by treatment/outcome				Outcome effect	Selection effect	Tax credit impact	SE
	P_{11}	P_{10}	P_{01}	P_{00}				
Renovation rate								
No confounder	0	0	0	0	-	-	0.0092	0.0031***
Neutral confounder	0.50	0.50	0.50	0.50	0.997	0.999	0.0091	0.00002***
<i>Confounder:</i>								
Owner	0.93	0.70	0.89	0.70	3.514	1.007	0.0090	0.0003***
Energy expenditure /m ² (> the average)	0.48	0.48	0.37	0.37	1.029	1.590	0.0089	0.0004***
Income (group 5)	0.39	0.34	0.34	0.31	1.181	1.147	0.0088	0.0001***
Knowledge of energy info area	0.25	0.18	0.16	0.13	1.341	1.511	0.0081	0.0003***
Renovation expenditures								
No confounder	0	0	0	0	-	-	0.2438	0.0456***
Neutral confounder	0.50	0.50	0.50	0.50	1.005	0.999	0.2437	0.0013***
<i>Confounder:</i>								
Owner	0.98	0.97	0.97	0.95	2.058	1.813	0.2404	0.0037***
Energy expenditure /m ² (> the average)	0.51	0.50	0.40	0.37	1.142	1.652	0.2382	0.0081***
Income (group 5)	0.40	0.39	0.36	0.36	1.035	1.187	0.2432	0.0029***
Knowledge of energy info area	0.26	0.24	0.15	0.19	0.759	1.625	0.2495	0.0063***

Note 1: We use a kernel estimator to estimate the impact of the tax credit. Bootstrap standard errors are estimated after 1,000 replications.

Note 2: ***significant at 1%; **significant at 5%; *significant at 10%.