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Victor Kahn

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THÈSE DE DOCTORAT

DE L'UNIVERSITÉ PSL

Préparée à Mines Paris-PSL

**The Impact of Energy Retrofit and Energy Efficiency
Obligations in France**

**Une Évaluation de la Rénovation Énergétique en France
et des Certificats d'Économie d'Énergie**

Soutenue par

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Résumé

Cette thèse évalue les effets des investissements dans l'efficacité énergétique et les politiques publiques qui les soutiennent. Elle est construite autour de trois analyses empiriques et se concentre sur les économies d'énergie, les émissions de CO₂, les effets redistributifs et la création d'emplois.

A partir de données de panel, le **Chapitre 1** évalue l'effet de la rénovation énergétique des bâtiments sur la facture énergétique et les émissions de CO₂ des ménages. L'analyse repose sur un estimateur à la Chaisemartin et d'Haultfoeuille (2021). Un placebo test garantit l'endogénéité du traitement et l'hypothèse d'évolution parallèle. L'effet estimé est une réduction de 4.97% de la facture énergétique chez les ménages rénovateurs, soit une économie de 17 € par an pour 1000 € investis. Mes résultats suggèrent que le dispositif CEE surestime de 40% l'effet des travaux qu'il finance. Par ailleurs, les ménages rénovateurs réduisent leurs émissions de CO₂ de 5.52%. Le **Chapitre 2** s'intéresse aux effets redistributifs du dispositif CEE. En particulier, il évalue les conséquences d'une réforme de 2016 qui a obligé et incité les parties prenantes du dispositif à financer des projets de rénovation chez les ménages précaires. Le **Chapitre 2** montre que cette réforme a fonctionné, les ménages du premier quartile de revenu ont reçu en moyenne 100 € du dispositif en 2019, tandis que pour les 50% les plus aisés, le dispositif a représenté un coût de 26€. A partir de données agrégées par code NAF à l'échelle nationale, le **Chapitre 3** évalue l'effet du dispositif CEE sur l'emploi dans la rénovation énergétique. L'analyse recourt à une méthode de groupe de contrôle synthétique développée par Abadie et Gardeazabal (2003). Les résultats sont statistiquement positifs, 15 000 emplois ont été créés par la politique en 2019-2020 soit environ 7.5 emplois par millions € investi.

Cette thèse remet sensiblement en question les effets de la rénovation des bâtiments sur la consommation d'énergie. Dans le cas français, des problèmes de gouvernance entravent la qualité moyenne des travaux réalisés. Régler ces problèmes de qualité est d'autant plus primordial que mes travaux montrent que les politiques de rénovation énergétique ont des effets redistributifs et génèrent des emplois.

Mots clés : Economie de l'Énergie, Politiques Publiques, Économétrie Appliquée, Certificats d'Économie d'Énergie

Abstract

This thesis explores the impact and effectiveness of energy efficiency investments and related public policies in the French residential sector. It is based on three empirical analysis that focus on energy expenditures, carbon emissions, distributional effects and jobs development.

Relying on panel micro data covering year 2000 to 2013, **Chapter 1** examines the impact of residential energy retrofit on energy expenditures and carbon emissions in France. Since there is treatment timing variation, I use an estimator à la de Chaisemartin and d'Haultfoeuille (2021). The endogeneity of the investment decision is addressed with placebo tests validating the ex-ante parallel trend assumption and household fixed-effects. I find significant but mild effects. My best estimate is that the average retrofit reduces energy expenditures by 4.97%. Put differently, an investment of EUR 1,000 leads to an annual saving of EUR 17 on energy expenditures. I find that the main French energy retrofit policy, the CEE program, overestimates by 40% the effect of the operations it subsidizes. Carbon emissions decrease a little bit more, with a 5.52% reduction for each EUR 1,000 invested. **Chapter 2** assesses the potential distributional effect of Energy Efficiency Obligations programs. In particular, I assess the impact of a 2016 regulatory change in the CEE scheme that was made to target low-income households. Obligated parties were required to support energy retrofits of dwellings occupied by lower-income households. I find that it worked. According to my estimates, it resulted in an average net annual cost of EUR 26 for households from the third and fourth income quartiles, while households from the first quartile benefit a net EUR 100. Using aggregate employment data by sector in France, **Chapter 3** assesses the effect of the CEE policy on employment in the energy retrofit industries. I use a synthetic control group method, originally developed by Abadie and Gardeazabal (2003) and Abadie et al. (2010). I find a statistically significant impact on employment. I estimate that at least 15,000 jobs were created thanks to the policy, equivalent to 7.5 direct jobs created per million euros invested annually.

This dissertation questions the actual energy retrofit impact on savings. In the case of France, this thesis points out several problems of governance that hamper the quality of achieved works. Addressing these problems appears all the more paramount since my work demonstrates energy retrofit policy might engender several positive spillovers such as distributional effect and job creations.

Keywords : Energy Economics, Public Policies, Applied Econometrics, Energy Efficiency

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Chapitre 1

Introduction

1 Buildings, energy scarcity and climate change

As I begin to write this introduction, energy efficiency might have become one of the world's most important and most urgent issues. The French President, Emmanuel Macron, has just declared that we have reached the end of the era of abundance (Lemarié 2022). European wholesale spot electricity prices are 10 times higher than three years ago (RTE 2022) and, according to Dr. Fatih Birol, the President of the International Energy Agency (IEA) : "the world has never witnessed such a major energy crisis in terms of its depth and its complexity" (Stringer 2022). Buildings, considering their use only, account for 30% of global energy consumption, ranking them as the world's biggest energy consumers, ahead of transport and construction sectors (IEA 2020). Since, in developed countries, new constructions only account for 1% of the housing stock each year (OECD 2022). Therefore, reducing the building sector's energy consumption will require improving the existing stock's thermal efficiency by improving insulation and replacing inefficient heating systems. Lastly, even without the current energy crisis, buildings still produce 27% of world's carbon emissions and thus play a major role in the global warming phenomenon (IEA 2020). As a result, improving the existing housing stock's energy efficiency must be a primary target for both the short and long terms.

With this purpose, several public policies have been implemented to support energy retrofit such as the Energy Company Obligations (ECO) in the UK, or the Energy Savings Certificates¹ (CEE) scheme in France, and the Weatherization Assistance Program (WAP) in the USA. Furthermore, almost all the post-coronavirus recovery plans involve investments in buildings efficiency. For instance, the USA, the UK, and Japan will spend more than USD 10 billion on upgrading buildings and energy infrastructure development during the current decade (O'Callaghan et al. 2021). The European Union is even more ambitious, and in 2020 launched the Renovation Wave, a EUR 200 billion climate-related investments program (European Commission 2020a). Focusing on the CEE scheme, which is main energy retrofit policy in France, my thesis aims at providing empirical evidence of the consequences of these instruments in terms

1. In French, the "Certificats d'Economie d'Énergie" scheme

of energy consumption, carbon emissions, income inequalities and employment in the renovation sectors.

2 Energy retrofit policies : what is at stake ?

2.1 The energy efficiency gap

While the energy transition is unquestionably necessary, economics aims at discussing what is the most cost efficient path to achieve it. In this regard, residential energy retrofit is often presented as one of the cheapest ways to reduce carbon emissions. Some residential energy renovations are argued to have negative carbon abatement costs, in other words, a rational decision maker should invest in energy retrofit regardless of the climate issue (McKinsey & Company 2009). Nonetheless, households are generally slow to renovate. This phenomenon was noticed by Hirst et Brown (1990) and theorized under the name of the “energy efficiency gap” : the difference between the cost-minimizing level of energy efficiency and the level of energy efficiency actually realized. The origin of this gap has been discussed in length in the economic literature. Gillingham et Palmery (2014) point out several obstacles that might impede households from carrying out renovation work. The first barriers are market failures which refer to asymmetric information and credit constraints. Other barriers come from behavioral anomalies, such as over-discounting of future energy savings or bounded rationality that bias households’ decisions. Gerarden, Newell et Stavins (2017) provide a comprehensive literature review about the energy efficiency gap controversy. Although, its relevancy and magnitude are much debated in the literature (Fowlie, Greenstone et Wolfram 2018 ; Davis, Fuchs et Gertler 2014 ; Liang et al. 2018), the energy efficiency gap is used as an argument to encourage governments to set up substantial retrofit support policies in order to address market failures and behavioral anomalies.

2.2 Energy efficiency obligations schemes

Policies enhancing refurbishment investment mainly fall into three categories : subsidy tools, informational programs, and energy efficiency obligations (EEOs). The latter ones require obligated parties, e.g. be energy suppliers (France) or distribution system operators (Italy), to meet energy savings targets. To do so, obligated parties encourage consumers (households, industries or services) to invest in energy efficiency. In most cases, obligated parties fulfill their obligation by subsidizing energy retrofit operations, with the result that EEOs have the same effect as a standard subsidy policy. However, EEOs represent a cost for the obligated parties, which pass it on through energy prices : the instrument thus mimics the effect of a tax on energy consumption. In 2017, 46 EEOs programs were implemented in the world : in twenty-six US states, fifteen countries from the European Union (including France, Italy, Spain and Poland), the UK² and countries like Korea, Brazil and Australia for instance (Rosenow, Cowart et Thomas 2019). The French EEOs, the CEE program, at a cost of roughly EUR 4 billion per year, is the biggest in Europe (Broc, Stańczyk et Reidlinger 2020).

2. Germany is a noticeable example amongst European countries that have not implemented an EEOs.

2.3 Fuel poverty

Compared to restrictive policies, such as carbon pricing and environmental norms, subsidizing energy efficiency appears as a more politically acceptable solution to reduce energy consumption. However, retrofit policies raise issues regarding their potential distributional side effects. First of all, higher-income households are more likely to benefit from the retrofit-related subsidies because they face less liquidity constraints. Worse still, EEOs have energy tax effects, which are known to be regressive (Douenne 2020). If they are poorly designed, these policies might result in low-income households funding the high-income households' renovation work (Rosenow, Platt et Flanagan 2013). In order to counter these negative spillovers, two types of measures may be undertaken : sub-obligations³ and bonuses. A sub-obligation compels obligated parties to target a specific household group - in our case low-income households, whereas bonuses consist in rewarding obligated parties with more certificates when they target the said household group. France is the only country which has implemented both mechanisms to target low-income households (Broc, Stańczyk et Reidlinger 2020), thus this country constitutes a relevant field to assess the potential distributional effect of an EEOS and to understand what are the respective impacts of each mechanism.

2.4 Green jobs and the energy transition

Finally, beyond its energy-savings aspects, buildings retrofit is expected to play a major role in the post-pandemic stimulus packages. Renovation industries involve manual workers mainly employed by local SMEs (European Commission 2020c). For policy makers, supporting energy renovation is thus a means to boost the local economy, but also to reallocate low-skilled workers from polluting industries likely to be negatively impacted by other environmental policies.⁴ High expectations about energy retrofit policies positive spillovers on employment are mainly based on ex-ante macro-models but ex post empirical evaluations are scarce. Such analysis would be highly relevant in order to compare energy retrofit with other sectors involved in the green transition regarding their impact on jobs. As a result, policymakers could set priorities in their energy transition schedules.

3 My contribution

This PhD dissertation gathers three empirical analyses exploring the impact of energy retrofit policies in France.

Chapter 1 focuses on the energy retrofit impact on households energy expenditures and residential carbon emissions. Using panel data on 10,000 French households energy-related behaviors, I run the first empirical ex-post study in France assessing the effect of retrofit investment on energy consumption. From the panel data, I also infer households residential carbon emissions

3. Some policies, which are not EEOs such as the WAP in the US, might also specifically target low-income households.

4. Such as carbon pricing, or environmental norms, for instance, see Reed Walker (2011), Vona et al. (2018) et Marin et Vona (2019)

and run an analysis on how they are impacted by energy renovation. The analysis uses a new difference-in-difference estimator constructed by Chaisemartin et D'Haultfoeuille (2021) in order to deal with treatment timing variation. The endogeneity of the investment decision is addressed with placebo tests validating the ex-ante parallel trend assumption and household fixed-effects. In line with other recent studies, I find that the energy retrofit impact is overestimated by ex-ante engineering models. Households that invest in energy retrofit reduce their energy expenditures by 4.97 %, which represents a decrease of 1.24% for each EUR 1,000 invested, or savings of EUR 17. I compare my results with the model calibrating the CEE program, *i.e.* associating each type of renovation with an amount of energy savings. I find that this model overestimates by 40% the savings achieved by the retrofit operations subsidized through the policy. Finally, I calculate that retrofitting households reduce their carbon emission by 5.54%. These results tend to question the energy efficiency gap hypothesis, and to advocate for an energy performance gap.

Chapter 2 explores the link between retrofit policies design and income inequality in the EEOs framework. I analyze the effect of a CEE program's reform enacted in order to target low-income households through two mechanisms. First, the total obligation was divided between "standard" certificates and "Précarité" certificates, the latter being obtained by subsidizing low-income households (the 50% poorest). In addition, bonuses were granted to obligated parties when they targeted very-low-income households (the 25% poorest). I assess the economic flows induced by the scheme after the policy reform. In particular, I compare, depending on their income, how much households pay in "CEE-induced tax" on energy and how much they receive in CEE-related subsidies for energy retrofit. I find that the reform successfully achieved positive distributional impacts, since the 50% richest pay EUR 25 per household for the program whereas the 25% poorest receive EUR 100. In a second step, I find that the distributional impacts were only achieved through the bonus mechanism whose very first effect is to reduce the total amount of energy savings delivered by the scheme. In other words, low-income households retrofit investments were fostered at the expense of global energy efficiency. Finally, the CEE program could become regressive again in the future because obligated parties have taken advantage from the generous bonus mechanism to bank "Précarité" certificates.

Chapter 3 analyzes the impact of energy renovation policies on jobs. Using panel data on the monthly workforce in businesses in France, I assess the effect of a large-scale CEE policy reform on employment in both the insulation and heating sectors. A package of regulatory changes package was implemented in 2018 and significantly increased the subsidies offered by the program for insulation and heating system operations. For these types of building works, the quarterly amount of subsidies granted by the scheme grew from EUR 200 million before 2017 to EUR 1,000 million by the end of 2019. I exploit this discontinuity with a synthetic control method (Abadie et Gardeazabal 2003; Abadie et al. 2010). My analysis compares affected sectors with unaffected sectors that are pooled and weighted to create a synthetic control whose pre-policy employment trend matches the employment trend of the affected sectors. I stopped the analysis just before the COVID-19 pandemic in February 2020, and I observed a clear impact of the change in policy on employment in energy retrofit companies after 14 months. This impact

seems to continue until after the pandemic. I estimate that at least 15,000 jobs were created thanks to the policy, equivalent to 7.5 direct jobs created per million euros invested annually. This figure is consistent with the different ex ante estimations provided concerning the impacts of energy retrofit impacts on employment.

All in all, this thesis substantially questions the actual impact of retrofit policies on energy savings. These disappointing results seem to come from low average quality performed on the renovation market. This is due to asymmetry of information that prevents households from controlling the quality of the service offered. My research also underlines structural governance issues in the case of the French CEE program. Specifically, the policy suffers from an unstable regulatory framework that attracts short-term actors and produces unexpected and unwanted effects in the long run. Addressing these quality and governance issues is all the more important since this thesis demonstrates that the CEE program engenders positive distributional spillovers and job creations.

Chapitre 2

The effects of home energy retrofit on residential energy expenditures and carbon emissions : Empirical evidence from France

Résumé

A partir de données de panel sur la période 2000-2013, cet article évalue l'effet de la rénovation énergétique dans le secteur résidentiel sur la facture énergétique et les émissions de carbone des ménages en France. Les ménages ne rénovent pas tous la même année, nous utilisons donc un estimateur à la Chaisemartin afin de palier le biais intrinsèque des estimations avec effets fixes temporels et individuels. Un test placebo garantit l'endogénéité du traitement et l'hypothèse d'évolution parallèle. Nous estimons qu'un ménage qui rénove réduit sa facture de 4,97%, autrement dit, un investissement de 1 000 € entraîne des économies annuelles de 13 €.

Abstract

Relying on panel micro data for the 2000–2013 period, the paper examines the impact of residential energy retrofit on energy expenditures and carbon emissions in France. Since we have treatment timing variation, we use an estimator *à la* Chaisemartin in order to deal with the two-way fixed effect inherent bias. We address the endogeneity of investment decision due to renovating households' self-selection by using control variables, fixed-effects and an ex-ante parallel trend assumption placebo test. We find significant but mild effects. Our best estimate is that an households achieving energy retrofit reduces its energy expenditures by 4.97% or that an investment of 1,000 € leads to a 13€ annual saving on energy bill. These results suggest to revise a common belief on the existence of a wide energy efficiency gap.

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1 Introduction

For several decades, many countries have implemented ambitious public policies to promote energy retrofits. In France, these policies mainly rely on providing financial support to homeowners through two instruments : tax credit and an energy saving obligations program. In total, this policy-mix grants more than EUR 5 billion per year to households and firms investing in energy efficiency. Besides since 2021, the Climate and Resilience Act requires tenants of low-energy performance housing to renovate.

This public intervention is mainly justified by two arguments. First, buildings are the biggest energy consumer accounting for 45% of final energy use in France, more than manufacturing and transport (INSEE 2020). Second, energy retrofit is commonly viewed as a cost-effective solution to reduce energy consumption and pollution. Several ex-ante engineering models go further, predicting that certain types of energy retrofit operations are privately profitable and thus cut carbon emissions at a negative cost (McKinsey & Company 2009).

However, homeowners are reluctant to achieve these investments. This paradox was initially described by Hirst et Brown (1990) who coined the term "energy efficiency gap" to qualify this difference between the cost-minimizing level of energy efficiency and the level of energy efficiency actually observed. For 30 years, economists have been trying to explain the width and origin of this gap (see Allcott et Greenstone (2012) or Gillingham et Palmery (2014)). Possible explanations include the existence of several failures on energy efficiency markets, including information asymmetry between buyers (in particular, when they are households) and sellers or behavioral biases. Stated preferences analysis point out hidden cost for households, such as disruption at home during the renovation, which are rarely taken into account by engineering models (see Alberini (2019) for a literature review).

The "energy efficiency gap" hypothesis has been recently challenged in a handful of ex-post studies. Fowlie, Greenstone et Wolfram (2018) have recently examined this issue with a randomized controlled trial involving 30,000 low-income households in Michigan. They found that a reason for this gap was the overestimation of the energy savings achieved by ex-ante models by 60% compared to the ex-post estimation. Davis, Fuchs et Gertler (2014) found that the installation of energy-efficient air-conditioners in Mexico led to about 25% less energy savings than predicted by ex-ante models, and Liang et al. (2018) using panel data found a 30 to 50% overestimation of energy savings for residential and commercial buildings in Phoenix, Arizona.¹ Charlier et Legendre (2021) discusses the influence of income heterogeneity on the width of the gap. Other studies argue that the disappointing savings delivered by energy retrofit comes from low average quality performance. Christensen et al. (2021) estimate that 43% of the energy efficiency gap was due to workmanship heterogeneity. Using data on renovation in Florida, Giraudet, Houde et Maher (2018) argue it is mainly due to low-quality working force.

Moreover, cutting carbon emissions is a major reason for reducing energy use. A set of studies includes this issue in the analysis. Boomhower (2019) argue that energy retrofit generate

1. For other studies in Maryland, USA or in New Zealand see Alberini, Gans et Towe (2013) or Grimes et al. (2016).

savings at the time when electricity is the most expensive and carbon-intensive, i.e., during heating and cooling peaks. Lang et Lanz (2022) contribute to this empirical literature with an evaluation taking into account carbon savings and by comparing different retrofit options. They find significant heterogeneity among these options with different rankings when based on energy savings or on carbon emissions (smart heat controllers are very efficient, whereas wall insulation's avoided carbon cost is worth 1000 EUR/tCO₂).

Our study is at the intersection of these two strands of the literature. As Lang et Lanz (2022), we look jointly at the impact of energy retrofit on energy expenditures and carbon emissions. In line with the first stream of the literature, we evaluate the wedge between engineering estimates and ex-post actual results. We provide the first empirical estimates for France.

We use data from the survey "Maitrise de l'Energie " covering about 7,000 households in France each year between 2000 and 2013. These households were asked every year their annual energy expenditures and whether they had energy retrofit. The data also include a vast array of information on the type of fuel used, the type and amount of investment in energy retrofit, and sociodemographics. We adopt a difference-in-difference approach. Since there are timing variations in investment decisions and because treatment effects are likely to vary over time, results with standard two-way regression with time and household fixed effects are likely to be biased (Borusyak et Jaravel 2018). This leads us to use the estimator recently proposed by Chaisemartin et D'Haultfoeuille (2021) that fits with our staggered adoption design. The endogeneity of the investment decision due to the households' self-selection in the treatment group is addressed with using control variables, fixed-effects and an ex-ante parallel trend assumption test.

We find a negative and significant impact of energy retrofit on both energy expenditures and carbon emissions. However, the effect is mild : the average retrofit reduces energy expenditures by 4,97% and carbon emissions by 5,52% (including the indirect emissions from power generation). Both effects are stable over time. The average investment in our dataset is about EUR 4,000, it means that for each EUR 1,000 invested in energy retrofit, households reduce their energy bill by EUR 17.

We then compare our results to the engineering model used in the French Energy Savings Certificates (CEE) program. We find it overestimates by 40% the energy savings achieved through the policy. All these results challenge the "energy efficiency gap" hypothesis. Households may be reluctant to invest in energy retrofits simply because it is less cost-effective than claimed by official bodies or energy efficiency contractors.

The paper is structured as follows. Section 2 presents the data. Section 3 describes the identification strategy. Section 4 reports the results. Section 5 discusses the results and derives policy implications. Section 6 concludes.

2 Data overview

2.1 The survey "Maîtrise de l'Énergie"

The survey "Maîtrise de l'Énergie" was carried out every year between 2000 and 2013 by TNS-SOFRES.² TNS-SOFRES strived to poll the same households each year, however the sample size fluctuates between 7100 and 8900 households a year. A household remains 6 years on average in the panel. This sample includes households representing the French population based on sociodemographic characteristics and home characteristics. It includes owner-occupants (73%) and tenants (27%). The data provide detailed information on households' energy expenditures and on their potential energy retrofit investments. Sociodemographic characteristics (household size, age, income, environmental preferences, etc.), housing characteristics (surface area, region, construction year, moving-in year etc.) are also available.

The estimation sample contains only 12,531 observations and 2,202 households. We call it the "restricted panel". The main reason for this gap with the whole sample is our estimation strategy. It requires two conditions that will be discussed in detail below. First, households have to be present at least 4 years in a row in the panel. We check that there is no correlation between being present several years consecutively in the panel and energy consumption and investments (see **Figure A1.4** and **Figure A1.5** in **Appendix 9**). Second, the sample excludes the households who invested twice or more during the study period.

We also drop the years 2003 and 2007 for which data on energy bills are missing³. Finally, households that changed ownership status during the survey or having invested less than EUR 1,000 are also dropped from the data set. It is also a constraint imposed by the estimation strategy.

2.2 Energy retrofit

In the survey, households were asked to list individual energy retrofit operations carried out from a list of 21 categories. In our restricted panel, 702 households have invested (once) in energy retrofits during the study period. In the following, this group is called the retrofitters and the remaining 1,500 households of the restricted panel are the non-retrofitters. **Table A1.6** in **Appendix 9** summarizes all the energy retrofit operations undertaken in our restricted panel. The sample size is not sufficient to exploit this category-level information. Our dependent variable is the sum of the amounts invested in all categories in a given year.

The 702 households investing in energy retrofits spend EUR 3,987 on average. 49% of the capital invested in retrofit is windows-related, heat boilers replacement follows with 32%, and insulation works rank third with 18%.

2. A French polling institute.

3. 2002-2004 and 2006-2008 are considered as consecutive years

2.3 Energy expenditures

Table 1.1 summarizes the main information about households' energy bill in the restricted panel. On average, households spend EUR 1,321 per year for residential energy consumption. Electricity, gas and fuel oil account for more than 90% of these expenditures which increased over the period studied, especially gas expenditures. This increase is due more to gas price inflation than to the adoption of gas heating (see **Figure A1.1** and **Figure A1.2** in **Appendix 9**).

2.4 Carbon emissions

The survey obviously does not give any hint about households' carbon emissions. We infer these emissions in two steps. In the first one, we convert bills (EUR) into energy consumption by fuel (kWh). The survey "Maitrise de l'Energie" unfortunately does not provide any information on the price paid by each household (including the fixed and variable part for power and gas). To circumvent the problem, we use the PEGASE database which gives the annual retail prices (EUR/kWh) for each energy vector and year for all contracts offered on the market in a given year including the fixed and the variable parts for gas and electricity. We then assign to each household the contract which maximizes its energy consumption given its expenditures. We also assume no household has a peak/off-peak subscription.

In the second step, we convert energy consumption into carbon emissions (kgCO₂). We here use the ADEME's⁴ CARBONE database⁵ that provides the carbon footprint of each energy source in France. For power, the carbon footprint depends on the time of the day the household consumes electricity. In France, electricity heating mainly occurs during the evening when the power mix is carbon intensive. CARBONE data take this into account by identifying specifically the carbon footprint of electricity used for heating. In the case where a household declares in the survey "Maitrise de l'Energie" that electricity is its main heating fuel, we assume that all the electricity consumed is for heating.⁶ Descriptive on carbon footprints can be found in **Table A1.7** in **Appendix 10**.

Table 1.1 summarizes the main information on the two dependent variables, the annual energy expenditures and the level of carbon emissions for the retrofiters and non retrofiters in the restricted panel. Two points must be underlined about this table : first there is no clear correlation between energy bills (which are mainly electricity expenditures) and carbon emissions drivers (which are mainly emitted by gas and fuel oil consumption). It shows that assessing separately carbon emissions and energy expenditures is paramount. Second the fuel mix of retrofiters is sensibly different from the one of non retrofiters. Households of the first group use

4. The ADEME is a French public independent agency which advises the state on environmental and energy topics

5. [Available here](#). We take the year 2018 as the reference year for two reasons. First, the method used for calculating the footprint in CARBONE has been improved on several occasions and experts argue that 2018 is the oldest year with the best method. Second, the carbon footprint of electricity has not drastically evolve between 2000-2013 and 2018.

6. In other words, we assume that the electricity that will be saved thanks to retrofit will be electricity used for heating. In the first order, only the footprint of the marginal carbon saved is important in our analysis, that is why we used heating electricity's carbon footprint. We run analysis using other assumptions and the results do not widely differ.

more gas and fuel oil, whereas the others use more electricity. As relative energy prices in France has changed during the period studied,⁷ we will need to control for this diverging evolution by including fuel-year fixed effects in the estimation equation.

TABLE 1.1 – Average annual household energy expenditures and carbon emissions by fuel for retrofitters and non-retrofitters

Energy Source	Non retrofitters		Retrofitters	
	Expenditures [EUR]	Carbon [kgCO ₂]	Expenditures [EUR]	Carbon [kgCO ₂]
Total	1,292	3,286	1,394	3,893
Power	716	872	706	865
Fuel Oil	160	861	177	962
Gas	303	1,332	395	1,826
Other	114	221	116	240
N	8740		3791	

Notes : Power is the main driver of the energy bill whereas gas and fuel oil are the ones of carbon emissions. This is due to the French power mix which is not carbon intensive. Moreover electricity bill and gas bill have a fixed part which obviously does not impact carbon emissions.

3 Identification

3.1 Endogeneity concerns

The main challenge for estimating the impact of retrofit is that individual households who renovate their home self select in the treatment group.

In this context, a potential source of endogeneity is an unobserved shock that increases the propensity to both retrofit and reduce energy consumption before the renovation. We call it the "Greta Thunberg effect" : A family watching a Greta Thunberg's conference suddenly increases its awareness of the climate change crisis and its potential contribution to mitigation by reducing energy use. This may lead the family to reduce energy consumption (e.g., by reducing indoor temperature) and to retrofit, which takes time and have effects on energy later on. Failing to account for this informational shock here leads to underestimate the true impact of retrofits. A similar endogeneity concern could create an upward bias in a case of an Ashenfelter's Dip (Ashenfelter 1978). Our solution is to check the validity of the ex-ante parallel trend assumption

7. Gas and fuel oil prices almost doubled while power price remained stable, see **Table A1.1 in Appendix 9**

by comparing energy expenditures evolution before refurbishment in between retrofitting and non retrofitting households.

A shock might also increase the propensity to achieve energy retrofit and increase the level of energy consumption after renovation. We call it the "baby effect". A family is expecting a baby. The parents thus anticipate an increase in their energy needs (e.g., because members of the family will spend more time at home to look after the baby or because the baby needs a higher indoor temperature in his/her bedroom). The family thus renovates before the birth of the baby. When the baby is born, they then use more energy. In contrast with the first story, this surge of energy use occurs after the retrofit. A naive estimation would, in this case, underestimate the retrofit impact. To deal with this problem, we use control variables : number of people living in the household, household head activity status⁸, income.

3.2 The estimator

The standard estimator to deal with our question would be a regression model with household and time fixed effects. However, this two-way fixed effect model (TWFE) is increasingly questioned (Borusyak et Jaravel 2018 ; Sun et Abraham 2021 ; Chaisemartin et D'Haultfoeulle 2020 ; Goodman-Bacon 2021). The problem originates in the control group used by this type of model. In a canonical DiD approach, treated individuals should be compared with never treated individuals. It is not the case in a TWFE regression when there are variations in treatment timing. If a household invests at time t , it will be compared at time $t+1$ with never treated individuals, but also with non-already treated individuals and even, more problematically, with households treated at time $t' < t$. As shown by Chaisemartin et D'Haultfoeulle (2020), this type of control group is particularly problematic when the treatment effect might vary over time.

We use the estimator developed by Chaisemartin et D'Haultfoeulle (2021) for contexts with staggered treatment and dynamic treatment effects.⁹ Its main characteristics is to restrict the comparison of newly treated households with non-already treated households.¹⁰

We define $\ln(Y_{it})$ the natural logarithm of either the energy expenditures or the carbon emissions of household i in year t , T_i the year when household i had retrofit. Conventionally we consider that $T_i = \infty$ if household i is never treated. Chaisemartin et D'Haultfoeulle (2021) define in Eq (2.1) the variable $DID_{t,l}$:

$$DID_{t,l} = \sum_{i:T_i=t-l} \frac{\ln(Y_{i,t}) - \ln(Y_{i,t-l-1})}{\sum_i \mathbb{1}_{i:T_i=t-l}} - \sum_{i:T_i>t} \frac{\ln(Y_{i,t}) - \ln(Y_{i,t-l-1})}{\sum_i \mathbb{1}_{i:T_i>t}} \quad (2.1)$$

This variable is the average difference in year t of energy expenditures (or carbon emissions) variations on the $l+1$ years time period and the households having renovated l years ago with the households who still have not renovated in year t .

8. Because the very same effect might happen with a person preparing his/her retirement.

9. Specifically, we use the `did_multiplegt` Stata command.

10. Sun et Abraham (2021) proposed a similar estimator comparing newly treated individuals with never-treated individuals. We decided to chose the Chaisemartin et D'Haultfoeulle (2021) estimator in order to increase our control group, since 33% of the panel is treated.

Since we have a staggered adoption design with binary treatment, our final estimator is equivalent to the weighted average sum of $DID_{t,l}$:

$$DID_l = \sum_{t=l+2}^{2013} \omega_{t,l} \times DID_{t,l} \quad (2.2)$$

where $\omega_{t,l}$ is the share in year t of the households treated for the first time l years ago in all households treated l years ago.

In addition, we control for : household income, the number of people living in the dwelling, the household head activity status and we include household fixed effects, region-year fixed effects which controls *inter alia* for weather and local economic shocks, a vector of fixed effects combining the heating fuel used with time, which controls for the possible correlation between the occurrence of retrofit investments and price variations of the heating fuel.¹¹

Chaisemartin et D'Haultfoeuille (2021) also provide a placebo estimator, which is a common trend test, that mimics the main estimator. It compares the evolution of energy expenditures in households retrofitting in year $(t - l)$ with non already retrofitting households in t but on the period between the $t - 2l - 2$ and $t - l - 1$ period. The formal placebo estimator is defined in Eq. 2.3 :

$$DID_{t,l}^{placebo} = \sum_{i:T_i=t-l} \frac{\ln(Y_{i,t-2l-2}) - \ln(Y_{i,t-l-1})}{\sum_i \mathbb{1}_{i:T_i=t-l}} - \sum_{i:T_i>t} \frac{\ln(Y_{i,t-2l-2}) - \ln(Y_{i,t-l-1})}{\sum_i \mathbb{1}_{i:T_i>t}} \quad (2.3)$$

4 Results

The estimation results are displayed in **Table 1.2**. It is however more convenient for interpretation to rely on a graphical representation.

Figure 1.1 presents the results for the impact on energy expenditures. We find a significant, but mild effect : one year after a retrofit, households reduce by 4.58% their energy expenditures. Put differently, EUR 1,000 invested in energy retrofit reduce the annual energy bill by EUR 17. This effect remains stable in the next two years.

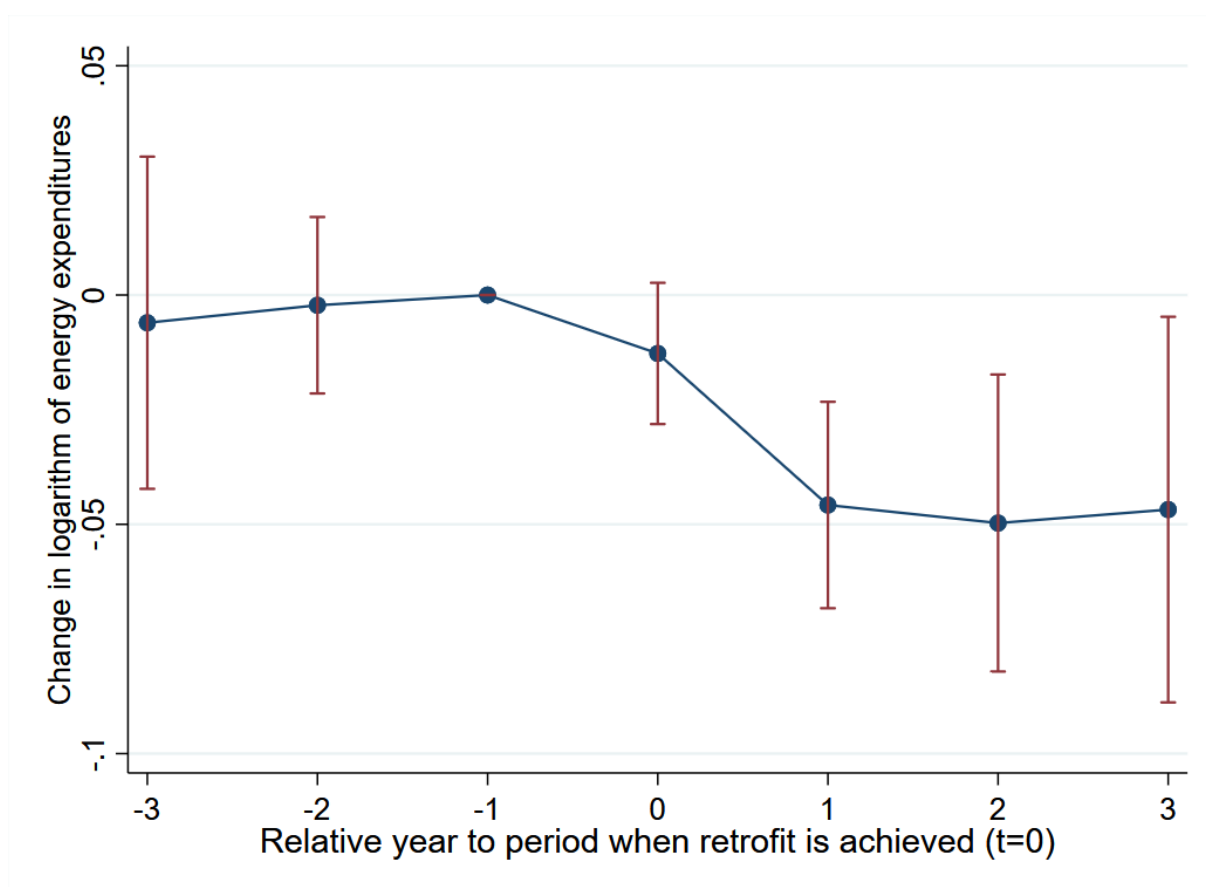
The ex-ante parallel trend assumption seems to hold as shown by the results of the placebo tests on the relative years -3, and -2 : the energy expenditures evolution of future retrofiters and the other households is not significantly different during the 3 years preceding the energy retrofit.

Figure 1.2 presents the estimates for residential carbon emissions. Again, we find a significant effect : carbon emissions decrease by 5.52% after retrofit and the effect is stable over time. The ex-ante parallel trend assumption also seems to hold. **Table 1.2** displays detailed results about the carbon effect estimation.

In **Appendix 7**, we present results with the standard OLS TWFE. We find retrofiters reduce by 1.97% their expenditures after renovation (see column (1) in **Table A1.2** in **Appendix 7**). It

11. Note that this specification prevents the analysis from estimating fuel switching effects. Fuel switching is however not frequent in the sample (see **Figure A1.2** in **Appendix 9**)

FIGURE 1.1 – Effect of having energy renovation on the energy expenditures (log)



Notes : Red is the confidence interval at 95% (200 bootstraps repetitions were computed).

FIGURE 1.2 – Impact of energy retrofits on the log of residential carbon emissions

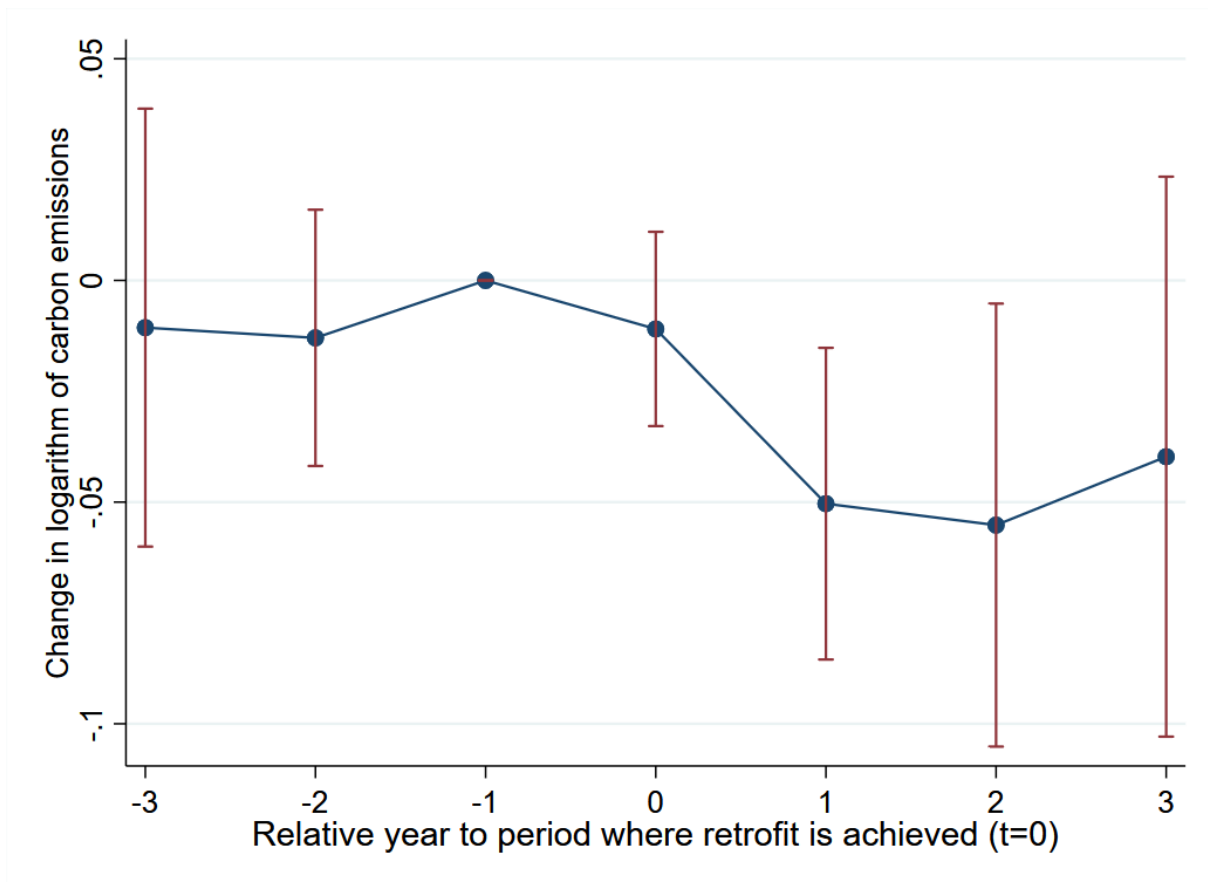


TABLE 1.2 – Impact of energy retrofit on energy expenditures and carbon emissions

	(1)	(2)	Group	
	Expenditures	Carbon	Control	Switchers
Effect t=0	-0.0127 (0.0079)	-0.0109 (0.0112)	7939	565
Effect t=1	-0.0458*** (0.0115)	-0.0504** (0.0179)	5774	376
Effect t=2	-0.0497** (0.0165)	-0.0552* (0.0255)	3897	250
Effect t=3	-0.0468* (0.0216)	-0.0398 (0.0322)	2356	160
Placebo t=-2	-0.0022 (0.0098)	-0.0130 (0.0147)	5802	404
Placebo t=-3	-0.0060 (0.0185)	-0.0106 (0.0252)	2369	155

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes : The table reads as follows : The third line (Effect t=2) means there were 250 "switchers", i.e., households that remained in the panel two years after retrofitting and 3,897 who had never retrofitted before and stayed three consecutive years in the panel ("control"). On average the 250 retrofitters reduced energy expenditures by 4.97 % compared to the 3,905 controls two years after the retrofit. These results were obtained using the *did_multiplot* command on stata.

demonstrates the relevancy to use our alternative estimator *à la* Chaisemartin et D’Haultfoeuille (2021).¹²

5 Discussion

5.1 Comparison with engineering models

Many real-world energy retrofit support instruments routinely rely on ex-ante engineering models to calibrate policy parameters. In France, the energy efficiency obligations program (CEE) associates to each type of energy retrofit measures an amount of certificates accounting for the savings generated according to the engineering estimates (GDEC 2022a). As an illustration, the engineering model forecasts a reduction of EUR 48 of the energy expenditures for each EUR 1,000 invested in wall insulation, EUR 47 for the same amount invested in the installation of efficient boilers or EUR 9.5 for the installation of a double glazing window.

We cannot compare directly our results with these values for two reasons. First, we estimate the average effect of the investments made between 2000 and 2013. The problem is that the portfolio of investments made has significantly changed since then. In particular, the share of investments in double glazing windows has diminished. Second, we estimate the effect of an energy retrofit relative to a counterfactual scenario without renovation. For some investment categories, this counterfactual includes an alternative investment. Take the example of boilers. In many cases, the investment in an energy-efficient boiler occurs when the old boiler has to be replaced. In this case, the counterfactual scenario is the installation of a basic, non-efficient, boiler. In contrast, the counterfactual of an investment in wall insulation is more likely to be the absence of investment. This leads us to assume that the opportunity upfront cost of an energy-efficient heating system is the difference between the upfront cost of the energy-efficient heating system and the upfront cost of the inefficient version. We address these two problems –the update of the portfolio and the definition of relevant counterfactual scenarios –with a method described in detail in **Appendix 8**. In essence, it rests upon the hypothesis that, although the engineering estimates of the absolute level of energy savings are biased, the relative valuation of the energy savings for the different investment categories is correct. Then, for each type of energy retrofit operations, we have assumptions about the upfront cost in the retrofit scenario and the cost in the counterfactual.

Under these assumptions, the ex-post estimation predicts an annual savings of EUR 34 for EUR 1,000 invested in energy efficiency while the CEE model predicts an annual savings of EUR 58. The engineering model thus overestimates the actual savings by 41%. This difference between our ex-post results and the predictions of the ex-ante models is of the same order of magnitude as that estimated in the studies cited in the introduction. Applying different methods, on different energy retrofit operations in different countries, Fowlie, Greenstone et

12. We also perform a simple OLS and a 2SLS IV regressions without all our restriction assumptions. For the simple OLS we find EUR 1,000 invested reduce by 0.43% energy expenditures, the IV regression finds a 2.41% reduction (see **Table A1.2** in **Appendix 7**). The results for the IV are roughly twice higher from our main estimation, however, the chosen instrument is likely to overestimate the effect of renovation and the result remains imprecise.

Wolfram (2018), Zivin et Novan (2016), Liang et al. (2018) and Davis, Fuchs et Gertler (2014) find overestimation rate between 25 and 60%. Christensen et al. (2021) find engineering models only account for 40% of the wedge between engineering models and actual savings. Furthermore, the ADEME, the French public independent agency which supervises the CEE program, assumes a 30% gap between the standardized energy savings predicted by the CEE model and actual savings. (ADEME et al. 2021)

5.2 Rationale for the wedge with engineering models

Our results confirm engineering models tend to substantially overestimate the effect of energy retrofit. In order to improve the effectiveness of retrofit policies, it is interesting to understand what are the reasons for a such a gap.

First of all, our study does not take into account any potential comfort gain. Nevertheless, the rebound effect relevancy is discussed amongst economists. For instance, on the one hand, Hong, Oreszczyn et Ridley (2006) find a gain emprised between 1.6°C and 2.8°C in homes after energy retrofit. Aydin, Kok et Brounen (2017) find a rebound effect in a range of 20-40 % the expected effect in the Netherlands, Nösperger et al. (2017) find 50 % in France, whereas stated preferences studies suggest households undertake renovation to improve their thermal confort (Alberini, Gans et Towe 2013). On the other hand, Fowlie, Greenstone et Wolfram (2018) find no evidence of rebound effect after energy refurbishment and Christensen et al. (2021) estimate the rebound effect to account only for 6% of the wedge between engineering models and observed savings.

Furthermore, energy retrofit market has similarities with the Akerloff's "Market for Lemons" (Akerlof 1970). Households suffer from the information asymmetry on quality with heating professionals. Giraudet, Houde et Maher (2018) find that retrofit operations made in Florida (on a panel of roughly 3,000 operations) were much less efficient when works had occurred on a Friday, when the workforce is less dedicated. Christensen et al. (2021) find 43% of the gap between predicted and actual savings comes from asymmetric information on quality. Lanz et Reins (2021) provide an review of empirical studies about information asymmetry on credence good markets and discuss linkages with the energy retrofit market. They discuss different solutions to address average-quality issues. For instance, they argue energy certification requires costly controls, and sellers might appropriate expected benefits from signaled quality products (Houde 2018). Lanz et Reins (2021) also show that third party ex-ante audits make households investments fit better with their need, even though, the high-cost of audits reduces welfare.

We thus advocate for a third party assistance for households throughout their renovation project : ex-ante audits, technical support during the construction and ex-post quality checks. Energy retrofit policies should focus on subsidizing the assistance on quality.

6 Conclusion

Using panel data on French households we estimate the impact of residential energy retrofit on energy expenditures and on residential carbon emissions. We find a significant but mild impact

of retrofitting on these two variables. Households who renovate reduce their expenditures by 4.97% and their carbon emissions by 5.54%.

In a second step we set up a method in order to compare our results with engineering models predictions. We find that the model calibrating the main French energy retrofit policy overestimates by roughly 40% the impact of the renovations it supports. Therefore, our work suggests energy retrofit is not financially profitable from a private point of view.

Note that the study does not take into account the potential comfort gains permitted thanks to energy retrofit. These gains might indicate that households are eventually rational, even though, they carry out financially non-profitable investments. Another weakness of our work is the quality of our dataset. On the one hand, it is seven years old, on the other hand, some data are missing which jeopardize the accuracy of our estimations.

Despite these weaknesses, the study questions the relevance of the "energy efficiency gap" assumption, and advocates for new public policy approaches towards increasing the average quality in the energy retrofit market and decreasing information asymmetry between households and professionals.

7 Robustness Check

7.1 Instrumental Variables

Using instrumental variables enables to deal with endogeneity and to address attenuation bias. The main idea is to use the time since move-in as an instrument for capital invested in energy retrofit. An household's decision to move-in is not likely to be correlated with any willingness to reduce its energy consumption. Indeed, we can consider the decision to move in a new home as independent from being environmental aware or facing a too expensive energy bill. Then, if an household's energy consumption unilaterally changes after move-in, it is only through the fact it has achieved energy renovation works¹³.

We consider that when people move-in a new home they are likely to keep improving their house during their first years of occupation. Actually, this intuition is confirmed by our dataset : 20% of recently moved-in household achieve energy retrofit, whereas this number drops to 13% for households that have moved in for more than 3 years (see **Figure A1.3** in **Appendix 9**). It must be understood that our goal is not to compare the energy consumption of an household before/after it has moved in, but to focus on its energy consumption evolution during the very first years after moving in. In other words, factors such as building age, or house appliances quality would be considered as fixed-effect.

To build our instrumental variables, we consider that an household has recently moved in if it has been living in its home for less than 2 years. Then, we interact the time since move-in with two fixed effects : being owner occupant and living in a old building. In deed, owner occupants are more likely to carry out refurbishment works than tenants, this likelihood is increased if the building where they have moved in is old. We eventually build four instruments from this information which are integer varying from 0 to 3 according to the number of years that an household meets the condition defines by the different interactions.

The instrument is not as good as random. First, if moving in is not linked with willingness to reduce energy consumption, it is likely to be correlated with expecting a new baby. Consumption the first years after moving in might be high because the household increased their indoor temperature for the baby comfort. The child growing up the consumption decreases with the indoor temperature. In this case, the energy retrofit effect is confounded with the "baby's effect" on energy consumption bringing an overestimation of energy retrofit impact. Besides, new owner occupants are likely to live in more modern homes and they might already have done some works in it before moving in. Thus, the refurbishment marginal gain might be lower than for other home energy retrofit operations. Conversely, buying and moving in a new home is part of a long-term and thought project. As a result, new owner occupant are more likely to be knowledgeable about their energy renovation needs and conscientious in their heating technology installer research. One euro invested in energy conservation by a new owner occupant may be more efficient than the same euro spent by an average household. However this instrument

13. There might be adaptation time in the new home. Households do not know their new house at the beginning, they might consume too much or not enough energy regarding their needs by the time they adapt changing their consumption. It certainly increases the variability of energy consumption during the first occupation years in a new home, but this effect is random and multi-directional, so it does not bias the estimation.

seems to be pretty exogenous and to provide a better estimation than a simple ordinary least squares estimation. In detail we define three events :

A_{it} : "The household i has moved in its home for less than 2 years at year t "

B_i : "The household i is owner occupant.

C_i : "The household i lives in a building built before 1974".

We use a log-linear fixed effects¹⁴ regression in order to estimate the impact of the capital invested in energy retrofit on households' energy bill.

$$\ln(Y_{it}) = \alpha * T_{it-1} + \beta * X_{it} + \delta_{r(i)t} + \lambda_{e(it)t} + \mu_i + \epsilon_{it} \quad (2.4)$$

$\ln(Y_{it})$ is the natural logarithm of energy expenditures or residential carbon emissions¹⁵ of the household i in year t .

T_{it-1} is a binary equal to 1 if the household i has renovated in year $t-1$.

X_{it} is a vector controlling for income, the number of people living in the household and the household head activity status i in year t .

μ_i is a household fixed effects vector.

$\delta_{r(i)t}$ is a region-year fixed effects vector which controls for weather effects and local economic circumstances.

$\lambda_{e(it)t}$ is a vector controlling for the principal heating energy source $e(it)$ used by household i in year t . It controls for the possible correlation between having retrofit operations and using an energy source with increasing price¹⁶.

ϵ_{it} is the error term.

We aim at estimating α in (2.4) which measures the marginal effect of 1€ invested in energy retrofit on the bill's/carbon emission's reduction in percentage.

Then, we define 4 variables $m_{it} = A_{it}$, $n_{it} = A_{it} \cap B_i$, $o_{it} = A_{it} \cap C_i$, $p_{it} = A_{it} \cap B_i \cap C_i$

Finally, we define M_{it} , N_{it} , O_{it} , P_{it} :

$$M_{it} = \sum_{k=2000}^t m_{ik} \quad (2.5)$$

$$N_{it} = \sum_{k=2000}^t n_{ik} \quad (2.6)$$

$$O_{it} = \sum_{k=2000}^t o_{ik} \quad (2.7)$$

14. Log-linear models are standards in energy efficiency field look at Fowlie, Greenstone et Wolfram (2018) or Liang et al. (2018)

15. We have two regressions one for the bill, the other for carbon emissions

16. We do not measure the fuel switching effect on the bill. Fuel switching is not so common (see appendix : Figure A1.2) and we can assume that it belongs to the energy refurbishment payoffs.

TABLE A1.1 – First stage Regression

	(1) Cumulative Capital Invested
M_{it-1}	-0.630*** (0.0764)
N_{it-1}	0.527*** (0.153)
O_{it-1}	0.0176 (0.0957)
P_{it-1}	1.124** (0.376)
tailleFoyer	-0.0548 (0.135)
Observations	19596
R-squared	0.224

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

$$P_{it} = \sum_{k=2000}^t p_{ik} \quad (2.8)$$

$M_{it-1}, N_{it-1}, O_{it-1}$ and $P_{it-1} \in \{0, 1, 2, 3\}$

We instrument K_{it-1} with $M_{it-1}, N_{it-1}, O_{it-1}$ and P_{it-1} in (2.4). First stage regression is given in **Table A1.1**, 3 out of 4 IVs have a significant impact especially being owner in a old building while having recently moved-in.

7.2 Energy bill results

The regression results for the effect of energy retrofit on the energy bill are shown in **Table A1.2**. The effect measured is low 2,41% of bill reduction for EUR 1,000 invested in energy retrofit. As expected because of the endogeneity and the attenuation bias, the effect measured by the simple OLS in column (2) is 6 times lower than with IVs in column (4). Column (3) presents the results when principal heating source is not taken into account, the effect measured is milder than in column (4) and non statistically significant : fuel oil and gas heated households have an higher propensity to achieve energy retrofit, a part of the savings is hidden by the inflation of energy prices compared to electricity.

TABLE A1.2 – Effect of cumulative capital invested in retrofit on energy bill

	(1)	(2)	(3)	(4)	
	OLS	OLS	IV	IV	
Retrofitting	-0.0197*** (0.00689)				
Cumulative Capital Invested		-0.00426*** (0.0008)	-0.0197 (0.0129)	-0.0241* (0.0130)	
Household Size	0.0495*** (0.00601)	0.0495*** (0.00648)	0.0469*** (0.00733)	0.0487*** (0.00708)	
Incomes	YES	YES	YES	YES	
Living Space Area	YES	YES	YES	YES	
Socio-Professional Status	YES	YES	YES	YES	
Region-Year FE	YES	YES	YES	YES	
Heating-Source-Year FE	YES	YES	NO	YES	
Restricted Panel	YES	NO	NO	NO	NO
Observations	10,610	19596	19596	19596	
R-squared	0.0083	0.228	-0.0217	-0.0494	
KP_Wald F-Stats			39.10	30.90	

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes : Stata command is ivreghdfe with robust option and households level clustered standard-error.

7.3 Residential carbon emissions results

Table A1.3 summarizes the regression results for the impact of energy retrofit on the residential carbon emissions. The effect is significant but low, a 3.84% decreasing for EUR 1,000 invested in energy retrofit. Using instrumental variables multiplies by 5.5 the measured effect in this case. This time, when energy source is not taken into account in column (3) the effect measured is higher than in column (4). The households carrying out retrofit investments, who are more likely to use gas or fuel oil heating, might have reduced partly their energy consumption (then their carbon emissions) because of the energy price inflation (demand elasticity). Then without taking into account inflation, the measured effect of energy retrofit is increased.

TABLE A1.3 – Effect of cumulative capital invested in retrofit on residential carbon emissions

	(1)	(2)	(3)	(4)
	OLS	OLS	IV	IV
Retrofitting	-0.0244*** (0.00934)			
Cumulative Capital Invested		-0.00698*** (0.00112)	-0.0459** (0.0193)	-0.0384** (0.0170)
Household Size	0.0378*** (0.0087)	0.0486*** (0.00890)	0.0479*** (0.0110)	0.0473*** (0.0100)
Incomes	YES	YES	YES	YES
Living Space Area	YES	YES	YES	YES
Socio-Professional Status	YES	YES	YES	YES
Region-Year FE	YES	YES	YES	YES
Heating-Source-Year FE	YES	YES	NO	YES
Restricted Panel	YES	NO	NO	NO
Observations	10,610	19596	19596	19596
R-squared	0.135	0.145	-0.0975	-0.0693
KP_Wald F-Stats		39.10	30.90	

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

8 Comparison with engineering models

To compare our result with the engineering model calibrating the CEE scheme requires us to know the average effect of EUR 1,000 invested in energy efficiency on both energy expenditures and carbon emissions. The β we calculate in our core analysis, are actually not exactly these searched value because they estimate the average effect for EUR 1,000 invested in energy retrofit which includes the cost of the standard low-efficient technology (1) and the extra-cost for the efficient one (2). In this section we first describe our assumptions regarding standard cost (1) and efficiency extra-cost (2) for each type of energy retrofit operations. Then, we provide a methodology to calculate the effect on savings and carbon emissions for each type of operations. Thus, we are able, for each type of retrofit measures, to calculate the expenditures and carbon emissions impact for each EUR 1,000 invested in the efficiency extra-cost (2). Finally, we compare our results with the CEE engineering model.

8.1 Energy retrofit and energy efficiency costs

Strictly speaking, from the household's point of view, there is a distinction between the energy retrofit cost and the energy efficiency cost when it undertakes a renovation. Indeed, for a given energy service, the true cost of efficiency is the difference between the cost of an efficient technology and the cost of the minimum available one which delivers the service. For instance, the

counterfactual of "the household A buys an efficient boiler" is not "the household A does not buy anything" : the true counterfactual is "the household A buys a basic boiler". As a result, the cost of energy efficiency for household A is eventually the difference between the price of the efficient boiler and the basic one. For insulation works, we assume the full investment is efficiency related, in other word, the counterfactual for insulation works is no investment at all. For windows and heating systems operations, we assume from Glachant, Kahn et Lévêque (2020b) the b_j which represents the cost of the basic technology as percentage of the efficient ones's cost. We then calculate e_j the percentage of the investment which is due to the extra-cost for efficiency. e_j is equal to $1 - b_j$ and we present e_j for all j in **Table A1.5**.

8.2 Effect for each type of renovation

In our core analysis we calculate β , the average energy savings (in EUR) achieved by an household through retrofiting. With an average investment in retrofit of EUR 3,987 in our dataset, we can infer a value β^{Data} , which is the average energy savings per EUR 1,000 invested. However, our analysis does not provide any hint about β_j^{Data} , the average savings per EUR 1,000 invested in the energy retrofit operation of type j , for instance attic insulation or double glazed windows.

The CEE program associates to each type of energy retrofit operation a number of certificates valued in energy savings (in MWh) (GDEC 2022a).¹⁷ Using the average energy prices between 2000-2013 (given in **Table A1.5**), we can infer an amount of savings in euro for each type of operation. Besides, the CEE scheme also provides a reference cost for each type of operation. As a result, we can infer from the engineering model calibrating the CEE policy the β_j^{CEE} that are the average savings for each EUR 1,000 invested in the operation of type j .

We assume that, even though the engineering model driving the CEE program is wrong in absolute, it provides an accurate estimation of relative efficiency between type of operations.¹⁸ Therefore, for each type of operations j we can define γ_j the relative cost efficiency of the operation compared to windows-related operations.¹⁹ γ_j is defined in equation 2.9. **Table A1.4** provides for each energy retrofit operation j ²⁰ the value of β_j^{CEE} and γ_j . From our assumption about the relative efficiency, it is obvious that in equation 2.9 γ_j only depends on j and is the same for both models, the ex-post one from our data analysis and the ex-ante the CEE program's one.

$$\gamma_j = \frac{\beta_j^{CEE}}{\beta_{Window}^{CEE}} = \frac{\beta_j^{Data}}{\beta_{Window}^{Data}} \quad (2.9)$$

Our dataset describes a certain portfolio of retrofit works. For each type of operation j , we define x_j^{Data} the percentage - in capital invested - that the type j accounts for in the portfolio.²¹

17. The model is publicly available here [available here](#)

18. This assumption is quite strong, and would deserve by itself a complete article to be checked.

19. The choice of windows-related operations as a reference is purely conventional, and does not affect the results

20. We simplify our categories from 21 to 9, in order to make them compatible with the information provided by the CEE program model

21. All x_j^{Data} are given in **Table A1.6** in **Appendix 9**

TABLE A1.4 – CEE program’s engineering model assumption on expected savings, lifetime and cost for different types of operations

Operation Name	Total Savings	Lifetime	Cost	β_{CEE}	γ
Wall Ins.	20	30	1,125 €	48	5.0
Roof Ins.	14	30	400 €	95	9.9
Ceiling Ins.	13	30	350 €	100	11
Sealing	0.73	30	150 €	13	1.4
Windows	44.2	30	1,311 €	9.6	1
Boiler	39.6	17	3,110 €	47	4.9
Fireplace	31.3	17	3,000 €	38	4.0
Radiators	0	17	XXX	0	1
HP	43	17	8,530 €	34	2.5

Notes : Total savings, lifetime and cost comes from the CEE scheme model (GDEC 2022a). β_{CEE} and γ are from authors’ calculation using, PEGASE database for energy prices, and ADEME’s Base Carbone for carbon footprint.

Assuming the average energy savings effect of the portofolio - β^{Data} - is the capital weighted average of each β_j^{Data} , for all type of operation j , we can rewrite β^{Data} as shown in equation 2.10 :

$$\beta^{Data} = \sum_k \beta_k^{Data} x_k^{Data} = \beta_j^{Data} * (x_j^{Data} + \sum_{k \neq j} \frac{\gamma_k}{\gamma_j} x_k^{Data}) \quad (2.10)$$

From equation 2.10 we can write β_j^{Data} as :

$$\beta_j^{Data} = \frac{\beta^{Data}}{(x_j^{Data} + \sum_{k \neq j} \frac{\gamma_k}{\gamma_j} x_k^{Data})} \quad (2.11)$$

We can access all the values at the right of equation 2.11 because the CEE scheme’s model provides γ_j for all j (given in **Table A1.4**). Therefore, we can calculate for each type of operations the savings in euro achieved for each EUR 1,000 invested in the operation on average. We then use the very same method to obtain $\beta_{CO_2,j}^{Data}$ for each operation j .²²

For our both models, from the data or from the CEE scheme, the different β_j^{Model} we calculate are the average energy savings per EUR 1,000 invested in energy retrofit, i.e., the cost for basic technology plus the extra-cost for the efficient one. For each model in (Data, CEE), we want to calculate α_j^{Model} the average energy savings per EUR 1,000 invested in the extra for energy efficiency. We define, in equation 2.12, α_j^{Model} as the ratio between β_j^{Model} and e_j the part of the investment cost which is due to the extra-cost for efficiency.

$$\alpha_j^{Model} = \frac{\beta_j^{Model}}{e_j} \quad (2.12)$$

Finally, for each model, we define α^{Model} the average energy savings for each EUR 1,000 invested

²². We use the average carbon footprint of each energy source to calculate relative carbon efficiency of each energy retrofit operations from the CEE programme’s model, which are given **Table A1.5**

TABLE A1.5 – Energy prices and carbon footprint associated with energy savings, and part of the investment efficiency-induced, for different type of retrofit

Operations	Energy Prices [€/MWh]	Carbon Footprint [kgCO ₂ /MWh]	e_j
Wall Ins.	81.3 ^a	205 ^b	100%
Roof Ins.	81.3	205	100%
Ceiling Ins.	81.3	205	100%
Sealing	81.3	205	100%
Windows	81.3	205	33%
Boiler	63	324 ^c	33%
Fireplace	63 ^d	324	33%
Radiators ^e	110	205	XXX
HP	81.3	Special ^f	70%

^a We calculate this price from the average prices of electricity, gas and fuel oil in our panel period the PEGASE database. We then calculate an average price of energy consumed with the distribution of main heating vector in our panel.

^b It is the average carbon footprint of the energy consumed in our panel, we calculate it from the ADEME's Base Carbone.

^c For boiler and fireplace we take the average price of fuel oil and gas as reference since few electricity heated households will change for a combustion heating technology.

^d For boilers the reference carbon footprint is fuel oil

^e Radiators are not covered by the CEE scheme, we assume it has no impact on energy efficiency.

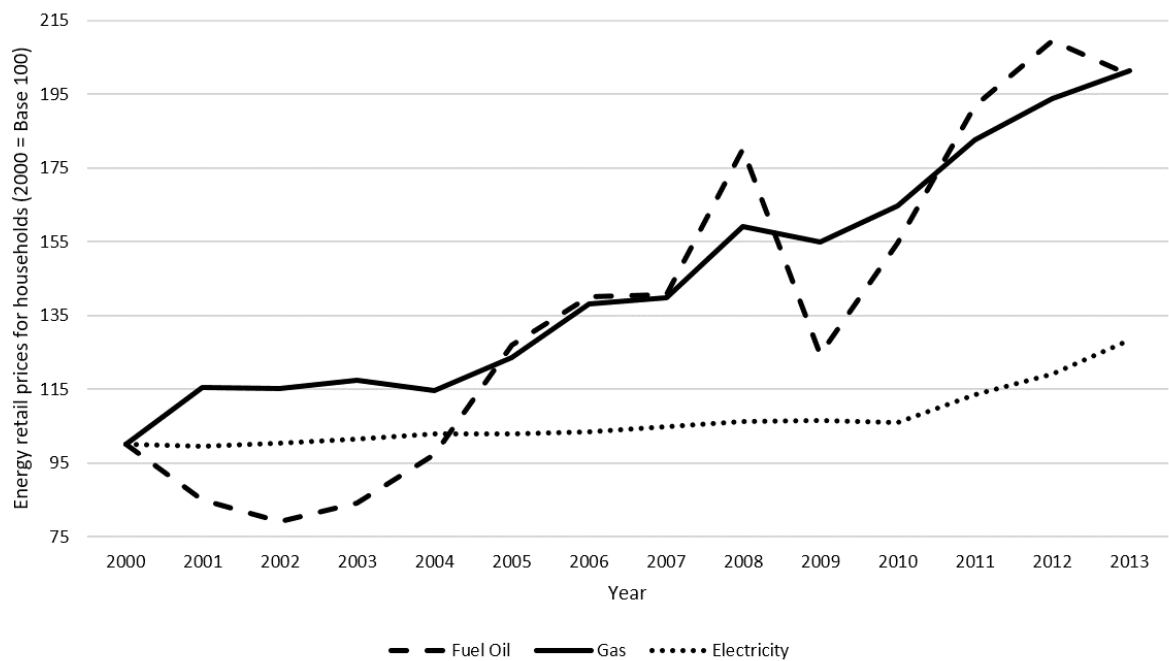
^f For Heat-Pump, there are two channels for carbon savings : those induced by energy savings, and those induced by fuel switching. Assuming the previous energy consumption is equal to 150% of the energy savings achieved the total carbon impact of an heat pump is worth : Previous Consumption * Fuel Oil Footprint - New Consumption * Electricity Footprint. The footprint are from the ADEME's Base Carbon

in our dataset portfolio in efficiency. α^{Model} is given in Equation 2.13. Under our different assumptions we obtain, $\alpha^{Data} = 34$ EUR and $\alpha^{CEE} = 58$ EUR arguing that real energy savings are 40% lower than what is predicted by the CEE programme's engineering model.

$$\alpha^{Model} = \sum_k x_k * \alpha_k^{Model} \quad (2.13)$$

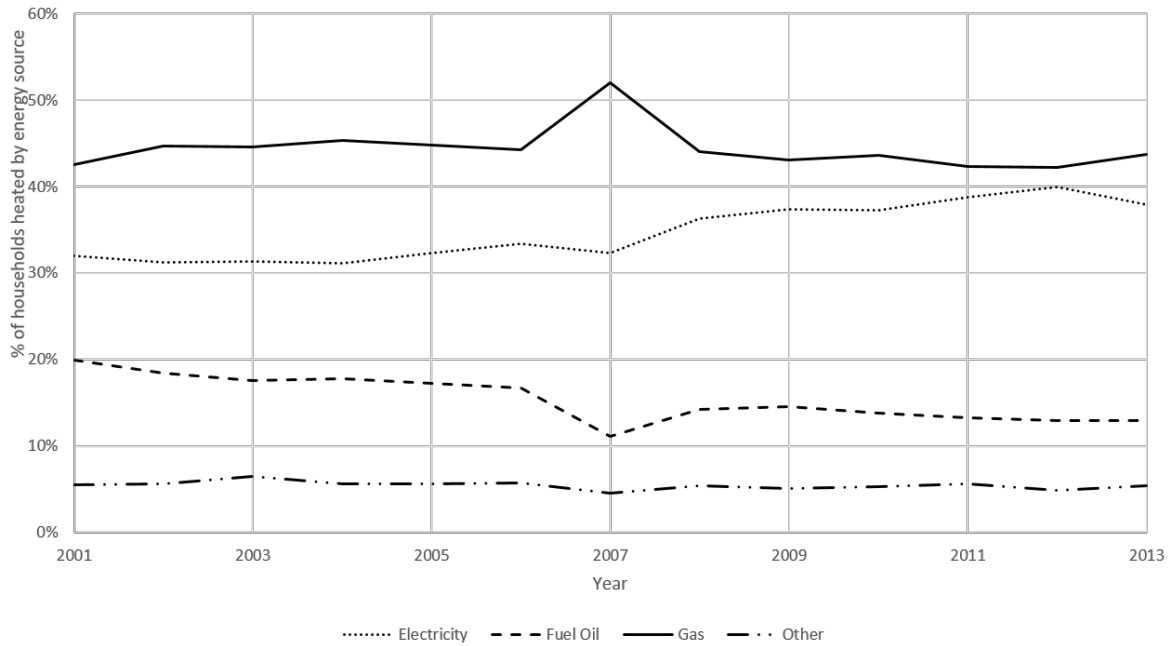
9 Panel survey descriptives

FIGURE A1.1 – Energy retail prices evolution between 2000 and 2013 for the main energy sources



Notes : Te graph displays the relative evolution of electricity, gas and fuel-oil prices, during our studied period with the year 2000 as a reference.

FIGURE A1.2 – Percentage of households by main heating energy source each year



Notes : The graph displays the evolution of the share of households heated by different energy vectors in our dataset. The main heating-fuels have remained sensibly stable even though households might have switched from fuel-oil shares decrease by 7% in 13 years and electricity shares increase by 7%.

FIGURE A1.3 – Share of households having energy retrofit by the time since move-in in years

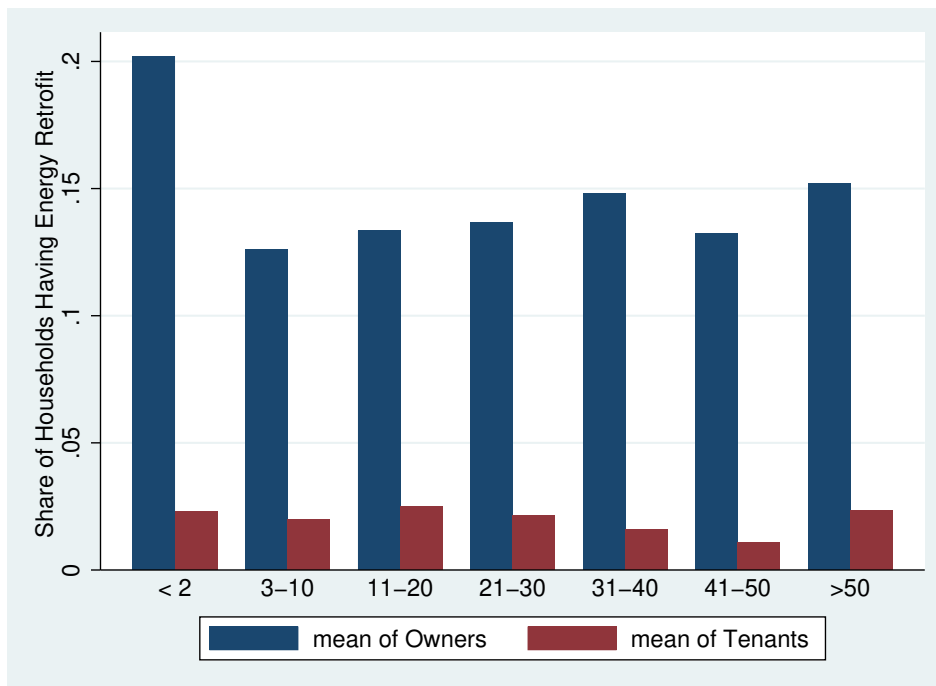
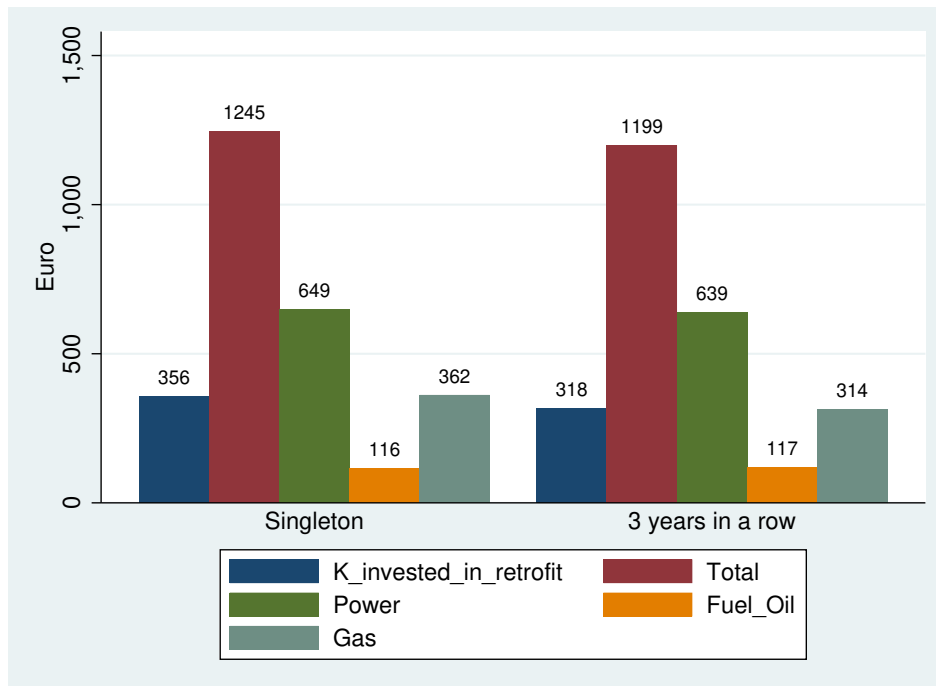
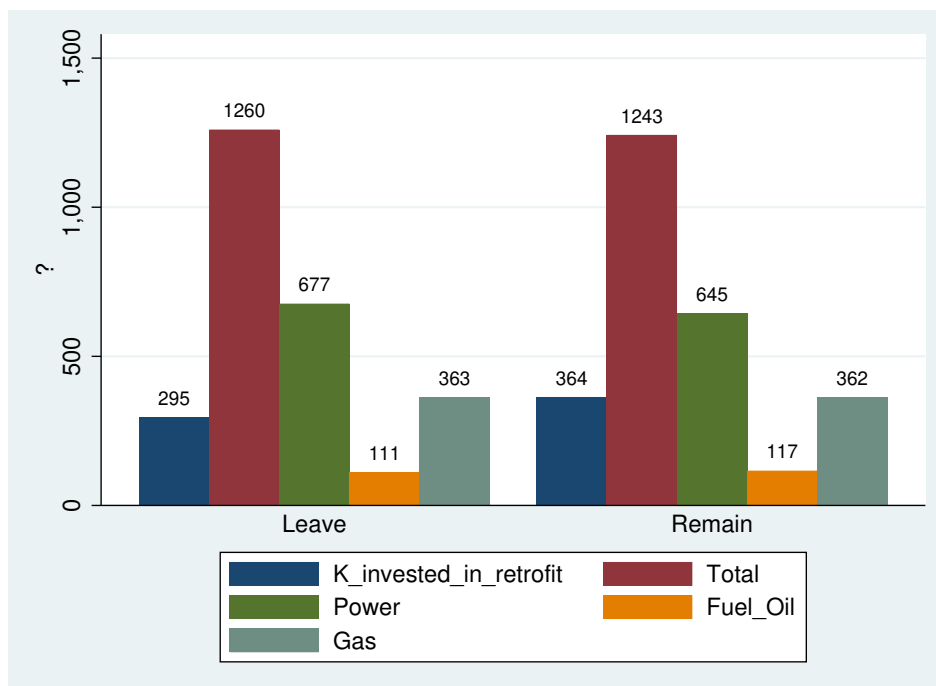


FIGURE A1.4 – Statistics according to be three years in a row in the survey



Notes : The graph displays, in EUR, the energy expenditures and the average energy investment of households considering if they were only one year in the panel or remained at least 3 years. There is no sensible difference between these values. That suggests our panel restriction does not bias our estimation.

FIGURE A1.5 – Statistics according to leave or remain in the panel



Notes : The graph displays, in EUR, the energy expenditures and the average energy investment of households considering if stay or remain in the panel. There is no sensible difference between these values. That suggests our panel restriction does not bias our estimation.

TABLE A1.6 – Households’ energy retrofit operations characteristics.

Operation Name	# operations achieved	Total capital invested [EUR]	Average capital per operation [EUR]	% of total capital invested in retrofit
In Wall Insulation	51	34,003 EUR	667 EUR	1.21%
Out Wall Insulation	19	111,987 EUR	5,894 EUR	4.00%
Roof Insulation	124	313,518 EUR	2,528 EUR	11.20%
Ceiling Insulation	21	17,822 EUR	849 EUR	0.64%
Floor insulation	14	18,839 EUR	1,353 EUR	0.68%
Sealing	12	2,019 EUR	168 EUR	0.07%
Windows replacement	226	1,007,085 EUR	4,456 EUR	35.98%
Windows replacement + double glazing	21	64,890 EUR	3,090 EUR	2.32%
Double glazing	17	37,831 EUR	2,225 EUR	1.35%
Shutter replacement	111	266,876 EUR	2,404 EUR	9.54%
Pipe Insulation	15	10,693 EUR	713 EUR	0.38%
New heat boiler	138	452,194 EUR	3,277 EUR	16.16%
Burner	4	2,652 EUR	663 EUR	0.09%
Closed fireplace	26	87,697 EUR	3,373 EUR	3.13%
Thermostat	13	2,508 EUR	193 EUR	0.09%
Heating programmer	13	4,131 EUR	318 EUR	0.15%
Dispatchers	2	2,850 EUR	1,425 EUR	0.10%
Radiators	62	154,769 EUR	2,496 EUR	5.53%
Thermostatic valve	6	3,770 EUR	628 EUR	0.13%
Ventilation	13	6,079 EUR	468 EUR	0.22%
HP	33	196,372 EUR	5,951 EUR	7.02%

10 French macro data

TABLE A1.7 – Residential energy consumed by source in 2018 and associated carbon footprint in France

Energy Source	Energy consumed [TWh]	Energy carbon footprint [kg/MWh]	2018 carbon footprint [MtCO ₂]	Average energy carbon footprint [kgCO ₂ /MWh]
Electricity	143.0	147	21.0	
Of which Heat Pump	5,2	0	0	
Natural Gas	144.8	227	32.9	
Fuel oil	43.3	324	14.0	
LPG	8.7	272	2.4	
Urban heating network	17.7	100	1.8	
Coal	2.8	387	1.1	
Wood	82.8	29,5	2.4	
Heat pump	10.4	0	0	
Total	439.0		75.6	0.172

Chapitre 3

Distributional Impacts of Energy Efficiency Obligations : An Ex-Post Analysis of the French Program

Résumé

Nous évaluons les effets d'une réforme du dispositif des Certificats d'Economie d'Energie, mise en place entre 2016 et 2018, pour que la politique bénéficie aux ménages les plus précaires. En utilisant des données agrégées, nous estimons la répartition des coûts et des bénéfices induits par le dispositif par classe de revenus en 2019. Nos résultats montrent que la politique a généré des effets progressifs. En moyenne, les ménages du 1er quartile ont reçu un bénéfice net de 100 € par foyer, alors que les ménages les 50% les plus riches ont payé un coût de 26 €. Cependant, étant donné l'instrument utilisé pour atteindre ces objectifs, qui fournit des certificats bonus pour les rénovations de logements occupés par des ménages précaires, le dispositif pourrait redevenir régressif à moyen terme. Nous expliquons pourquoi et proposons des implications pour le design des politiques publiques de type CEE.

Abstract

We assess the distributional effects of the French energy efficiency obligations on households. More specifically, we consider the impact of a reform implemented over the period 2016-2018 which aimed at increasing the program's contribution to fuel poverty alleviation. Using aggregated data, we estimate the distribution of costs and benefits between different income groups in 2019. We find the program managed to be progressive. On average, households from the bottom 25% of incomes distribution received a net benefit of EUR 100 per household, taking into account the subsidies received and the increase in energy prices induced by the program, while households from the top 50 % experienced a net cost of EUR 26. However, we argue that, given the instrument used for achieving this result – awarding bonus certificates to retrofits of dwellings occupied by poor households – the program is now likely to have opposite effects. We explain why and derive policy implications for the design of energy efficiency obligations.

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1 Introduction

Since 2012, the Energy Efficiency Directive (2012/27/EU) and its amended version (2018/2002) have set binding energy savings targets for European Union Member States, implying a 33% reduction in their 2007 energy consumption by 2030. In order to achieve this goal, the directive strongly advocates the implementation of energy efficiency obligations (EEOs). The instrument has been adopted by fifteen Member States, including France, Italy, Spain and Poland, and by the United Kingdom (Broc, Stańczyk et Reidlinger 2020). EEOs require obligated parties, usually energy suppliers of electricity, gas, and gasoline, or distribution system operators, to deliver a set amount of energy savings. They are expected to achieve this by encouraging energy consumers to invest in energy efficiency by granting subsidies. For each type of retrofit operation, the regulator delivers an amount of certificates reflecting the amount of energy savings realized. These certificates are then used by obligated parties to justify compliance with their obligation. They can also be traded, like in France, in which case they are referred to as white certificates and have a market price.

Energy efficiency obligations potentially raise social equity concerns. The reason is that wealthier households face laxer liquidity constraints and are thus more likely to invest in energy retrofit and receive subsidies. In parallel, the energy suppliers pass the costs of complying to the obligation through to consumers by increasing energy prices, which affects all households. This could lead to a situation where low-income households fund indirectly the energy retrofit investments made by high-income ones (Rosenow, Platt et Flanagan 2013 ; Cayla et Osso 2013). Moreover, because of the cost pass-through, EEOs mimic an energy tax which tends to be regressive (Douenne 2020 ; Berry 2019). Energy efficiency obligations may therefore amplify fuel poverty and economic inequalities. The problem is potentially serious, as the financial flows involved are significant. For instance, the French CEE program (for *Certificats d'Economie d'Energie*), provides nearly 4 billion euros in subsidies per year, including 2.5 billion euros for the residential sector only¹, and increases energy prices by 3 to 4%.

In order to limit those potential detrimental distributional impacts, several EU countries have introduced provisions to target low-income or fuel-poor households (Broc, Stańczyk et Reidlinger 2020). These measures fall into two categories : a sub-obligation whereby energy suppliers are required to achieve a share of energy savings in dwellings occupied by fuel-poor households or a bonus system which rewards obligated parties with additional certificates when they support investments in such dwellings.

This paper focuses on the French CEE program which was launched in 2006 and works in period of 4 years. Between 2016 and 2018, the French government has gradually implemented both types of measures : a sub-obligation, called "Précarité" and a bonus system. The primary objective of this paper is to study the distributional impacts of this reform. In a first step, we estimate the distribution of its costs and benefits across different income groups in 2019. The analysis takes into account a wide range of effects : its impact on energy prices, on energy consumption, and the type of energy retrofit works subsidized. We find that the measures have

1. authors' calculations see below

been successful in the short term. On average, households from the bottom 25% of incomes distribution received a net benefit of EUR 100 per household, taking into account the subsidies received and the increase in energy prices induced by the program, while households from the top 50% experienced a net cost of EUR 26. This pattern is not qualitatively changed when accounting for the long-term energy savings from the retrofit investments.

In a second step, we show that this success has been only temporary. Although they fostered low-income households' investments, bonuses had a detrimental side-effect : they reduced the scheme's global efficiency (Glachant et Kahn 2021). Therefore, from the 5th period, started in January, 2022 bonuses have been almost fully cancelled and the sub-obligation has become the only mechanism targeting low-income households. However, taking advantages of the bonus system, obligated parties have banked² quantities of "Précarité" certificates during the 2018-2021 period. As a result, obligated parties had already met a large part of their 5th period "Précarité" sub-obligation even before it has begun. By investigating the microeconomic properties of the policy reform, we show that the problem lies in the design of the bonus system. We derive policy implications for the design of energy efficiency obligations.

The literature examining the efficiency of energy efficiency obligations is well-developed (Quirion et Giraudet 2011 ; Giraudet, Bodineau et Finon 2012 ; Rosenow et Bayer 2017 ; Rosenow et al. 2020 ; Osso, Nösperger et Laurent 2019 ; Di Santo et Chicchis 2019 ; Giraudet, Glachant et Nicolai 2020). In contrast, the distributional impacts of energy efficiency obligations have received much less attention.

Our contribution to the literature is to provide the first quantitative estimates of the distributional impacts of an energy efficiency obligations program, the French "*Certificats d'Economie d'Energie*" (CEE), which is the largest energy efficiency obligations program in Europe (Broc, Stańczyk et Reidlinger 2020). We are not aware of any other comparable works on other programs. Rosenow, Platt et Flanagan (2013) examine the distributional effects of British energy efficiency obligations. Their question is similar to ours, but their evaluation rests upon a theoretical description of the structural risk inherent to energy efficiency obligations regarding social justice. They also provide a critical review of reports from the grey literature. Bourgeois, Giraudet et Quirion (2021) quantify distributional effects of French energy efficiency policies, but the scope differs –they analyze a policy mix including multiple policies, among which energy efficiency obligations –and they adopt a modelling top-down approach, whereas our analysis is based on ex post simulations. ONRE (2021) examines the distribution of subsidized investments in the 2016-2019 period, and establishes they were equally distributed across income groups. We extend this evaluation by accounting for energy price variations and, since our focus is on year 2019, we take into account the last wave of reforms targeting low-income households.

We also contribute to the literature by relating these distributional outcomes to the design of the social equity measures. The French case illustrates the risks of combining a bonus system and a sub-obligation. Our policy recommendation is to simplify the program by removing the bonus system.

2. In the CEE program, certificates have a period + 1 lifetime, and then might be banked from one period to another.

The paper is organized as follows. The first section describes the CEE program, the second part presents the data and the method used. We present the results on the short-term impacts in a third section. We combine conceptual arguments with empirical observations to interpret what happened after 2019 and derive policy implications. The conclusion summarizes the main takeaways of the paper.

2 Background

2.1 The CEE program

In France, the "Certificat d'Economie d'Energie" obligations fall on suppliers of electricity, gas, and gasoline. Individual obligations are assigned in proportion to their sales, with differing coefficients depending on the fuel considered. By design, compliance with individual targets extensively relies on ex ante standardized savings : for any investment subsidized, obligated parties are granted by the regulator a pre-defined amount of energy savings certificates, quantified in MWhc,³ in exchange for a proof of implementation (e.g., invoice of insulation installation).

The calculation of the standardized amount of energy savings certificates for a given type of energy efficiency investment is described in so-called "CEE datasheet".⁴ This amount depends on the size of the project and the location of the dwelling. For instance, installing a high-efficiency boiler in Lille generates 47 certificates while insulating 20 square meters of roof generates 34 certificates. Sponsored investments are made in the residential, tertiary, and industry sectors⁵.

The policy works by four-years periods, each one having its own regulatory framework, but some rules can be changed within a period. The 5th period has started on January 1st, 2022. This paper focuses on the 4th period, and specifically on year 2019.

Obligated parties can also choose to delegate the fulfilment of their obligation to other stakeholders. They can also bank certificates because they have a period + 1 lifetime. Finally, obligated parties are allowed to trade energy savings certificates. Transactions are recorded on an online platform⁶. The market can be supplied by non-obligated parties, yet eligible to produce certificates, parties such as local communities. With 288 TWhc and 179 TWhc traded respectively in 2019 and 2018, trading represents a significant share of the 533 TWhc annual abatement target.

2.2 Social equity measures

Between 2016 and 2018, the French government has gradually adopted several provisions aiming at reducing fuel poverty. The reform of the program was gradually implemented in two stages. In 2016, the regulator set the so-called sub obligation "Précarité", requiring energy suppliers to obtain at least 25% of their certificates from subsidizing low-income households defined

3. MWhc stands for cumulative MegaWatt hour since the savings are cumulative and discounted on the whole lifetime of the technology.

4. all are [available here](#)

5. Agriculture and transport are also targeted but in a very marginal way.

6. www.emmy.fr

as those from the first and second income quartiles⁷. This sub obligation was supplemented by the “Grande Précarité Energétique” bonus system doubling the amount of certificates obtained from investments in dwellings occupied by households from the first income quartile. This design thus defines three income groups we will refer to as Q1, Q2, and Q3-4 in the following (see **Table 2.1**).

TABLE 2.1 – Social equity measures applying to the different household groups

Income Quartile	Sub-Obligation	Bonus
Q1	YES	YES
Q2	YES	NO
Q3 - Q4	NO	NO

In 2018, the bonus system was strengthened in two ways. First, the "Grande Précarité Energétique" bonus was extended to the households of the second quartile for five specific energy renovation operations (attic and floor insulation, installation of a biomass boiler, a gas boiler or a heat pump). Second, additional bonuses, namely the "Coups de Pouce", were introduced for these very same five operations. For example, the number of certificates issued for a floor insulation project was multiplied by a factor of 2.3 to 4 depending on the climate zone. This was a major adjustment of the program as these five operations accounted for more than 85% of the residential certificates generated in 2019. Although the "Coups de Pouce" apply to all income classes, their combination with the bonus "Grande Précarité Energétique" has increased the level of subsidies offered to first and second quartiles households to reach the full coverage of the investment cost leading to the flourishing of "1€ operations".

3 Methodology and data sources

3.1 Indicators

We assess the distributional impacts of the CEE program with two indicators. The first one is the size of the direct financial flows induced by the program, that is, how much each household pays through the increase in its energy bill and which amount of subsidies it receives when investing in energy retrofit. We call it the direct effect :

$$\text{Direct Effect} = G - B \tag{3.1}$$

7. We classify the households by income group although the actual classification also takes into account their geographical location. The quartile distribution is however a good proxy for identifying the relevant groups.

where G represents the amount of subsidies received and B the increase in the energy bill.

The second indicator captures the complete financial flows induced by the program. In addition to the direct flows included in the first indicator, it takes into account the investment cost of energy retrofit and the related cumulative energy savings in euro. We call it the full effect :

$$\text{Full effect} = -I + S + G - B \quad (3.2)$$

where I is the investment in energy retrofit and B the discounted amount of energy savings achieved over the lifetime of the investment.

3.2 Data sources

We use many data sources to calculate the direct and full effects. They are listed in **Table 2.2** and described extensively in the following subsections.

TABLE 2.2 – Data sources

Variables	Data	Sources
Amount of subsidy ^a	# certificates delivered	GDEC (2020)
	Unit subsidy per certificate	Webscrapping on commercial websites
Energy price variations ^b	Sales to obligations coefficient	GDEC (2017)
	CEE production cost	CEE market
Impact on energy bill ^c	Demand elasticities	Douenne (2020)
	Energy use	Enquête Budget de Famille
	Energy prices	PEGASE
Investment	Amount per income group & works	ONRE (2021) & ADEME (2018)
Energy Savings	Amount per income group & works	ONRE (2021) & ADEME (2020)

^a The method to calculate the average amount of subsidies is described in details in **Appendix 7.1**

^b The method to calculate the CEE program’s impact on energy prices is described in details in **Appendix 7.2**

^c The method to calculate the CEE program’s impact on energy expenditures is described in details in **Appendix 7.3**

3.3 Subsidies granted

We estimate the volume of subsidies and their distribution among the different income groups in two steps. First, using data from the French Ministry of Ecological Transition, we compute the amount of certificates delivered to the three household groups. For sake of simplicity, we restrict the analysis to the certificates obtained from six retrofit operations : attic, wall and floor insulation, installation of a biomass boiler, a gas boiler or a heat pump, a mild restriction as these operations represent around 90% of the CEE-sponsored retrofit works in the residential sector. Second, we use data on retrofit commercial websites in order to assess on the level of subsidies granted for the different retrofit operations.⁸ This investigation shows that the subsidy

8. We thank Pille-Riin Aja and Louis-Gaëtan Giraudet for providing us with a sample of web scraped data on the CEE premia offered by obligated parties

offered for a given type of energy retrofit is proportional to the number of certificates it generates and the subsidy per certificate is remarkably uniform across the different types of operations. Multiplying the average subsidy per certificate, which is equal to EUR 5.6, to the number of certificates, we estimate that the program granted EUR 1.0 billion to the Q1 households, EUR 0.7 billion to Q2 ones, and EUR 0.8 billion to Q3-4 households. Keeping in mind that the Q3-4 group is twice as large as Q1 or Q2, these figures mean that the average Q1 household received more than twice as much subsidy as that of Q3-4.

3.4 Energy bill increases

To start with, we estimate the impact on energy prices. The CEE regulatory framework provides, for each type of energy retailer, a coefficient that gives its obligation by linking each MWh sold to a number of certificates (GDEC 2017). From this document we can calculate the program's price impact, assuming an average production cost of EUR 9 per certificate, which is the certificate's market price in 2019 (EUR 8) plus one euro of administrative fee, and a 100% pass-through.⁹ The corresponding fuel prices variations are presented in **Table 2.3** for each energy vector.

TABLE 2.3 – Fuel prices per MWh and the price increase generated by the CEE

	Average fuel price [€/MWh]	CEE effect [€/MWh]	CEE effect [%]
Power	178	5.62	3.16 %
Gas	82	3.78	4.61 %
Fuel oil	178	3.72	4.00 %
Car fuel	156	5.18	3.32 %

Notes : The average price includes the fixed and the variable part.

To estimate the effect of this price increase on energy bills, it is necessary to know the energy consumption by fuel type. The INSEE's "Enquête Budget de Famille"¹⁰ provides data on household energy expenditure by income group and fuel type. By matching this data with the price data of **Table 2.3**, we are able to calculate the energy consumption in MWh per household for each fuel and for each income group.

Moreover, we take into account the fact that this price increase leads households to reduce their energy consumption. The price elasticities of energy consumption by income groups needed to calculate the magnitude of this adjustment are taken from Douenne (2020) (See **Table A2.5** in **Appendix 8** for more information.). **Table 2.4** gives the resulting CEE-induced increase on energy expenditures for the different fuels and income groups.

9. This assumption comes from informal talks with obligated parties.

10. [available here](#)

TABLE 2.4 – Impact of the CEE on energy bills in 2019 per household, by energy vector and by income group

	Q1	Q2	Q3-4	Average
Power	+17 €	+20 €	+26 €	+22 €
Gas	+10 €	+12 €	+16 €	+14 €
Fuel Oil	+4 €	+5 €	+5 €	+5 €
Car Fuel	+13 €	+20 €	+30 €	+23 €
Total	+45 €	+59 €	+80 €	+66 €

Notes : These estimates take into account the increase in fuel prices and its short-term impact on the level of energy consumption, but not the long-term impact of retrofits on energy consumption.

3.5 Investment cost and energy savings

The average investment costs for the six types of energy retrofits by household income group are extracted from two reports published by the energy retrofit observatory ("Observatoire de la Rénovation Énergétique") (ONRE 2021) and by ADEME (2020).¹¹

Estimating the actual energy savings achieved through the CEE program is difficult (for a discussion, see Glachant, Kahn et Lévêque (2020b)). In this paper, we use the estimation performed by the French Energy Retrofit Observatory in 2021 (ONRE 2021). It provides the energy savings for several types of retrofits, including the six ones covered in our analysis. The energy savings are cumulative and discounted across the lifetime of the technology at a 4% rate, the value used by the regulator in CEE "datasheets".

4 Results

4.1 Direct distributional effects

As a reminder, the direct effects take into account the financial flows directly induced by the CEE as defined in equation (1) : the subsidies received and the increase in energy bill. **Table 2.5** presents the results of the simulations. In the aggregate, the program is globally beneficial for the residential sector : the average household receives a net benefit of EUR 20, which corresponds to EUR 600 million for the whole population. A possible explanation for this positive result lies in the fact the tertiary sector, which also faces the CEE-induced energy prices increase, might pay for the residential energy retrofit. Besides, obligated parties took the opportunity of energy efficiency actions made cheaper in the residential sector by bonus system to get more certificates in 2019.

11. See **Table A2.2** and **7.3** in **Appendix 8**.

Note also that this overall effect would have been negative if the households did not reduce their energy use in response to the CEE impact on energy prices (see **Table A2.8** in **Appendix 8**). This means that the positive monetary impact of the CEE described in **Table 2.5** is associated with less energy usage, and therefore with possible comfort losses.

The most important result is the financial transfer from high-income households to low-income and very-low-income households. The average Q1 and Q2 households receive respectively EUR 100 and EUR 31. Conversely, the households of the third and fourth quartiles are net contributors.

TABLE 2.5 – Direct distributional effect of the CEE in 2019

	Grants [M€]	Expenditures increase [M€]	Total [M€]	Per households [€/hh]
Q1	1,000 M€	- 300 M€	700 M€	100 €
Q2	700 M€	- 450 M€	250 M€	31 €
Q3-4	800 M€	-1,200 M€	- 400 M€	-26 €
Total	2,500 M€	- 1,950 M€	600 M€	20 €

4.2 Full distributional effects

In order to estimate the full effect of the program as defined in Equation (2), we now add the investment cost of energy retrofit and the cumulative discounted energy savings achieved. **Table 2.6** presents the results for the different household groups.

The message drawn from the evaluation of the direct effects survives. Q1 households are net winners while others lose. The surplus difference between Q1 and Q3-4 remains roughly the same as that of **Table 2.5**, around EUR 120. The positive impact on disposable income is not negligible as the net benefit for Q1 households corresponds to 0.22% of their income.

TABLE 2.6 – Full distributional effect of the CEE in 2019

	With energy retrofit	Without energy retrofit	All	Percentage of income
Q1	1,650 €	- 42 €	50 €	+0,22 %
Q2	1,550 €	- 63 €	- 11 €	-0,03 %
Q3-4	350 €	- 83 €	- 70 €	-0,10 %
All	1,100 €	- 67 €	- 21 €	-0,04 %

Our simulations ignore the comfort gains associated with energy retrofit. We can reasonably assume that their inclusion would not alter the general message, as they are presumably higher for low-income households because they often take advantage of energy retrofit to improve their home temperature rather than to reduce their expenditures.

4.3 Robustness checks

The results on the full effects are probably less robust than the estimation of the direct effects as they rely on more hypotheses. The estimation of the energy savings realized is a first concern, as mentioned above. Two additional assumptions could be challenged : the uniform value of the discount rate, and the systematic additionality of the subsidy (i.e., all households would not invest without this support). We now investigate how the results of **Table 2.6** are robust to these hypotheses.

Differentiated discount rate

The discount rate is likely to depend on income. Low-income households discount more as they tend to have liquidity problems which impede investment (Sutherland 1991 ; Arnould et Jaeger 1991). To explore how this could affect the results, we run additional simulations with differentiated discount rates. We consider discount rates of 6, 4, and 2% for Q1, Q2 and Q3-4 households respectively. **Table A2.6** in **Appendix 8** provides the full effect with this new assumption. The results sensibly change : the gap between Q1 and Q3-Q4 becomes narrower although low-income households still derive a positive benefit from the CEE program. This however does alter qualitatively the general message.

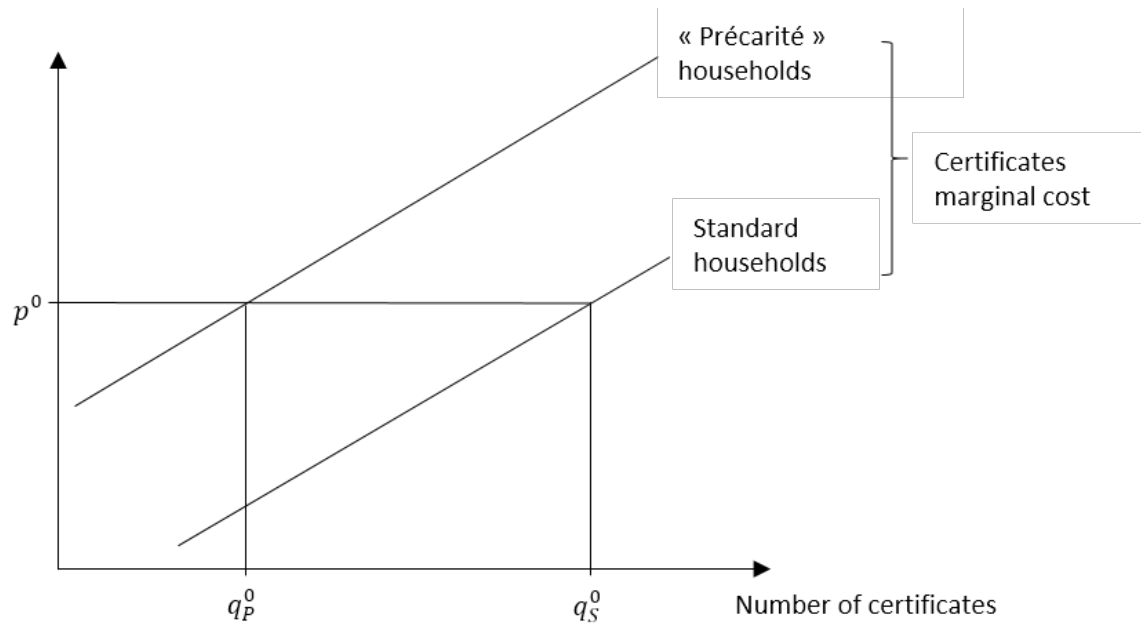
Inframarginal energy retrofits

A recent study by the environmental agency points out that 11% of CEE-sponsored retrofit works would be inframarginal, i.e. they would have been implemented in the absence of CEE financial support (Bertrand et al. 2020). The lack of data at the income group level precludes a full-fledged analysis. As a robustness check, we can however take the conservative assumption that these 11% only concern Q3-4 households. **Table A2.7** in **Appendix 8** presents the revised simulation results under this assumption. This does not modify our conclusions : the CEE still induces a transfer from the richest households to the poorest households.

5 Dynamic analysis

The analysis in the previous sections yields a snapshot on the distributional impacts of the CEE program in 2019. We now examine what happened in the following years and the related consequences on the CEE contribution to fuel poverty alleviation.

Taking into account the dynamics is necessary because the obligation covers several years. More precisely, the program operates by period at the end of which the regulator checks whether the volume of certificates held by an obligated party meets its obligation. If any, the certificates

FIGURE 2.1 – The CEE market equilibrium with an obligation of $q_P^0 + q_S^0$ 

in excess at the end of the period can be transferred to meet the obligation of the subsequent period.

These features are essential because the bonuses-induced rush towards certificates "Précarité" in 2019 may have potentially reduced their subsequent production and thus the positive impact of the reform on low-income households. In order to examine these issues, we first develop a simple conceptual framework which describes the interactions between the bonus system and the sub-obligation "Précarité". We then confront its implications to the facts observed over the period 2019-2022.

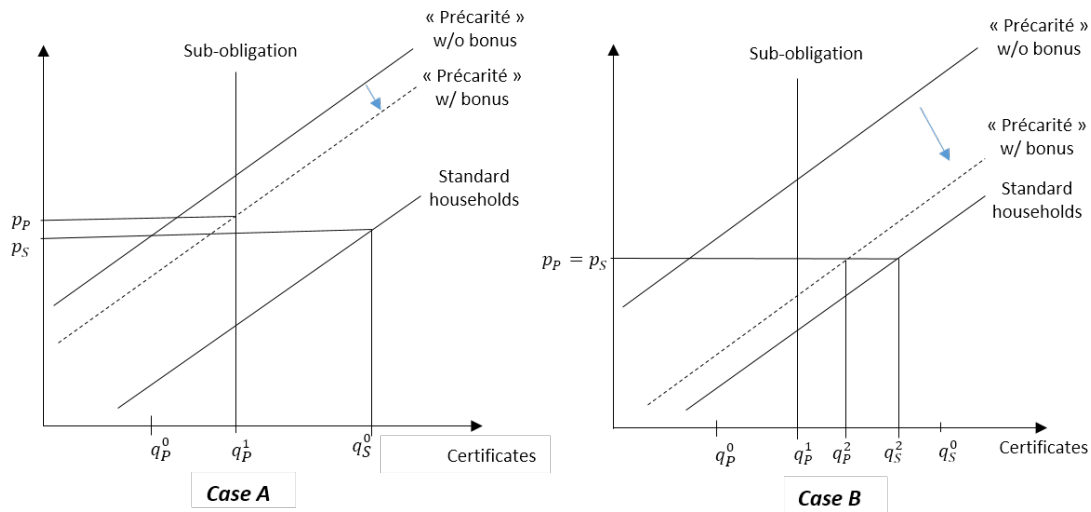
5.1 The conceptual framework

Figure 2.1 shows the CEE program's market equilibrium without any social equity provision, i.e., before the 2016-2018 reform. We make the realistic assumption that the marginal cost of producing a certificate is higher when subsidizing retrofit works in dwellings occupied by low-income households that will be eligible to the sub-obligation "Précarité"¹². In this context, the number of certificates produced from subsidizing low- and high-income households is respectively equal to q_P^0 and q_S^0 when the overall obligation is $q_P^0 + q_S^0$. Given this objective, the (unique) price that emerges on the CEE market is p^0 . The role of a sub-obligation or a bonus system is to increase the number of certificates obtained by subsidizing low-income households beyond q_P^0 .

Let us now introduce the policy mix including a sub-obligation q_P^1 , with $q_P^1 > q_P^0$ and a bonus system, reducing the marginal production cost of a certificate "Précarité". **Figure 2.2** displays how this combination influences the market equilibrium in two cases. In Case A, the

12. Otherwise, sub-obligations or bonuses would be useless : it would be advantageous for obligated parties to target low-income households anyway.

FIGURE 2.2 – The market equilibrium when we introduce a sub-obligation and a bonus system



bonus factor is relatively low, which leads to a market price of a certificate “Précarité” which remains higher than the price of a standard certificate ($p_S < p_P$).

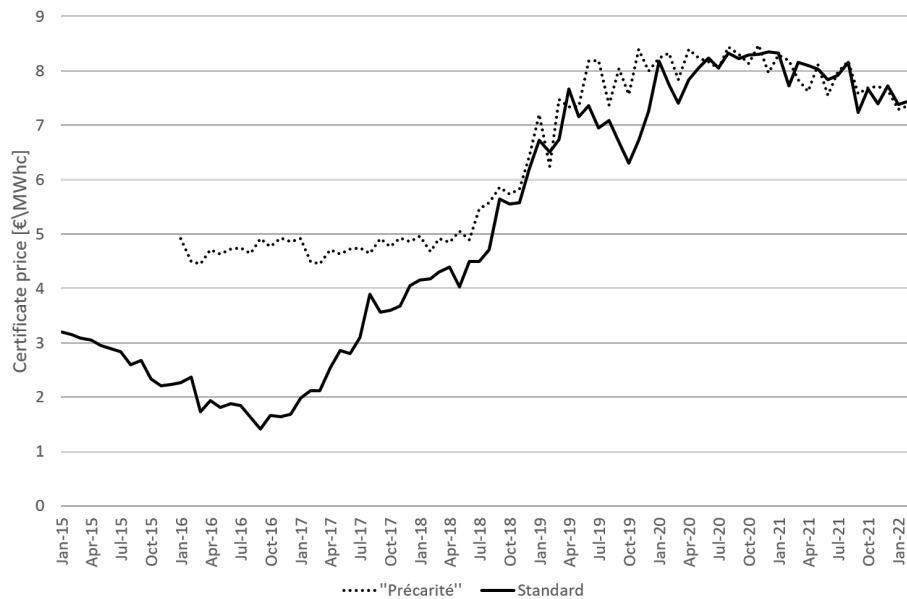
In Case B (right), the bonus factor is sufficiently high for the marginal production cost of a certificate "Précarité" at the sub-obligation level q_P^1 to fall below the price of a standard certificate, p_S . As certificates “Précarité” may be used to comply with the overall obligation, this leads obligated parties to produce more certificates than the sub-obligation, as long as their marginal production cost is below the standard certificate price p_S . At the equilibrium, the price of both types of certificates are equal and energy suppliers produce a higher quantity of certificates "Précarité" than their sub-obligation ($q_P^2 > q_P^1$). This overproduction offsets the reduction of the quantity of standard certificates.

Three messages stem from this theoretical analysis :

- Combing two instruments to mitigate fuel poverty is useless, the outcome would be the same with a single instrument.
- Bonus mechanisms reduce the energy integrity of the program by generating uplifts certificates rewarding no additional savings. Thereby, they *de facto* limit the actual level of the obligations and the compliance cost for obligated parties.
- Whereas an obligation directly sets the amount of investments, the bonus system sets a price signal encouraging obligated parties to subsidize more investments in a certain sub-category of households.¹³ The volume of investments thus depend on how the obligated parties react to this signal. Given its partial information on the expected costs of producing certificates, the regulator cannot predict this response. As a result, a bonus system might jeopardize the policy’s governance.

13. This echoes a general discussion in environmental economics on the relative merits of price-based versus quantity-based policy instruments initiated by **empty citationempty citation**

FIGURE 2.3 – Evolution of certificate prices between 2016 and 2022



5.2 The CEE program since 2019

We can reasonably wonder which of the 2 cases presented in **Figure 2.2** corresponds to the state of the CEE program since 2019. The data clearly fit with Case B. As shown by **Figure 2.3**, we observe a convergence of the price of standard and "Précarité" certificates. They are now roughly equal since January 2019.

The observation of certificate quantities provides a second piece of evidence. On December 31st, 2021, the end of the compliance period 2018-2021, obligated parties had generated 1.6 times more certificates "Précarité" than their sub-obligation ($q_P^2 > q_P^1$). In the same period, 46% of the delivered certificates were "Précarité" (GDEC 2020).

These facts suggest that the distributional effects we estimated in the previous section might be temporary. The key point here is that these certificates "Précarité" delivered in 2019 (and subsequent years) will be used in the compliance period 2022-2025. The available stock of excess certificates represents 40% of the 2022-2025 sub-obligation "Précarité". If this obligation is not adjusted upward, the distributional impact is clear : much less investments (and subsidies) for low-income households.

At the end of 2021, the regulator took two decisions. First, the bonus system has been drastically downsized, restricting the "Coups de pouce" to so-called deep retrofits (that is, one-shot investments combining several retrofit measures). Second, new stricter obligation and sub-obligation have been set.

In principle, these adjustments are in line with what we would recommend. The sub obligation is now the reference instrument for mitigating fuel poverty. We saw above that a single instrument – either the bonus system or a sub obligation – was sufficient. In this perspective, keeping the sub obligation seems to be the best choice. The bonus system has indeed several drawbacks.

First, it has distorted the energy efficiency market. By subsidizing selectively a subset of retrofit operations with bonus certificates, it has disconnected their value in certificates from their impact in terms of energy savings. It has thus led obligated parties or their subcontractors to prioritise these investments at the expense of the cost efficiency of the program.

Another weakness of a bonus system is the low predictability of its impact on the amount of investments, and thus on the number of certificates delivered. At the end of 2018 when the "Coups de Pouce" were launched, the regulator did not expect such a boom in the production of certificates "Précarité" leading to a huge stock of unused certificates at the end of the period. This underestimation of the amount of certificates "Précarité" still prevailed when the new obligation was defined at the end of 2021. It led the regulator to set an insufficient sub-obligation for the new period 2022-2025. The stock of certificates "Précarité" now represents 40% of this sub-obligation, reducing by almost one half the amount of energy savings to be achieved in low-income households' homes by 2025. The situation is sufficiently critical for all actors to anticipate a revision of the obligation before the end of the period. We are still paying for the mistake of having introduced a bonus system on top of the sub-obligation "Précarité".

6 Conclusion

This paper processes in two stages to analyse the distributional impacts of measures taken to reduce fuel poverty in France. First, relying on data for the year 2019, we run simulations which establish that the program induced a very significant transfer from high-income households to low-income households in that year.

Second, we develop a simple conceptual microeconomic framework in order to examine the relevance of the policy mix which led to this result and its subsequent impacts since 2019. Our analysis shows that combining two instruments to tackle fuel poverty – a bonus system and a sub-obligation – as observed in France is not necessary. Depending on their calibration, the key variables being the bonus factor and the level of the sub obligation, this analysis shows that the amount of investments made is fully determined by only one of these measures.

The observation of the certificate prices and the quantities of certificates "Précarité" delivered in this period reveals that the outcome observed in 2019 was entirely driven by the bonus system, i.e., the same outcome would have been observed in the absence of the sub-obligation "Précarité". The problem is that this boom in the production of certificates "Précarité" in the 2019-2021 period has created a stock of certificates usable in the new period that will reduce the program contribution to fuel poverty alleviation by crowding out investments in dwellings occupied by low-income households.

This stock of certificates corresponds to 40% of the sub obligation "Précarité" for the period 2022-2025. This magnitude reveals that the regulator under-estimated the stock's size when setting the new sub obligation. This highlights a generic weakness of bonus systems. Unlike an obligation which directly sets the amount of investments, the bonus system sets a price signal providing obliged parties with incentives to subsidize more investments. The volume of investments thus depend on how the obligated parties react to this signal. Given its partial

information on the expected costs of producing certificates, the regulator cannot predict this response. With a bonus system, ex-post surprises are inevitable.

In addition, beyond the issue of fuel poverty, the bonus system has distorted the energy efficiency market. By selectively subsidizing a subset of retrofit measures with bonus certificates, it has disconnected the value of individual investments in certificates from their impact in terms of energy savings. It has thus led obligated parties or their subcontractors to prioritise these investments at the detriment of the cost efficiency of the program.

The French example shows how combining a bonus system and a sub obligation in energy savings obligations programs to reduce fuel poverty is hazardous. The policy recommendation is clear : if one seeks to secure a given amount of investments in dwellings occupied by low-income households, the sub-obligation is the right instrument.

A general open question is the relevance of using energy efficiency obligations to reduce energy poverty. At the end of this analysis, we try to identify the best way to improve the impact of the CEE program on fuel poverty. But the solution may lie elsewhere. The program coexists with more traditional government grants ("MaPrimeRenov"). It may be preferable that energy poverty objectives fall under this other public policy. The answer to this question is left to future research. It is also important to note that we equate fuel poverty to the level of income as done by the CEE policy. However, fuel poverty describes a much broader phenomenon, that does not only depend on household's income.

7 Detailed indicators estimation

7.1 CEE grants

Since 2016, the French Ministry of Ecological Transition has published monthly “information letters”¹⁴ giving precise information on the certificates delivered. More specifically, it provides their distribution across certificates "Précarité" and standard certificates, and the share of each type of retrofit work in the total. For the “Coups de Pouce” operations, the letters even detail the percentage of the certificates "Précarité" that were generated from Q1 households, and the percentage from Q2 households. Those operations represent 85 % of the residential certificates in 2019. To distribute the 15 % rest we had to make assumptions¹⁵. We mostly use the January 2020 information letter, which gives statistics on the certificates delivered during year 2019 by type of retrofit work and by category of household. We then use web-scraping on several energy retrofit commercial websites in order to know the average grant given to households per certificate. We find that the average grant is EUR 5.6 per certificate. All in all, we estimate that the program granted EUR 2.5 billion to households in 2019 : EUR 1.0 billion for Q1, EUR 0.7 billion for Q2, and EUR 0.8 billion for Q3-4.

7.2 CEE impact on energy prices

The CEE impact on energy prices is directly linked to the definition of the obligation, and how costly it is for obligated parties to generate certificates. The official obligation is given by the Ministry of Ecological Transition, which associates to each energy vector a number of certificates to obtain for each MWh sold (GDEC 2017). In 2019, the CEE price in the market was EUR 9 per certificate. Using this information, we can define the CEE price effect in EUR/MWh for each energy vector (Table 3).

7.3 CEE impact on the households’ energy bill

The program’s impact on the households’ energy bill depends on three elements : its impact on energy prices, the distribution of the different energy vectors in the households’ energy consumption, and the households’ price elasticity for residential energy consumption. In order to know the energy expenditures for each category of household, we use the "Enquête Budget de Famille" (Insee) which gives the average expenditures of French households by energy vector (including transport) and by income decile. We transform these expenditures in households’ energy consumption using the PEGASE database, which provides monthly prices for all energy vectors in France. Finally, we assess the yearly impact of the CEE on the households’ total energy expenditures. We use data on households’ price elasticity by income group from Douenne (2020) in order to evaluate the effect of the CEE-induced increase in energy prices on energy consumption (see Table A2.5). The yearly impact on the energy bill by income group is given in Table 4.

14. [Available here](#)

15. Actually, these 15% are mainly represented by walls insulation. Table A2.2 presents the number of wall operation we assumed for each quartile in 2019

8 Data

8.1 Living Space Area

TABLE A2.1 – Living Space Area

	Retrofit [m ²]	Non Retrofit [m ²]
Q1	100 m ²	76 m ²
Q2	107 m ²	85 m ²
Q3-4	120 m ²	101 m ²

8.1.1 Number of retrofit, by income group and investment category

TABLE A2.2 – Numbers of retrofit

	Attic	Floor	Walls	Biomass	Gas	Heat pump
Q3-4	162,000	50,100	37,000	2,900	105,000	61,000
Q2	162,000	75,000	11,000	800	21,000	21,000
Q1	217,000	50,000	67,000	1,200	33,000	26,000

8.1.2 Retrofit Cost

TABLE A2.3 – Average retrofit Cost, by investment category

	Attic	Floor	Walls	Biomass	Gas	HP
Q3-4	3,837 €	3,600 €	10,800 €	6,500 €	5,000 €	12,500 €
Q2	3,422 €	3,230 €	9,600 €	6,000 €	4,750 €	11,700 €
Q1	3,200 €	3,000 €	8,000 €	5,500 €	4,500 €	11,300 €

8.1.3 Energy Savings

TABLE A2.4 – Annual energy savings, by income group and investment category

	Attic	Floor	Wall	Biomass	Gas	Heat pump
Q3-4	195 €	180 €	460 €	350 €	325 €	732 €
Q2	175 €	160 €	440 €	310 €	273 €	683 €
Q1	160 €	146 €	420 €	290 €	255 €	638 €

8.1.4 Energy Price Elasticity

TABLE A2.5 – Price Elasticities, by income group

	Q1	Q2	Q3-4
Transport	- 0.53	- 0.50	- 0.41
Residential	- 0.28	- 0.24	- 0.20

Source : Douenne (2020)

8.2 Robustness Checks

TABLE A2.6 – Full distributional effects of the CEE with differentiated discount rates

	Retrofit [€/hh]	Non Retrofit [€/hh]	Total [€/hh]	Total [% income]
Q1	774 €	- 42 €	1 €	+0,01 %
Q2	1,550 €	- 63 €	- 11 €	-0,03 %
Q3-4	1,938 €	- 83 €	- 27 €	-0,04 %
Total	1,567 €	- 67 €	- 16 €	-0,03 %

TABLE A2.7 – Full distributional effects of the CEE taking into inframarginal energy retrofits

	Retrofit [€/hh]	Non Retrofit [€/hh]	Total [€/hh]	Total [% income]
Q1	1,650 €	- 83 €	50 €	0.22 %
Q2	1,550 €	- 63 €	- 11 €	-0.03 %
Q3-4	950 €	- 42 €	- 57 €	-0.09 %
Total	1,350 €	- 58 €	- 19 €	-0.11 %

TABLE A2.8 – Direct distributional effects of the CEE with zero demand elasticity

	Subsidies	Energy bill increase	Total	Per household
Q1	1,000 M€	- 500 M€	500 M€	75 €/hh
Q2	700 M€	- 750 M€	- 25 M€	- 5 €/hh
Q3-4	800 M€	-1,700 M€	- 900 M€	- 165 €/hh
Total	2,500 M€	- 2,950 M€	- 425 M€	- 15 €/hh

Chapitre 4

Making Jobs out of the Energy Transition : Evidence from the French Energy Efficiency Obligations Programme

Résumé

Les plans de relance post COVID-19 prévoient près de 1 000 milliards € de dépenses publiques dans la transition énergétique censées générer de la croissance et des emplois. Cependant, il n'existe que peu d'études empiriques sur l'effet des investissements verts sur l'emploi, en particulier pour le secteur de la rénovation énergétique des bâtiments. Ce dernier semble pourtant avoir un potentiel important en terme d'efficacité énergétique et de création d'emplois. Nous réalisons la première évaluation ex-post de l'effet d'une politique publique de rénovation énergétique sur l'emploi en exploitant un choc sur les subventions versées par le dispositif des Certificats d'Economie d'Energie en France. Avec une méthode de groupe de contrôle synthétique, nous estimons que la politique génère 7,5 emplois par million € investi par an.

Abstract

Recovery packages from COVID-19 are committing nearly one trillion dollars of public spending to green investments globally, with strong expectations of economic growth and job creation. Yet, we crucially lack ex-post validations of the multiplier effects widely used to forecast new green jobs. This is especially the case for energy retrofits in buildings, which are likely to have among the highest potentials for climate action and job creation at the same time. We provide the first ex-post analysis of a large-scale retrofit program on job creation by exploiting a large discontinuity in the provision of subsidies through the French Energy Efficiency Obligation programme. Using a synthetic control method, we estimate that the policy sustains 7.5 jobs per million euros invested annually.

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1 Introduction

Recovery packages¹ from COVID-19 are committing nearly one trillion dollars of public spending to green investments globally, amounting to a third of global recovery spending (O’Callaghan et al. 2021). Not only are these investments expected to drastically reduce Greenhouse Gas Emissions (GHG), but also to significantly boost employment. The European Commission, for instance, believes that meeting the 2030 climate and energy targets could create almost 1 million new green jobs (European Commission 2020b). Such positive expectations for the impact of green investment on employment are supported by several ex-ante forecasts using input-output models (Mikulić, Bakarić et Slijepčević 2016 ; Markandya et al. 2016 ; Dell’Anna 2021) or computed general equilibrium models (Sooriyaarachchi et al. 2015 ; Wei, Patadia et Kammen 2010).

However, we considerably lack ex-post confirmations. In particular, we are aware of no ex-post evaluation of the job-creating potential of energy retrofits *per se*, even though buildings account for 25% of global emissions (IEA 2020) and this sector is probably one with the highest potential for local green job creation.²

The empirical evidence is also insufficient to determine which types of green investments are most likely to stimulate employment. Popp et al. (2021) provide the first ex-post analysis of a green investment package on employment, and find that, in the long run, for each million dollars invested in green technologies, the 2009 American Recovery and Reinvestment Act (ARRA) created 2 to 4 jobs in the construction sector. However, they cannot separate the impact of the many types of green investments performed (such as energy renovation, green infrastructure, or the installation of renewable energy technologies). Their estimate is an average that may bundle investments with strong impacts on employment with others with near-zero effect. In that regard, Fabra et al. (2022) find radically different outcomes for solar versus wind energy investments in Spain.³ Other categories, especially energy retrofits, have not been analyzed in a similar fashion.

This paper provides the first ex-post analysis of the employment effect of a large-scale energy retrofit policy in France, which also happens to be among the largest energy efficiency policies in Europe (Broc, Stańczyk et Reidlinger 2020). We find levels of jobs creation similar to ex-ante studies. We also find that energy retrofits might have a stronger impact on job creation than the other types of green investments for which there is ex-post evidence.

We exploit a large discontinuity in the provision of subsidies to French households and businesses with two reforms of the French Energy Efficiency Obligation (EEO) Programme in

1. e.g. NextGenerationEU (European Commission 2021) or the American Rescue Plan Act (Office of the Federal Register, 2021).

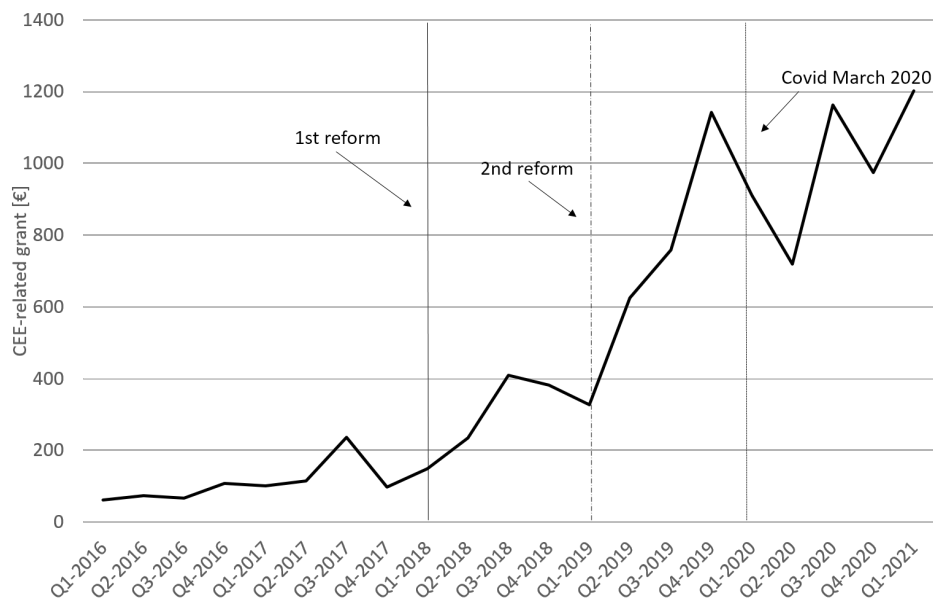
2. Retrofits are one of the main green investment types. The Renovation Wave in the European Union includes a EUR 200 billion investment in “greening [. . .] buildings, improving lives and creating jobs” (European Commission 2020a). Moreover, ex-ante studies have forecasted impacts in the range of 12 to 29 direct and indirect jobs created per million dollars invested in energy retrofits, of which about half would be direct hires in the energy retrofit sector (BPIE 2020). Energy retrofits are often performed by SMEs ((European Commission 2019) and involve manual workers who are most likely to be negatively impacted by other environmental policies (Reed Walker 2011 ; Vona et al. 2018 ; Yip 2018 ; Marin et Vona 2019 ; Vona 2019 ; Marin et Vona 2021).

3. For each million dollars invested in solar panels, 0.8–1.1 local jobs were created. In contrast, they find no effect on local employment for investments in wind energy.

March 2018 and January 2019. This discontinuity is observable in **Figure 3.1**, where we estimate that the total amount of subsidies to households for insulation and heating retrofit operations through the scheme went from less than EUR 200 million per quarter before 2018 to more than EUR 1,000 million per quarter at the end of 2019.

The presence of such a discontinuity greatly facilitates our analysis. Other analyses (i.e. Popp et al. (2021); and Fabra et al. (2022)) had to take care of endogenous treatment or local selection effects. In our case, the sudden increase in subsidies allows us to use a synthetic control method (Abadie et Gardeazabal 2003; Abadie et al. 2010). Our analysis compares affected sectors with unaffected sectors that are pooled and weighted to create a synthetic control whose pre-reform employment trend matches the employment trend of the affected sectors. We discuss methods and hypotheses in detail, with a series of robustness checks and tests to ensure that our findings are not driven by potential biases or shortcomings in the method employed, such as a violation of the stable unit treatment value assumption or effects of anticipation. We also perform several inference tests to ensure our results are robust to specification choices.

FIGURE 3.1 – Estimated amount of subsidies received by households for insulation and heating works through the French EEO Programme



Notes : The graph displays an estimated value for the quarterly value of all subsidies received for insulation and heating retrofit operations in France through the EEO programme. To compute this amount, we used data from the Ministry of Ecology (GDEC 2022b) to compute the quarterly number of renovation projects launched through the EEO programme, based on a monthly average of applications submitted and the average delay between the time of application and the start of projects. The Ministry of Ecology (GDEC 2022c) also provides the distribution of different types of energy retrofit operations that have been validated. Validation leads to the emission of energy savings certificates. To match both sources, we assume an 18-month delay between the start of projects and the emission of certificates (Glachant, Kahn et Lévêque 2020a). We then calculate the number of certificates emitted for insulation and the installation of heating equipment corresponding to each period. We finally multiply this number by the price of certificates to compute a total value of emitted certificates. We estimate the final value received by households to be equal to 70 percent of the total value of certificates. This is because we assume that 30 percent of the certificate values is used to cover management costs and intermediaries. This figure of 30 percent is taken from (Darmais, Glachant et Kahn 2022).

Stopping the analysis just before the COVID-19 pandemic in February 2020, we observe a clear impact of the change in policy on employment in energy retrofit companies 14 months after the second reform. This impact seems to continue until after the pandemic. We estimate that at least 15,000 jobs were created thanks to the policy, equivalent to 7.5 direct jobs created per million euros invested annually. This figure is consistent with ex-ante estimates for direct jobs (at about 4.3 to 9.2 direct jobs per million dollars invested) (BPIE 2020), and therefore confirm current expectations of job creation through retrofits. Since Popp et al. (2021) find 2 to 4 jobs in construction sector, and Fabra et al. (2022) find 0.8-1.1 jobs in the solar industry, energy retrofits could have a stronger potential for job creation than other types of green investments. However, these are not homogeneous comparisons since these studies have a different scope and use different methods.⁴

4. For instance, we focus on direct jobs at national scale whereas Fabra et al. (2022) focus on direct jobs at local scale. Popp et al. (2021) use a method that should provide overall results for both indirect and direct job

Recent economic studies have questioned the effectiveness of energy retrofit programs, with realized energy savings being significantly lower than predicted savings (Fowlie, Greenstone et Wolfram 2018; Liang et al. 2018; Lang et Lanz 2022; Davis, Fuchs et Gertler 2014). Our paper contributes to the growing literature pointing to significant co-benefits of energy retrofit programs despite lower-than-expected savings, including : comfort gains (Aydin, Kok et Brounen 2017); public health benefits (Howden-Chapman et al. 2007); economic transfers from high-income households to low-income ones (Darmais, Glachant et Kahn 2022); and, in the case of our paper, job creation.

Furthermore, empirical research on the green transition has focused on the employment effect of restrictive policies to cut down emissions (Reed Walker 2013; Vona et al. 2018; Yip 2018; Marin et Vona 2019; Vona 2019; Greenstone 2002; Reed Walker 2011; Kahn et Mansur 2013; Yamazaki 2017; Hille et Möbius 2019; Metcalf et Stock 2020; Marin et Vona 2021)), with much fewer analyses looking at investment policies. This paper contributes to fill this gap, finding a relatively high job potential of investments in energy retrofits

The remainder of this paper is organized as follows. Section 2 describes the studied policy. Section 3 presents our data and method. Section 4 presents our results, and a last section concludes.

2 The French Energy Efficiency Obligation Scheme

2.1 The scheme design

In 2006, the French government established a regime of energy efficiency obligations (Certificats d'Économies d'Énergie in French) under the supervision of the General Directorate of Energy and Climate (GDEC) (Direction Générale de l'Énergie et du Climat, in French). The scheme consists of periods of four years during which a national energy savings target must be met. It is in its 5th period since January 1st, 2022 and the total energy savings target for 2022-2025 is set at 2,500 cumulative TWh.⁵

Each period-specific national energy savings target is broken down into individual targets of energy savings for all obligated parties. The obligated parties are energy providers, mainly gasoline, electricity, and natural gas providers. They must fulfill their individual obligations by obtaining energy savings certificates delivered by the regulator for home improvements performed in either the residential sector, the industrial or the tertiary sectors. These individual obligations depend on the amount and type of fuel they sell in the residential and tertiary sectors during the period. For instance, during the 4th period (2018-2021), for each MWh of electricity sold, energy providers had to obtain 0.604 energy savings certificates (GDEC 2017).⁶ In addition,

creations.

5. TWh are cumulative because the energy savings are calculated on the lifetime of the energy operation achieved. Part of this target (730 cumulative TWh during the 5th period) must go to projects benefiting to low-income households, as explained in the following pages.

6. Each fuel has a different coefficient converting sales (in MWh) into obligations (in certificates). The calculation can be complex. For the fourth period, for instance, the regulator first calculated the total share of energy provided by each fuel (from sales in MWh) and its market share (from sales in euros). These two shares were then

since 2016, a share of certificates must be obtained from subsidizing renovation efforts in lower-income households with annual income roughly below the median income in France. There are therefore two individual obligations per obligated party (a general obligation and a low-income obligation) and two types of certificates (general and low-income). It is possible to fulfil a general obligation with low-income certificates, but it is not possible to use general certificates to fulfil low-income obligations.

To obtain certificates, the obligated parties must have an active role and provide an incentive to a renovation project, i.e. fund entirely or in part the project. They must be mentioned as such on the project invoice. As a result, in 2019, obligated parties provided EUR 2.5 billion of grants for energy efficiency projects through the scheme in the residential sector (Darmais, Glachant et Kahn 2022). Renovation projects can be undertaken on behalf of residential, industrial, or tertiary actors. Once the renovation is completed, the obligated party claims the quantity of certificates corresponding to the retrofit operations undertaken as part of the project. The number of certificates associated with each energy retrofit operation is set in advance by the regulator. This quantity essentially depends on the energy savings that each operation conveys. There are more than 200 standard energy retrofit operations that correspond to a set number of certificates. For instance, in 2019, one square meter of insulated wall in an electricity-heated house in the north of France was associated with 2.4 certificates.⁷ If the renovation effort benefits a household with income below a threshold close to the national median, then the certificate obtained is a low-income certificate. Moreover, the number of certificates obtained from the same renovation effort is doubled if the renovation benefits a household belonging to the 1st quartile of income.

The obligated parties can delegate all or part of their obligations to third-party companies, called delegated parties, usually energy service providers or simply traders. Obligated and delegated parties are allowed to exchange certificates through over-the-counter operations. Therefore, while there is no organized market for certificates, these are still traded between different parties. Monthly price indices for general and low-income certificates are publicly available from the national register of EEOs (called EMMY).⁸ They correspond to the average price of all the certificates sold during a month.⁹ These indices are used as a signal by stakeholders, who may monitor their activities and make decisions under the scheme based on the evolution of these indices (Glachant, Kahn et Lévêque 2020b).

Even though obligated and delegated parties freely set the financial conditions for the home

weighted (with a weight of 75 percent for the energy share and 25 percent for the market share) to calculate the required contribution of a given fuel to the total obligation during the fourth period (of 2,133 cumulative TWh for 2018-2022). Finally, the regulator forecasted total energy sales per fuel during the fourth period. The coefficient converting sales into obligations is the ratio between the required contribution (in cumulative TWh, and therefore in certificates) and the forecasted sales (in MWh) of each fuel. It is therefore expressed in certificates per MWh.

7. For more informations, all the standard operations are [available here](#)

8. For more information on the register, see : <https://opera-energie.com/emmy-registre-national-cee/>, (accessed 19th September, 2022).

9. This price index is sometimes difficult to interpret because it includes certificates sold in very different conditions, not only certificates traded with contracts “on the spot” happening during month m , but also certificates from forward contracts that came to maturity during month m . Moreover, the price index also includes price information from trades happening between subsidiary companies belonging to the same mother company.

improvements that they subsidize, energy efficiency grants to households and businesses ultimately depend on the number of certificates associated with each energy retrofit operation, and the price of certificates as signaled by the price indices of certificates. This is considering that obligated parties can always buy certificates to others through over-the-counter operations.

Figure 3.2 displays the evolution of the market value of the certificates that obligated and delegated parties obtained when undertaking selected energy retrofit operations. This value has been computed by multiplying the price of certificates with the number of certificates associated with each operation. We provide this information separately for different income quartile of households since the value of the operations is different. As explained before, the obligated and delegated parties can claim low-income certificates for home improvements performed in the 1st and 2nd quartiles of income, and twice as many of these certificates for improvements benefitting the 1st quartile.

Figure 3.2 shows that, for each operation, the market value of the certificates was very stable between January 2016 and March 2018, and then increased sharply until it plateaued in 2019. For instance, the total value of the certificates obtained for one square meter of roof insulation went from less than 10 euros to more than 20 euros on average.¹⁰ For heat pumps, the financial value of certificates was multiplied by about 5. Altogether, the number of subsidies delivered to households through the French EEO scheme increased substantially, from less than EUR 1 billion in 2017 to EUR 2.5 billion in 2019 (Darmais, Glachant et Kahn 2022).¹¹

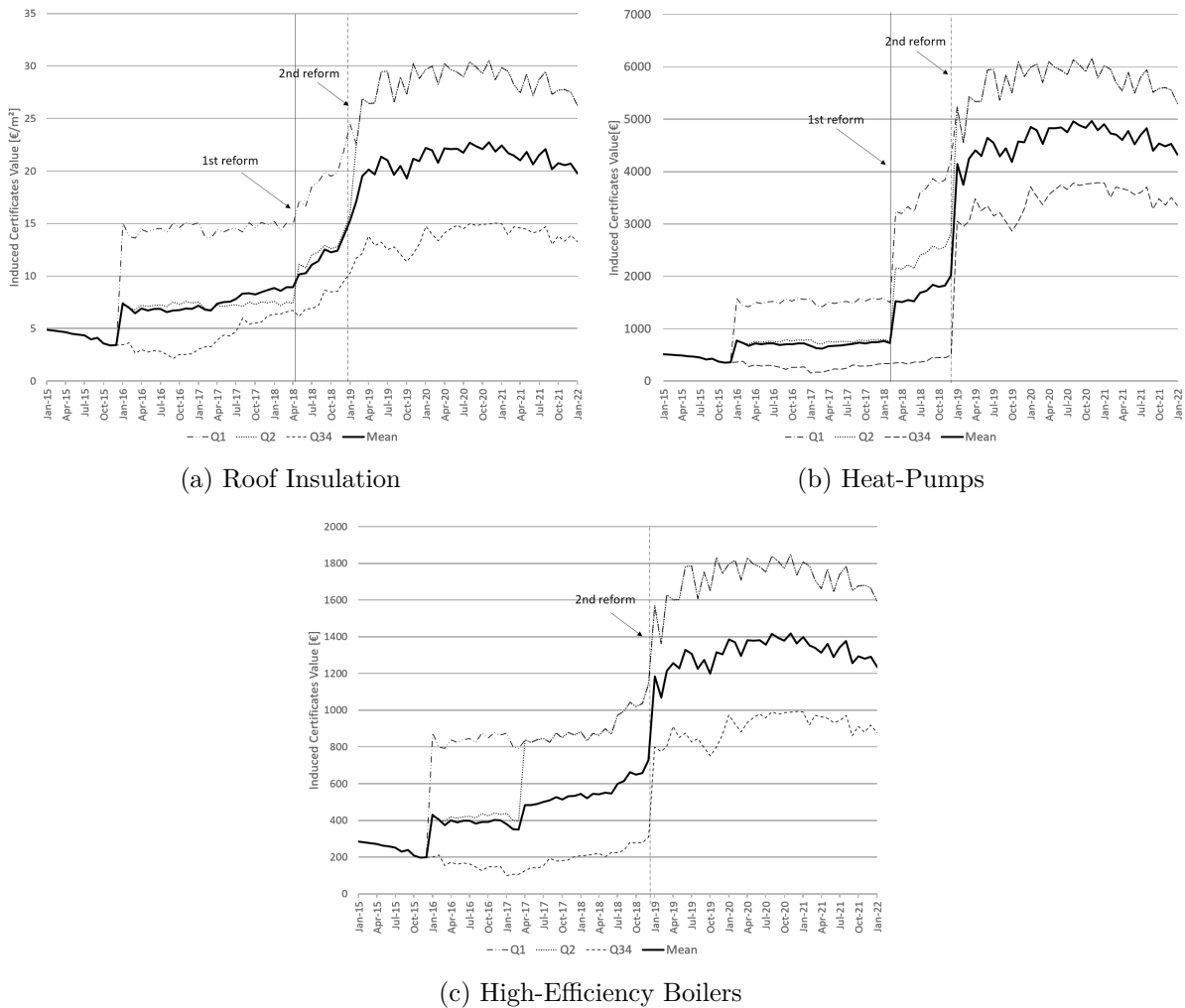
Three changes explain this increase in the value of individual operations. First of all, the price of general and low-income certificates increased. Especially, the scheme entered its fourth period of implementation in January 2018. The total obligation, set at 2,133 cumulative TWh for 2018-2022, was nearly twice as ambitious as the total obligation of 1,166 cumulative TWh of the previous period (2014-2017). The price indices of certificates increased steadily at the beginning of the fourth implementation period, e.g. from EUR 5 in January 2018 to EUR 8 in December 2018 for general certificates. They stabilized after that. In parallel, the French government increased the number of certificates that it would grant for specific operations. A first reform occurred in April 2018. The number of certificates was multiplied by 4.5 for all heat pumps. The regulator also increased by 10 percent the number of certificates obtained for attic, roof and floor insulation benefitting to households belonging to the first two quartiles of income. In January 2019, there was another reform in the delivery of certificates. The number of certificates delivered for all heating-system related operations was doubled. The regulator also increased the number of certificates that would be granted for insulation operations : by 17 percent for general certificates and by 60 percent for low-income certificates (i.e. for operations benefitting households with income below the national median).

The April 2018 and January 2019 reforms explain the sudden jumps in value displayed in **Figure 3.1** and **3.2**. After 2019, the value of certificates could cover some installations in full, for instance energy efficient boilers (with certificate values of € 1,800) or roof insulation (€ 30

10. These values do not account for inflation. Inflation was however very low in the Eurozone between 2016 and 2019.

11. As explained in the description of **Figure 3.1** in Introduction, households are likely to receive about 70 percent of the market value of certificates due to a series of operational and intermediary costs.

FIGURE 3.2 – Evolution of the market value of the certificates associated to a selection of operations covered by the EEO scheme



Notes : Data are from the French Ministry of Ecological Transition (GDEC 2022a). The full line represents in average the market value of certificates associated with either roof insulation (a), heat pumps (b) or boilers (c) that fulfil the energy efficiency eligibility conditions of the scheme (e.g. this is only high efficiency boilers in the case of boilers). Other lines break down the market value by type of residential household (Q1 for those in the first quartile of income, Q2 for those in the second quartile, and Q34 for those in either the 3rd or 4th quartile). The value of certificates is calculated by multiplying the number of certificates associated with each energy operation by the relevant price index (for either general or low-income certificates). Units on the y-axis are in current euros/m² (a) and in current euros (b and c).

per square meter) for low-income households. Commercial offers to replace boilers and insulate homes for one symbolic euro boomed in 2019 and 2020.

3 Data & Methodology

3.1 Data

To estimate the impact of the EEO scheme on employment, we obtained monthly data on the total number of employees in every business in Metropolitan France from the Worker Movement Database (WMD) of the French Ministry of Labour (French Ministry of Labour, s.d.). The data is available from 2015 to 2021 and includes a total of 686 codes corresponding to different sectors. Later on, we focus on the two sectors most effected by the policy, which are those corresponding to “insulation works” and the “installation of heating equipment”.¹²

The WMD collates all records from an official document that companies must fill every month and which is entitled the Nominative Social Declaration (NSD).¹³ The NSD contains information about employee activity periods including, among other things, the start and end dates of each employment contract, the type of contract (e.g. permanent or fixed-term), sick leaves, maternity and paternity leaves. Therefore, the NSD provides information that can be aggregated to determine the number of people working in a certain business or sector each month.

Nonetheless, the total numbers of employees at sector level should not be directly compared over time due to missing data. The NSD came out of an effort from the French government to harmonize and simplify business declarations. It started as a voluntary scheme in 2013, became compulsory for large companies in 2015 and finally for all businesses that hire employees in 2017. Despite being compulsory since 2017, several small companies did not fill any NSD before 2019, when automation ensured that all companies were finally registered and filling their NSD every month. At the beginning of 2016, only 33% of businesses filed an NSD. They were 60% in 2017 and 80% in 2018. Compliance rates strongly depended on business size. More than 90% of companies with more than 50 employees were already filing their NSD by mid-2016, against only half of businesses with less than 10 employees.

The Ministry of Labour has developed a method of weights to extrapolate the number of employees in each sector over time from missing declarations (DARES 2018). In a nutshell, the method consists in associating a weight to each observation (a business in month m and year t), each weight being inversely proportional to the probability that an observation would have filled the NSD. This is very close to what would be done in a survey, where weights are given to each respondent according to their inverse probability of response. Inverse probabilities were estimated for different classes of respondents according to the number of employees in the business, the number of subsidiary businesses the mother company has, the region of the business, and its activity sector (tertiary, industry or construction), the age and the revenue of

12. In the dataset, these are codes 4329A and 4322B respectively.

13. *Déclaration Sociale Nominative* in French

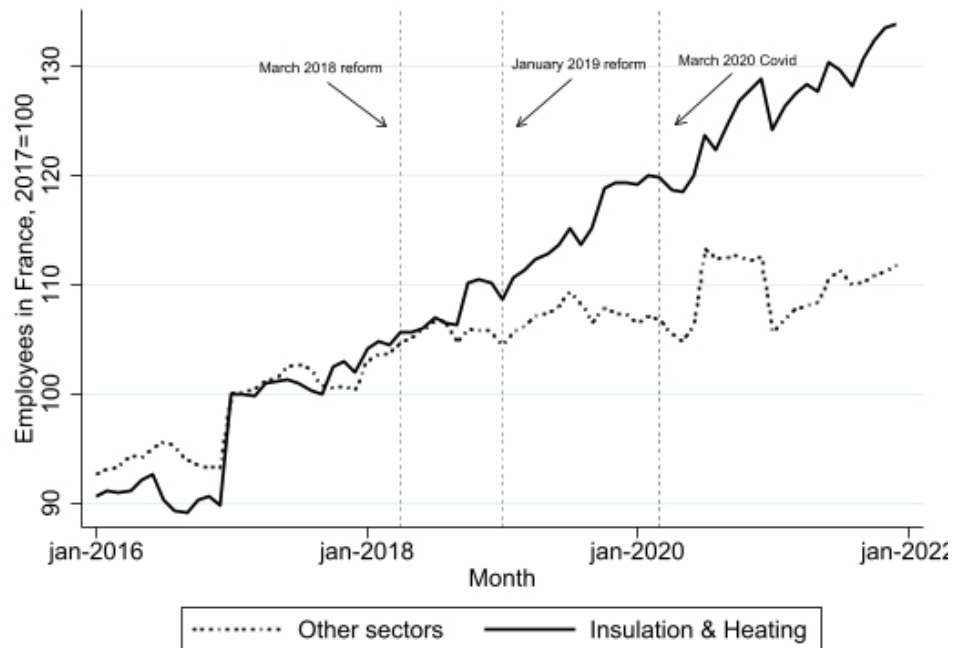
the business. All in all, the weighted data can be swiftly used to recalculate total employment levels across classes, especially at sector level.

We therefore use the weights provided by the Ministry of Labour to calculate sector-level employment levels by month (DARES 2018). We do so at national level to determine the total number of employees in each month and in each sector in Metropolitan France between 2016 and 2021.¹⁴ This level of aggregation ensures that any measurement error in employment levels coming from the weighting method is minimized so that comparisons over time can be drawn.

Figure 3.3 displays the relative evolution of workforce the relative evolution of workforce in the sectors of “insulation works” and “installation of heating equipment” compared to all other sectors in France. The total number of employees across all other sectors grows slowly while employment in the two energy renovation sectors experienced a much faster growth. However, this growth started before the reform of the EEO scheme. **Figure 3.3** also shows that, at national scale, there is no discontinuity in 2019 when NSD collection became fully automated. There is a discontinuity in January 2017, which is when NSD declarations became compulsory. This could impact the reliability of our statistical model, something we discuss more in detail later on. In **Appendix 6.5**, we show that our findings are not affected by this discontinuity in pre-policy trends.

14. The dataset starts in the second semester of 2015. However, the data collection quality at the beginning was lower due to the progressive rollout of NSDs. For that reason, we do not use 2015 data in our baseline analyses.

FIGURE 3.3 – Evolution of workforce in France per industrial sector (january 2017=100)



Notes : The energy renovation sectors are those corresponding to “insulation” and the “installation of heating equipment”. They correspond to codes 4329A and 4322B respectively in the data from the French Ministry of Labour (French Ministry of Labour, s.d.). National aggregates are computed monthly and rely on the weights developed by the French Ministry of Labour (DARES 2018) to account for a methodological difference in data collection between 2019 and previous years. The two vertical lines correspond to the introduction of the major changes in the attribution of certificates in March 2018 and January 2019.

3.2 Method

The two first vertical lines on **Figure 3.3** correspond to the introduction of the major changes in the attribution of certificates in March 2018 and January 2019. The third one indicates the beginning of the COVID-19 lockdown in France. We perform a policy analysis to compare the evolution of total national employment in the two treated sectors (insulation, and installation of heating equipment) covered by EEO and control sectors that are unaffected by the reforms of the EEO programme.

To choose the control sectors, we use a synthetic control method (Abadie et Gardeazabal 2003; Abadie et al. 2010). This method has been widely used in the past few years in labour economics (Allegretto et al. 2017; Reich, Allegretto et Goddy 2017; Peri et Yasenov 2019; Justin C Wiltshire 2021a; Jardim et al. 2022). Synthetic control methods are appropriate for policies implemented at aggregate level and affecting a small number of units (Abadie 2021), which is our case. Moreover, the expected magnitude of the policy has to be high-enough to be detectable (Abadie 2021). We believe this is likely to be the case because the EEO scheme subsidized more than EUR 2.5 billion of installation in 2019, compared to less than EUR 1 billion in 2017 before the policy change (Darmais, Glachant et Kahn 2022). Synthetic control models are also superior to a classical regression model because effects are not extrapolated from estimated coefficients

which values are assumed to be stable. This could be misleading when using only a small number of observations that lack commonalities. Moreover, the definition of the control group does not rely as much on the subjectivity of statisticians since it is defined mathematically and beforehand using an algorithm (Abadie 2021).

With this method, we create a synthetic control which is a weighted average of the employment level in a subset of control sectors taken from a pool. Weights are determined to ensure that pre-policy trends between the treated sectors and the synthetic control are as similar as possible. Falkenhall, Månsson et Tano (2020) followed a similar approach, using control sectors to analyse the impact of a VAT reform Sweden. Our synthetic control group is a weighted sum of a subset of the 684 sectors recorded in our dataset other than “insulation” and the “installation of heating equipment”.

We also exclude other construction-related sectors¹⁵ from the pool of control sectors because we believe they may have been impacted by the reform, even if these sectors were not the primary recipients of the policy. For instance, even though companies are not considered to be part of "insulation" or “installation of heating equipment” sectors, they might still perform this type of services, especially if there are generous subsidies associated with. Besides, if someone insulated their home and then decided to have other improvements performed at the same time, other construction professionals could indirectly benefit from the policy. In the U.S., Cohen, Glachant et Söderberg (2017) show that households tend to perform several house improvements at the same time. Including these sectors in the donor pool would thus create a downward bias. Conversely, workers from certain construction sectors could be relocated to "insulation" or “installation of heating equipment” ones. Taking into account these construction sectors in our analysis would introduce an upward bias. One could argue we should still consider these sectors as treated. However, we prefer to restrain our analysis to the targeted sectors, i.e insulation and heating, in order to remain at a four digits level that is more suitable to identify affected industries. In **Appendix 6.6**, we run another estimation, at the two digits level, where we consider all the construction related sectors as treated.¹⁶

The definition of the weights across the control sectors to build the synthetic control group is as follows. Let define Y_{it} the number of employees in France the sector i at time t . We have $J+1$ sectors in our dataset, and we define sector 1 as our sector of interest, i.e. the energy renovation sector, the J other sectors constitute the “donor pool”. We want to know what would have been the value of Y_{1t} without the reform. For this purpose, we build a counterfactual Y_{it}^N which is a convex and weighted sum of all sectors in the “donor pool”. Y_{it}^N is defined as :

$$Y_{1t}^N = \sum_{j=2}^{J+1} \omega_j Y_{jt} \quad (4.1)$$

With for all j , $\omega_j \geq 0$ such that $\sum_{j=2}^{J+1} \omega_j = 1$. Let’s T_0 be the first month when the policy

15. There are 36 construction-related sectors. In the WMD, those have sector codes starting by 41, 42 or 43.

16. As expected, the reform seems to positively impact jobs in the "specialized construction" sector with the "43" code. Conversely, the "new construction" sector with the "41" code might have suffered from job reallocation. Even though, both analysis do not produce statistically significant estimates.

was implemented. $\forall j$, we chose the w_j that minimize the Root Mean Score Percentage Error (RMSPE), as defined in Eq. (4.2) :

$$RMSPE = \sqrt{\frac{1}{T_0 - 1} \sum_{t=1}^{T_0-1} (Y_{1t} - \sum_{j=2}^{J+1} \omega_j Y_{jt})^2} \quad (4.2)$$

For $t \geq T_0$ the policy effect is τ_t defined in Eq. (4.3) :

$$\tau_t = Y_{1t} - Y_{1t}^N \quad (4.3)$$

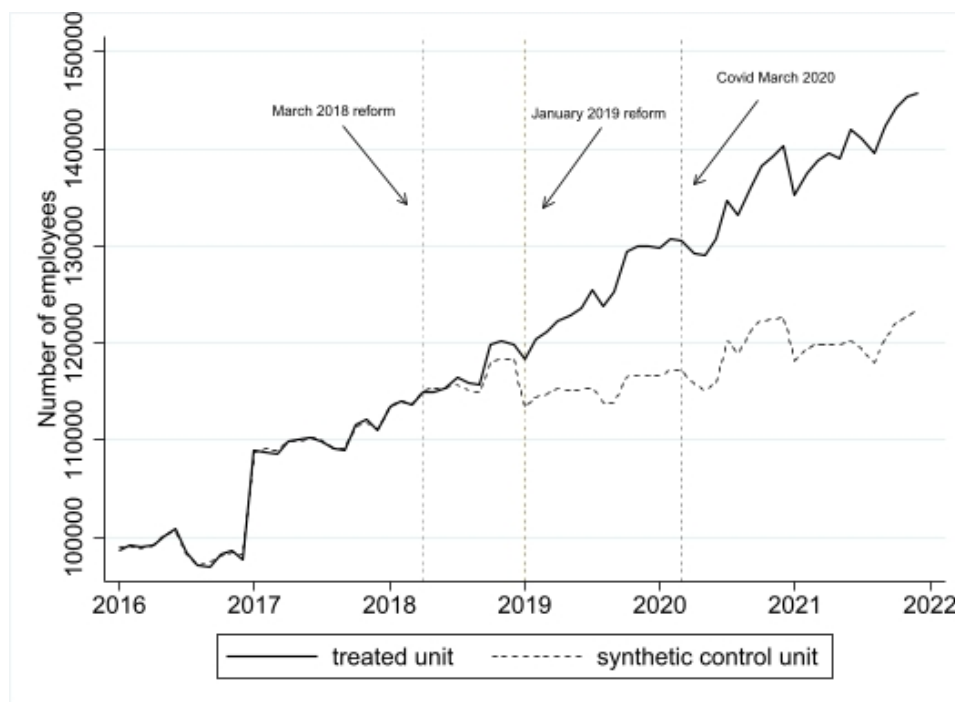
We follow Abadie (2021) to calibrate this model. Especially, Abadie (2021) recommends to restrict the donor pool of control sectors to those with an outcome Y_{it} relatively close to the outcome of the treated sector. We therefore restrict the donor pool to those sectors that have comparable levels of employment. Let T_{-1} be the month right before the first change in policy (February 2018). We select our $J+1$ sectors such that the difference in employment level between each control sector and the treatment sector is below 50 percent in T_{-1} . Mathematically, the condition is that $(Y_{1T_{-1}}/Y_{iT_{-1}})$ and $(Y_{iT_{-1}}/Y_{1T_{-1}})$ have to be both below 1.5 for sector i to be included in the donor pool. With this condition, we obtain a donor pool of 37 sectors. This number of sectors is close to the 38 States that Abadie et al. (2010) used in their study of the Californian anti-smoking reform. Naturally, 50 percent is a rule of thumb. We use different rules of exclusion as a robustness check and show that results are stable.

4 Results

4.1 Main results

Our main results are provided in **Figure 3.4**, which compares the evolution of the workforce in the energy retrofit sectors and the synthetic control group. Before the introduction of the first change in policy in March 2018, the workforce in the energy retrofit sectors is very similar to the evolution in the synthetic control group. This implies that the model is reliable to assess the impact of the policy reforms on employment. Between March 2018 and December 2018, there is barely any effect, suggesting that the first policy change did not have any substantial impact on employment. This is consistent with **Figures 3.1 and 3.2**, since much of the difference in the delivery of certificates occurred from 2019 onwards. In that regard, we find that the second policy change, which led to the most drastic change in policy design, also led to a strong increase in the number of employees in the treated sectors, equivalent to about 15,000 new jobs by February 2020 (before the first lockdown in France due to the COVID-19 pandemic). This is a 13 percent increase in employment in these sectors by February 2020 compared to February 2018. The difference in employment levels between the treatment and control groups remains during and after the pandemic.

FIGURE 3.4 – Trend in national workforce : Energy renovation vs synthetic Energy renovation



Notes : The full line represents the evolution of the workforce in the energy renovation sector, the dotted line displays the evolution for its synthetic control group.

A set of consistency tests and robustness checks described hereafter substantiate that the results of **Figure 3.4** can be attributed to the policy. Conversely to standard linear regression models, there is no inference test to estimate whether the difference observed in **Figure 3.4** is statistically significant or not. We follow Abadie et al. (2010) and use a placebo test to analyse whether the difference between the control and treatment groups can be attributed to the policy. Namely, these authors use each unit in the donor pool (in our case the 37 control sectors) and Eq. (4.1) to (4.3) to create synthetic controls for these sectors (using the other 36 control sectors). In theory, since none of the control sectors were affected by the policy, there should be no tangible difference in employment levels before and after March 2018 and before and after January 2019 between the control sectors and their synthetic controls. If the placebo test shows that the gap estimated for the energy retrofit sectors is sensibly larger than the post-reform differences in employment obtained with the sectors from the donor pool, then we can infer that the reform had a noticeable impact on employment in energy retrofit industries. Otherwise, results should be considered as not statistically different from zero.

A graphical presentation of the placebo test is provided in **Appendix 6.1**. The energy renovation sector records the 7th highest effect (out of 38). While this places it in the top 20 percent compared to the placebos, our treatment group does not record the highest post-policy difference in employment compared to its synthetic control. Very importantly though, the relevance of the ex-post values depends on the quality of the pretreatment fit. This is because large values post-treatment can either be attributed to a post-treatment effect or simply to high variance due to poor model fit.

This is why comparing the magnitude of effects directly could be misleading. Instead, Abadie et al. (2010) recommend comparing the model fit of the synthetic controls (for the treatment group and the control groups of the donor pool used as placebos) before and after the implementation of the policy. The idea is that the model fit should be similar before and after the policy for the placebos, whereas it should be much lower for the treatment group after the policy since there should be a noticeable post-treatment difference between the treatment group and its synthetic control group.

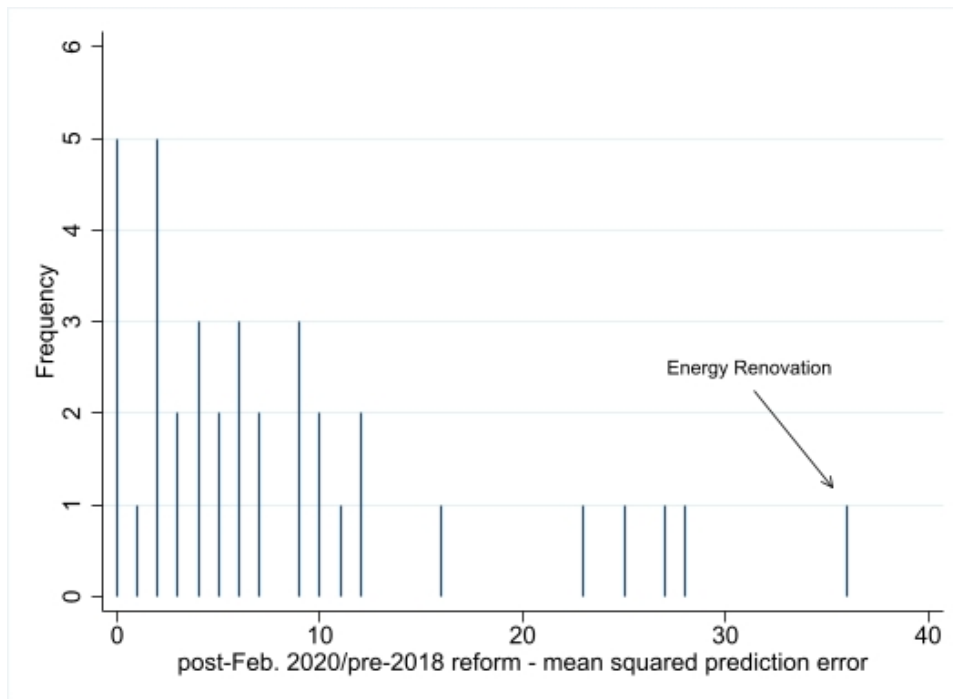
Following Abadie et al. (2010), we calculate two measures of model fit : the pre-reform RMSPE (between January 2016 and March 2018) and the post-reform RMSPE (between March 2018 and February 2020) (formula in **Appendix 6.2**). These measures allow computing a ratio (of the post-reform RMSPE over the pre-reform RMSPE) that Abadie et al. (2010) called the inference score of a synthetic control as estimated at time T for unit j. In our case, time T is February 2020 just before the start of the pandemic and the units are the treatment and control sectors. The higher the inference score, the largest is the difference in model fit before and after the introduction of the reforms between the observed values for sector j and the fitted values of the synthetic control. We would therefore expect the inference score to be large for the treated sectors and small for the control sectors used as placebos.

Figure 3.5 displays the distribution of the inference score across the energy retrofit sectors and the 37 placebos. The energy renovation sector has, by far, the largest score. We can therefore conclude that the highest values shown in **Appendix 6.1** for the placebos are due to lower model fit rather than a difference in predictive value of the placebos before and after the implementation of the policy. A p-value of 0.027 can be obtained following Abadie (2021) (formula in **Appendix 6.2**), implying that the predictive value of the synthetic control group in the case of the energy retrofit sectors is statistically lower than the predictive value of the synthetic control groups in the case of the placebos. In simpler words, the synthetic control method tends to predict equally the evolution of all 37 placebos before and after the policy, whereas it is a comparatively poor predictor of the evolution of the energy renovation sectors once the policy starts.

The inference test above suggests that the difference in employment between the renovation sector and its synthetic control in **Figure 3.4** is due to the introduction of the policy. This result is robust to changes in model calibration. In particular, we calibrated our synthetic model in a way that the comparison is drawn from a pool of 37 sectors. This is because we only selected control sectors with a difference in employment level with the treatment sector below 50 percent just before the first reform (in February 2018). Mathematically, we only selected sectors for which (Y_{1T-1}/Y_{iT-1}) and (Y_{iT-1}/Y_{1T-1}) were both below 1.5. Moreover, we have performed the inference test (of **Figure 3.5**) at a specific date, which is February 2020 (just before the COVID-19 pandemic) to assess effects at 14 months.

In **Table 3.1**, we provide the results of inference tests when we modify these parameters. We use a different criterion to select sectors in the donor pool, either only selecting sectors for which (Y_{1T-1}/Y_{iT-1}) and (Y_{iT-1}/Y_{1T-1}) are below 1.33 or, in contrast, selecting more sectors with (Y_{1T-1}/Y_{iT-1}) and (Y_{iT-1}/Y_{1T-1}) below 2 or below 3. We also provide results for December 2018 (just before the introduction of the second reform), and for December 2020 and 2021, i.e.

FIGURE 3.5 – Inference score ratio of post-and pre-2018 reform : energy renovation and 37 control sectors



Notes : The graph displays the distribution of the inference score for energy renovation sector and the 37 other donor pool sectors. The y-axis corresponds to the number of sectors with a given inference score. The formula of the inference score is in **Appendix 6.2** and follows Abadie et al. (2010).

two and three years after the second reform. These longer-term results are however less reliable since the COVID-19 pandemic might have impacted control and treated sectors differently.¹⁷

TABLE 3.1 – p-value obtained for different pre-filters

Date	Criterion for Y_{1T-1}/Y_{iT-1} and (Y_{iT-1}/Y_{1T-1})							
	< 1.33		<1.50 (baseline)		< 2		< 3	
	p-value	Rank	p-value	Rank	p-value	Rank	p-value	Rank
Dec.2018	0.069	2/29	0.081	3/38	0.066	4/60	0.040	4/100
Fev.2020	0.034	1/29	0.027	1/38	0.066	5/60	0.040	4/100
Dec.2020	0.034	1/29	0.027	1/38	0.050	3/60	0.020	2/100
Dec.2021	0.034	1/29	0.027	1/38	0.016	1/60	0.010	1/100

Notes : The table provides the p-value of the inference test that we described in the text, following Abadie (2021). We also provide the rank of the inference score of the treatment sectors compared to the placebos. The number of sectors varies according to the criterion used to select sectors in the donor pool. This criterion is specified at the top of the Table, while we calculate the p-value and rank at different times (in row).

All tests in **Table 3.1** are statistically significant at 10 percent. The tests performed before the implementation of the second reform (in January 2019) tend to be statistically significant

17. Figures with the distribution of inference scores for different periods are provided in **Appendix 6.3**. For concision, we only provide them for Y_{1T-1}/Y_{iT-1} and (Y_{iT-1}/Y_{1T-1}) below 1.5.

at 10 percent only, since only one out of four is statistically significant at 5 percent. However, nearly all tests (eleven tests out of twelve) performed after the second reform, which was the strongest one, are statistically significant at 5 percent, with only one test with a p-value above 5 percent (of 0.066). The policy has detectable effects before the pandemic as well as during the COVID-19 pandemic.

Besides, the synthetic control method requires that a non-anticipation condition (i.e. no anticipatory effects of the policy) be respected. In **Appendix 6.4**, we run an anticipation test where we assume that the starting date of the policy is August 2017. Results are robust to this change of date.

Finally, there is a discontinuity in the pre-policy employment data in January 2017, when employment records became compulsory. This discontinuity is not necessarily an issue for the synthetic control method since it should push the model to give stronger weight to the synthetic controls that had under-reporting levels similar to the treatment group in 2016. However, this could cause an over-fitting problem because we are constraining observations to follow an unusual pattern between December 2016 and January 2017. In **Appendix 6.5**, we run the model using only the data from January 2017 onwards and find similar effects, implying that the discontinuity between 2016 and 2017 had no substantial impact on our results.

All in all, we can therefore conclude from our analysis that the French EEO programme led to an increase in employment in the most affected sectors. We know that the EEO programme led companies to subsidize energy retrofits by EUR 2.5 billion per year. Therefore, the policy sustained 7.5 direct jobs for each million euro invested every year.

We can compare this estimate with other studies exploring the relation between green investments and jobs. Interestingly, our results are consistent with ex ante estimations. BPIE (2020) provides a literature review of 35 of such studies assessing the link between refurbishment and jobs. The review argues that energy renovation might provide a range of 13 to 28 direct and indirect jobs per EUR million invested, of which one third (this is 4.29–9.24) would be direct jobs. In the US, Garrett-Peltier (2017) uses an input-output model and finds that 4.55 direct jobs were created by USD million invested in energy retrofits. Other similar studies find higher results : 10 direct jobs per million euros invested in Pikas et al. (2015), and 11 direct jobs in Mikulić, Bakarić et Slijepčević (2016). Considering both direct and indirect jobs, the European Commission has used 8.52 Full-Time-Equivalent (FTE) per EUR million invested as the reference job multiplier for energy renovation (Esser et al. 2019). Overall, our results imply that we can expect post-pandemic stimulus packages to have the expected impact on job creation in the energy retrofit sector.

We can also compare our estimate with other ex-post studies. Popp et al. (2021) find 2 to 4 jobs in construction sector, Fabra et al. (2022) find 0.8-1.1 jobs in the solar industry. This suggests that energy retrofits could have a stronger potential for job creation than other types of green investments.

Nonetheless, these estimates are not fully comparable. The estimates from Popp et al. (2021) and Fabra et al. (2022) are for long-term impacts. In the long-term, it is possible that the job creation potential differs, either because some jobs are temporary, or because of a multiplier

effect. Our analysis is only fully reliable before the start of the pandemic, and this is too short of a period to assess longer-term impacts. The question remains to know if the French EEO programme is only creating temporary jobs while the subsidies are in place, or if it will allow structuring a supply chain for energy retrofits durably. The analysis by Fabra et al. (2022) suggest lower job creation in the long term for industries that rely on the installation of equipment, since maintenance is likely to be less labour intensive. In contrast, Popp et al. (2021) find stronger impacts in the long term, possibly because investments may allow structuring value chains.

Moreover, the evaluation by Popp et al. (2021) is more likely to capture indirect as well as direct jobs, because it is done at a wider scale of analysis and provides estimates at a larger level of aggregation, e.g. for the construction sector as a whole. In this paper, we have only analyzed direct job creation. The policy could have employment effects outside of the sectors considered. Especially, we do not assess the potential impacts on the rest of the energy retrofit value chain (on manufacturers, salespeople, etc.). In contrast, Fabra et al. (2022) only consider direct local job creation. The scope is therefore narrower than Popp et al. (2021) or ours. This is since our analysis is national and would therefore cover job creation at national level. However, if we consider that most energy retrofits are performed by SMEs locally, then our estimates and those of Fabra et al. (2022) can be more closely compared.

Finally, the French EEO programme has some features that make it particularly interesting to study. However, impacts may not be fully transferrable to other investment programmes because of its specificities. Especially, the cost of the policy is put on energy providers, who are required to provide subsidies to households and businesses. There is little government expenditure and the policy is much more socially acceptable than a carbon tax. However, the financial burden of the EEO Programme is likely to have been considerably passed through to consumers with increases in energy prices. Darmais, Glachant et Kahn (2022) estimate that a 4-percent increase in residential energy prices would be necessary to cover the cost of the EEO programme. The evidence on the responsiveness of consumers to energy prices for energy-using products and home improvements is mixed. Long-term energy costs may be underestimated by consumers, even though energy price increases could still trigger improvements in energy efficiency (Houde et Myers 2021 ; Schwarz et al. 2020 ; Cohen, Glachant et Söderberg 2017 ; Kiso, Chan et Arino 2022). Therefore, the effect of the EEO programme on investments may not exclusively come from the subsidies, but also from the concomitant increase in energy costs for households, who may decide to invest in energy efficiency because of the increase in energy prices.

Importantly, energy price increases due to the EEO programme could only concern households and (low-consuming) businesses in the tertiary sector. This is because industrial energy consumption is exempted from the programme : obligations do not depend on the amount of energy sold in the industrial sector, and some providers, who exclusively sell energy to the industrial sector, were not covered by the EEO programme. This was done to ensure that the EEO programme would not lead to a contraction of economic activity in other sectors. We can therefore presume that there was no job loss in industrial sectors because of the introduction of the policy.

5 Conclusion

We exploit a sharp discontinuity in the French EEO scheme to estimate the impact on employment of one of the largest energy retrofit policies in Europe. Our synthetic control method detects a strong increase in employment in energy renovation following two reforms in March 2018 and January 2019, with about 7.5 jobs sustained per million euro invested every year in the EEO programme.

To the best of our knowledge, this study constitutes the first ex post analysis of the employment co-benefit of energy retrofits. It allows confirming widely used multiplier effects for the impact of energy retrofits on employment. When compared to the other two analyses of the impact of green investments on jobs (Popp et al., 2021 ; and Fabra et al., 2022), our results suggest that energy retrofits might have a stronger employment potential than other investment types, even though scope and methods are not fully comparable. Our analysis also highlights some of the social benefits of energy retrofit policies compared to other sorts of green investments in the energy transition.

There are a few limitations to what we do in this paper. Future research could complement this analysis by running a synthetic control method on disaggregated data. Abadie et L'Hour (2021) and Ben-Michael, Feller et Rothstein (2021) have recently proposed state-of-the-art methods to do so. Moreover, our analysis has focused on all employment categories together. While our data does not contain information about the qualifications of the workforce, we do have information on contract type. Future research could therefore separate effects for permanent positions and fixed-term contracts, and therefore provide some information on the likely long-term impacts of the policy. Finally, it would be fascinating to extend the analysis to other impacts on French workforce, especially to employment effects for energy providers, as well as understanding better the effect of the policy on local energy prices and energy demand.

6 Appendix

6.1 Graphical representation of placebo test

Figure A3.1 displays the estimation for the 37 members of the donor pool. The energy renovation sector, in bold, is among the top 20 percent of sectors with highest post-policy difference, but it does not seem to be the most impacted after April 2018. However, the significance of the ex-post values depends on the quality of the pretreatment fit. When using the test of Abadie et al. (2010), we find that high post-policy differences in the case of the placebos are due to high variance in model fit, something that does not explain the difference between the energy renovation sector and its synthetic control.

6.2 Calculation of Inference Score and P-Value

The inference test defines a score which compares, for each unit, the quality of the fit in the post treatment period relative to the fit in the pre-treatment period. For each unit i at time T the inference score R_{iT} is defined in Equation (4.4). Basically, it is the ratio between the post-treatment *RMSPE* before the trend and after the pre-treatment *RMSPE*.

$$R_{iT} = \sqrt{\frac{\frac{1}{T-T_0} \sum_{t=T_0}^T (Y_{it} - \sum_{j \neq i}^{J+1} \omega_j Y_{jt})^2}{\frac{1}{T_0-1} \sum_{t=1}^{T_0-1} (Y_{it} - \sum_{j \neq i}^{J+1} \omega_j Y_{jt})^2}} \quad (4.4)$$

The treated unit is supposed to be the only one impacted by the assessed reform. As a result, its ex-post fit must be the worst compared to the ex-ante fit, otherwise it would mean that another sector was more impacted by the reform so that the analysis is not significant. We then expect the treated unit to have the biggest score R_{iT} . Figure A3.2 displays the distribution of the different inference scores for different dates. The energy renovation sector has the biggest score in December 2019, 2020 and 2021. Furthermore, if the December 2019 score is close to the other ones, the December 2021 one seems to be abnormal, showing that the effect becomes more significant by the time. This inference test demonstrates the impacts on jobs our analysis finds out is significant.

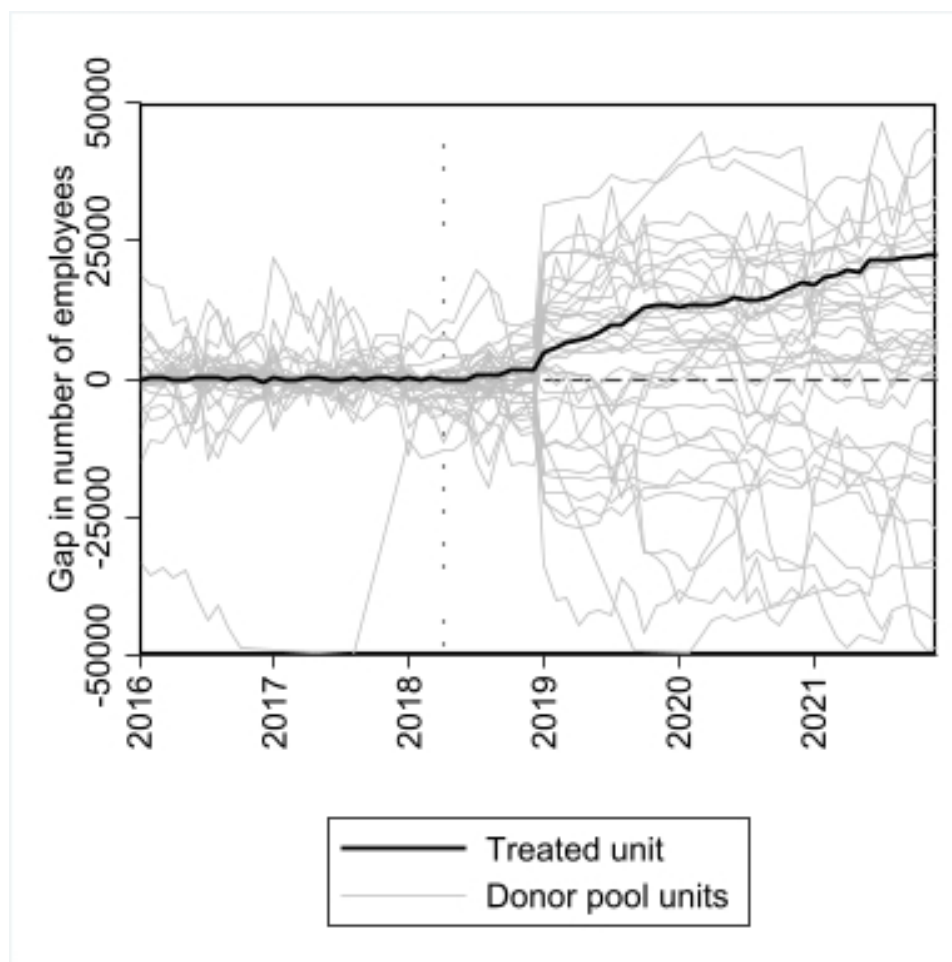
From the inference test score R_{iT} , Abadie (2021) defines a p value p_T to quantify the event study significance. The p value is basically the ration between the ranking of the treated unit in inference score R_{iT} classification and the donor pool size.¹⁸ The exact formula to calculate the p value is given in Equation (4.5).

$$p_T = \frac{1}{J+1} \sum_{j=1}^{J+1} I_+(R_{jT} - R_{1T}) \quad (4.5)$$

With $I_+(x) = \begin{cases} 1 & \text{if } x \geq 0 \\ 0 & \text{if } x < 0 \end{cases}$.

18. As a results, the experience p value is minored by $1/Size_{DP}$

FIGURE A3.1 – Graphical representation of placebo test

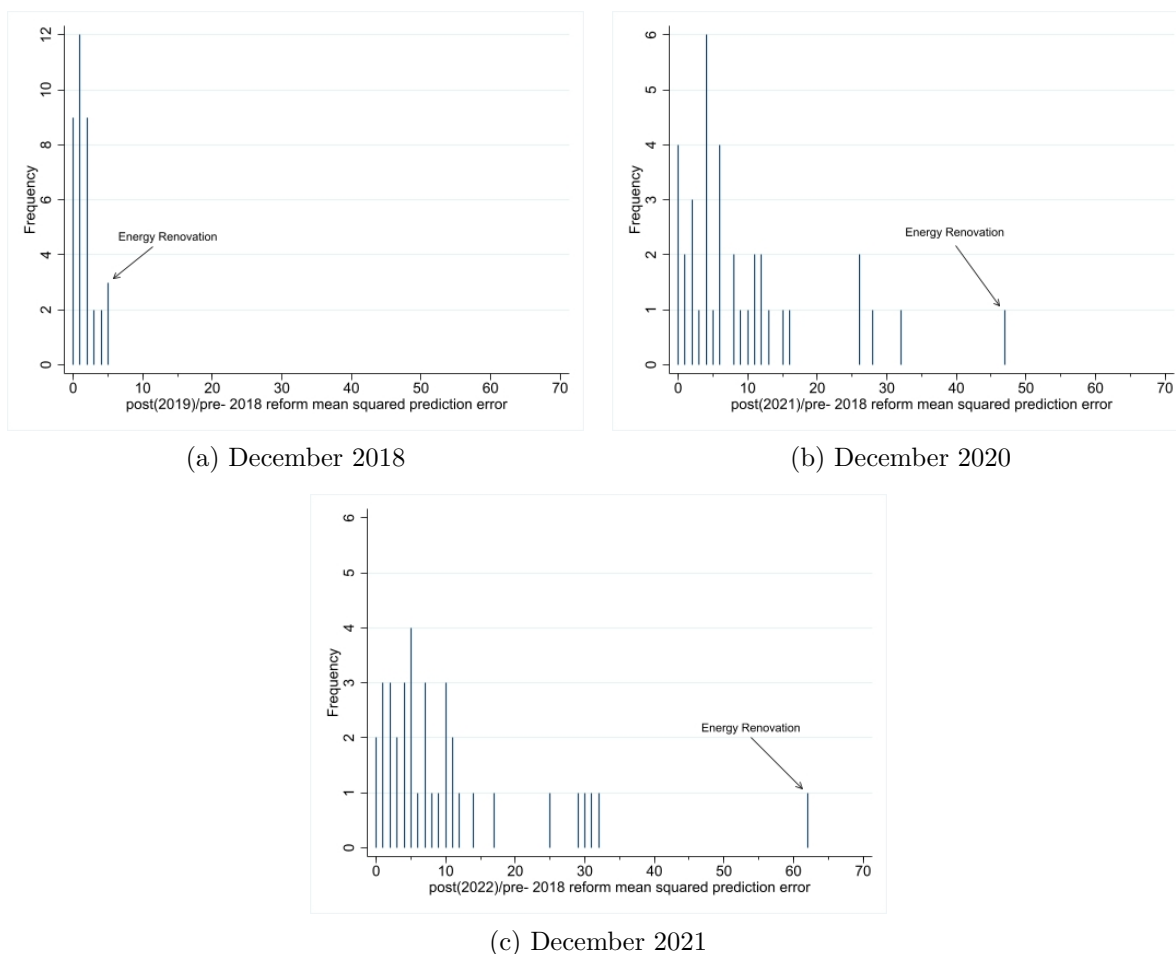


Notes : The y-axis records the difference between a given sector, for instance the energy renovation sector (treated unit in bold) and its synthetic control before and after the implementation of the first reform in March 2018. The placebos are in light gray, and correspond to the difference in employment level between each control sector and their respective synthetic control. The quality of the pre-treatment fit can vary, and therefore large post-policy effects can be explained by poor model fit. These results were obtained using the command *allsynth* in Stata, as provided by Justin C. Wiltshire (2021b))

The p-value corresponds to the share of units in the donor pool which have a higher inference score than the treated unit. Under the assumption that inference scores are normally distributed if there is no treatment, we can compute the probability p_T to obtain an inference score ranking equal or higher than the current ranking of the treated group under the null hypothesis.

6.3 Distribution of inference scores at different periods

FIGURE A3.2 – Inference score ratios of energy renovation and 37 control sectors at different periods



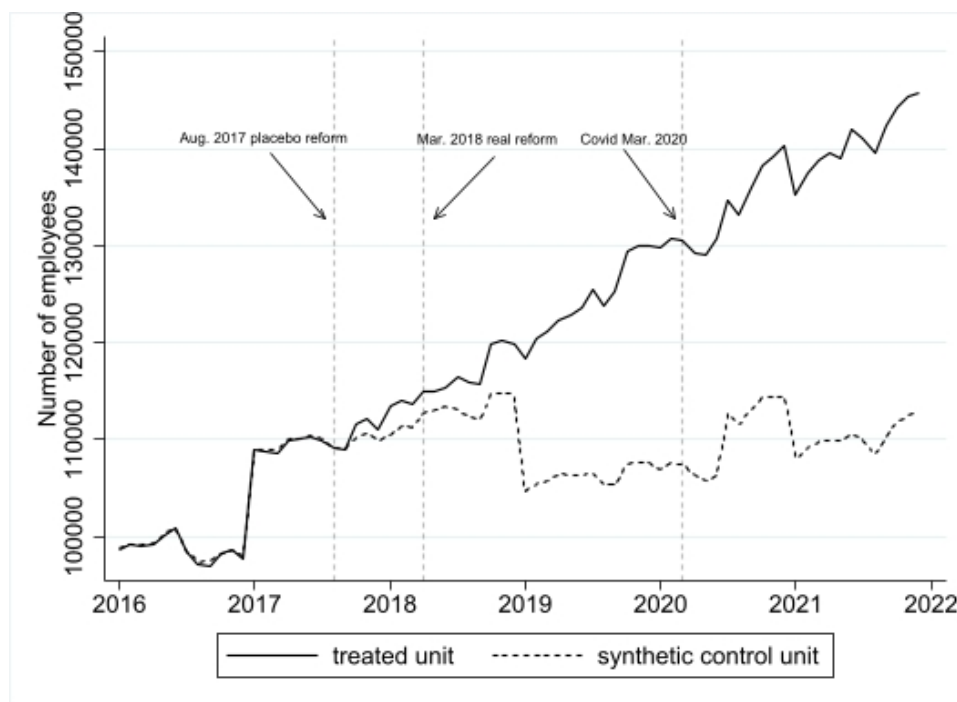
Notes : The graph displays the distribution of the inference score for energy renovation sector and the 37 other donor pool sectors in (a) December 2018, (b) December 2020 and (c) December 2021. The y-axis corresponds to the number of sectors with a given inference score. The formula of the inference score is in Appendix 6.2 and follows Abadie et al. (2010).

6.4 Anticipation Test

For the synthetic control method to be valid, there should be no anticipatory effect of the policy. Abadie, Diamond et Hainmueller (2015) proposes a placebo test to check this. It consists in running the same analysis, but as if the policy reform had occurred a bit earlier. If an effect can be observed during the placebo period, then the non-anticipation condition does not hold.

We perform this test in **Figure A3.3** below. We assume that the reform occurred 7 months earlier, in August 2017. Results do not diverge compared with our analysis with a policy date in March 2018.

FIGURE A3.3 – Trend in national workforce in energy renovation vs synthetic control, assuming a policy start in August 2017



Notes : The full line represents the evolution of the workforce in the energy renovation sector, the dotted line displays the evolution for its synthetic control group, assuming a policy start in August 2017.

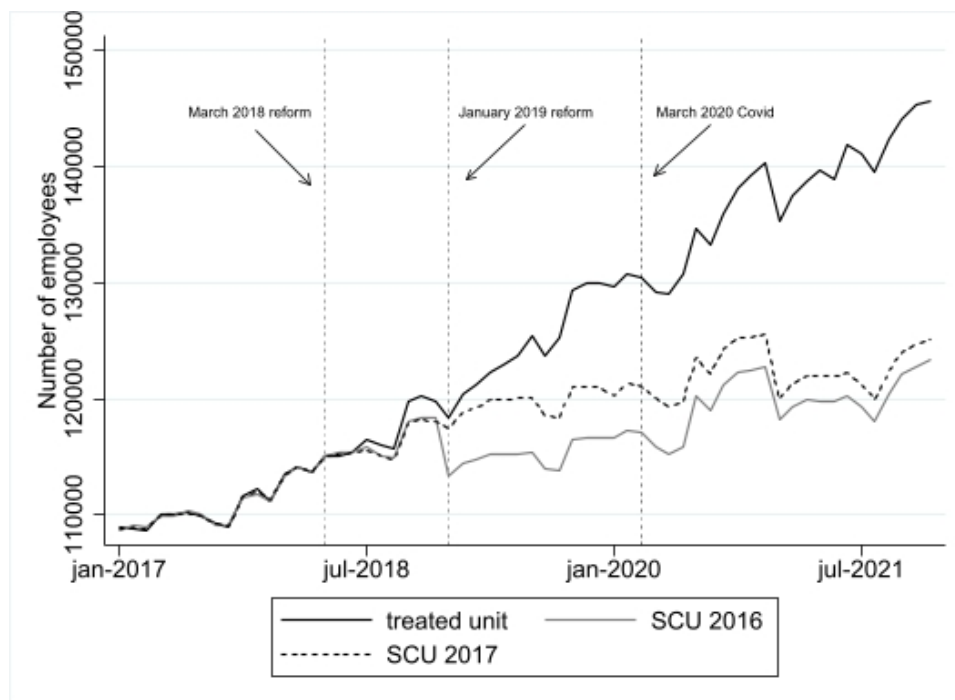
In **Figure A3.3**, it can be observed that the trend for the energy renovation differs from its synthetic control group before April 2018. It argues that the placebo test is not perfectly passed and there seem to be some anticipation effects. Nevertheless, as in the main specification **figure 3.4** the sensible changes occur only from the year 2019. As a result, we can still argue our analysis to be robust to the placebo test, and the effect we measure to be mainly caused by the 2018 reform.

6.5 Model only using data from 2017 onwards

There is a discontinuity in job estimates between December 2016 and January 2017 in our data, plausibly because reporting became compulsory in January 2017. In this appendix, we run our synthetic control model with data from January 2017 only, to assess whether using earlier data could impair our analysis. **Figure A3.4** displays the evolution of the number of employees in France for energy renovation sector, the baseline synthetic control group using 2016-2018 data, and an alternative synthetic control group using 2017-2018 data only. Results with both synthetic control groups are sensibly the same. However, we lose some precision when only using data from 2017 onwards. When running the inference tests, the p-value is 0.081 in March 2020,

and 0.027 from December 2020 with the alternative synthetic control group.

FIGURE A3.4 – Trend in national workforce in energy renovation vs synthetic control, using only data since 2017 for fitting



Notes : The full black line (treated unit) represents the evolution of the workforce in the energy renovation sector. The gray line (SCU 2016) is for the baseline synthetic control unit relying on data from 2016 onwards. The dotted line (SCU 2017) is for the alternative synthetic control group using only data from 2017 onwards.

6.6 Construction

As a robustness check, we run our analysis at a larger scale using two digits sector codes. In particular, we explore the effect of the reform on both "new construction" and "specialized construction" sectors¹⁹. **Figure A3.5** displays the results for both sectors. Although, it does not provide any statistically significant result, both p-value are higher than 0.40 in February 2020, this analysis suggests that, on the one hand, the "specialized construction" sector also widely benefited from the reform. On the other hand, there might have been a reallocation phenomenon from "new construction" sector to "specialized construction" one.²⁰

19. The corresponding code are respectively "41" and "43". Both "insulation" and the "installation of heating equipment" sectors are part of the "specialized construction" sector. The sector "42" is almost insignificant

20. The **Figure A3.5** seems to show very significant results for the "specialized construction group". However this is because, this sector is one of the biggest in absolute in France. As a results, when it is compared to other sectors in term of absolute workforce evolution it appears as being much more impacted. Nevertheless, its size prevents the sector from having a good ex-ante fit and thus makes the post-treatment estimates non statistically significant.

FIGURE A3.5 – Results for "specialized construction" and "new construction" sectors



Notes : The y-axis records the difference between a given sector, for instance the energy renovation sector (treated unit in bold) and its synthetic control before and after the implementation of the first reform in March 2018. The placebos are in light gray, and correspond to the difference in employment level between each control sector and their respective synthetic control. The quality of the pre-treatment fit can vary, and therefore large post-policy effects can be explained by poor model fit. These results were obtained using the command *allsynth* in Stata, as provided by Justin C. Wiltshire (2021b)). The graph displays two estimations : (a) represents "specialized construction" and was run with < 5 as criterion for (Y_{1T-1}/Y_{iT-1}) and (Y_{iT-1}/Y_{1T-1}) ; (b) represents "new construction" and was run with < 5 as criterion for (Y_{1T-1}/Y_{iT-1}) and (Y_{iT-1}/Y_{1T-1}) .

Conclusion

1 Summary of findings

Relying on a French panel of households followed between 2000 and 2013, **Chapter 1** provides new evidence for questioning the energy efficiency gap. I find that households who renovated their dwelling reduced their energy expenditure by 4.97%. It represents EUR 17 saved per year for each EUR 1,000 invested. Regarding carbon emissions, the results have the same magnitude, with a 5.55% reduction after refurbishment. I compare my result with the engineering model used to calibrate the French main retrofit policy, the CEE program which involves Energy Efficiency Obligations. This model associates an amount of energy savings to each type of retrofit operation. My results suggest that the CEE scheme overestimates by 40% the impact of the renovation works it subsidizes which is in line with other estimations in the literature.²¹

Chapter 2 explores the distributional effect of the French CEE program. In particular, we assess the effect of a reform enacted to orientate energy retrofit subsidies towards low-income households. My results suggest that the reform succeeded in making the scheme progressive. Indeed, in 2019, the policy tool costed the 50% richest households an average of EUR 24 whereas the households from the first income quartile received an average of EUR 100 from the program. French government had implemented two mechanisms in order to make the scheme target low-income households : a sub-obligation and bonus certificates. Chapter 2 demonstrates that the sub-obligation was useless, and the progressive impact was reached only through the bonuses mechanism. As a result, social justice was achieved at the expense of the program's effect on energy savings. Besides, our analysis expects the policy to turn back regressive in the future because of a new regulatory framework and involved parties' banking strategies.

Chapter 3 provides the first precise analyse of energy retrofit support policy impact on employment in the renovation industries. I exploit a sharp discontinuity in the French EEOs to estimate the employment effect of the largest energy retrofit policy in Europe. I use a synthetic control method following Abadie et Gardeazabal (2003) and I compare the insulation works and heating systems sectors to a virtual counterfactual made of a convex weighted average of other sectors. This analysis detects a strong increase in employment in energy renovation following two reforms in March 2018 and January 2019, with about 7.5 jobs sustained for each EUR million invested every year through the French EEOs. The results are consistent in magnitude with the

21. Fowlie, Greenstone et Wolfram (2018) find a gap in a range of 30% and 50%.

target of employment claimed by governments about energy retrofit policies.

2 Policy implications

This thesis is in line with a growing literature that questions the actual impacts of energy retrofit on residential consumption as opposed to the impact estimated by engineering models. The "energy efficiency gap" seems to have been overtaken by the "energy performance gap". Future retrofit policies implemented must bridge this gap and focus on improving the average renovation quality. As discussed in **Chapter 1**, energy retrofit market has similarities with the Akerloff's "Market for Lemons" (Akerlof 1970). Energy renovation is a credence good whose quality is hard to assess before and after undertaking the operation. Therefore, information asymmetry appears as the main source of low energy efficiency delivery of retrofit operations. In particular, renovation companies take advantage of their better knowledge to under-perform during the construction (Giraudet, Houde et Maher 2018; Christensen et al. 2021). I strongly advocate for restrictive quality labeling in order to ensure an high average level of performance in the renovation sector. The CEE policy in France involved roughly EUR 4 billion in 2019. This amount was almost integrally dedicated to subsidies and intermediaries. Part of the financial flows induced by the scheme should be used to train the retrofit workforce in order to provide them quality labels. Moreover, the program must strongly focus on quality controls which are at a very low level considering the CEE scheme's magnitude. At least 1% of the program's financial manna should be dedicated to control. Finally, on the demand-side, households should be supported during their projects, with more third parties ex-ante diagnosis and project management assistance during construction, both funded through the scheme.

The CEE program specifically suffers from an hazardous governance. Shocks like the "Coup de Pouce" reform²² are too frequent in the scheme to permit actors to roll out long-term strategies (Glachant, Kahn et Lévêque 2020b). This hampers the development of a resilient and high end renovation sector in France. Those repeated regulatory shocks encourage opportunistic behavior from short-term actors who have no incentives to enhance their reputation. Therefore, I advocate for a more stable regulatory framework even if it means reducing the periods' duration. The CEE program's efficiency is also hindered by the opacity of the engineering model implementation process. There is no information about how are built the CEE "datasheets" that associate to each type of retrofit an amount of certificates quantified in MWh. Each datasheet is defined after a discussion involving, the Minsitry of Ecology, the ADEME²³, obligated parties, renovation professionals and manufacturers. Consumer organizations do not participate in this process, although they are also a major actor of the program. More widely, the ADEME's role regarding the policy is problematic. The agency is both judge and party, since it is proactive in the program design but is also in charge of its official evaluation. As a result I also advocate for more ambitious CEE scheme evaluations performed by a public actor that is independent from the scheme.

22. Analyzed in **Chapter 2 and 3**

23. a French public independent agency which advises the state on environmental and energy topics

Improving the scheme’s governance and the average quality of the works it supports appears even more paramount considering the positive spillovers retrofit policies might engender. First of all, as discussed in **Chapter 2** when specific rules are implemented, EEO programs might generate positive distributional effects, as the CEE program did during the 4th period. I still recommend not to use a bonus mechanism to achieve social objectives through EEO program because it reduces policy’s global efficiency. Sub-obligations are better suited to pursue these types of objectives²⁴. Bonuses might be more efficient in awarding qualitative approaches, such as audits or project management assistance. Furthermore, the energy renovation sector is called upon to play a major role in the energy transition. **Chapter 3** demonstrates that retrofit support policies generate a significant amount of jobs, even though this thesis cannot assess the long-term effect on employment of such policies.

3 Avenues for future research

Quality is the main issue surrounding energy retrofit works, and the performance gap is argued to come from information asymmetry. Therefore, future research must strive to assess the effect of the informational context on the energy savings achieved. Giraudet, Houde et Maher (2018) already assess the effect of the context on average quality, but only from the supply-side point of view. They show that renovation are less efficient when achieved on a Friday²⁵, suggesting that the workforce performance has a significant impact on savings. These effects must be studied on the demand-side, for instance, by estimating the effect of an ex-ante diagnosis on renovation performance. The Energy Efficiency Obligations programs remain a vast area of studies. On the one hand, my work does not assess directly the effect of the CEE scheme on savings, and to my knowledge, there is still no empirical evidence about any EEO program’s impact on energy consumption. On the other hand, the EEOs price effect potential impacts are also an important question as it marks its very difference with a classical subsidy policy. In particular, assessing the effect of an EEO program-induced price increase on households’ investments appears a promising research.

Furthermore, whereas my thesis points out positive distributional impact induced by retrofit policies, there is few empirical evidence on a potential heterogeneous renovation effect between low and high income households. On the one hand, low-income households live in worst quality homes and thus represent an higher field of potential savings. On the other hand, low-income households are more likely to produce a rebound effect. If renovation are proven more efficient into low-income homes, it could be interesting to mainly focus on these type of households.

Last but not least, the global value-chain of energy retrofit deserves a specific analysis. My research underlines a positive effect on employment, but it must be taken a step further. Especially, a substantial question remains about how resilient these jobs are. The sector might have only taken advantage of current grants to develop in the short run, but without any long-

24. Actually, the 5th period of the CEE program, which has started January 1st 2022, removed almost integrally bonus mechanism and will rely on sub-obligations to target low-income households(JORF 2021)

25. Especially when the operation involves a performance whose quality is hard to check for households, such as insulation

term impact. My third chapter might be deepened by running an analysis comparing the effect on open-ended and fixed-term contracts. Besides the bonuses regime has almost stopped since January 2022. The quantity of subsidies could now be reducing, it would thus be paramount to light up the employment effect of the CEE policy after 2022. Finally, beyond employment consequences, the effect of retrofit policies on the upstream of the value chain remains one of the main gap in the literature. An analysis of the French EEO program's effect on revenues and profits of involved company would be a major contribution.

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RÉSUMÉ

Cette thèse évalue les effets des investissements dans l'efficacité énergétique et les politiques publiques qui les soutiennent. Elle est construite autour de trois analyses empiriques et se concentre sur les économies d'énergie, les émissions de CO₂, les effets redistributifs et la création d'emplois.

A partir de données de panel, le **Chapitre 1** évalue l'effet de la rénovation énergétique des bâtiments sur la facture énergétique et les émissions de CO₂ des ménages. L'analyse repose sur un estimateur à la Chaisemartin et d'Haultfoeuille (2021). Un placebo test garantit l'endogénéité du traitement et l'hypothèse d'évolution parallèle. L'effet estimé est une réduction de 4.97% de la facture énergétique chez les ménages rénovateurs, soit une économie de 17 € par an pour 1000 € investis. Mes résultats suggèrent que le dispositif CEE surestime de 40% l'effet des travaux qu'il finance. Par ailleurs, les ménages rénovateurs réduisent leurs émissions de CO₂ de 5.52%. Le **Chapitre 2** s'intéresse aux effets redistributifs du dispositif CEE. En particulier, il évalue les conséquences d'une réforme de 2016 qui a obligé et incité les parties prenantes du dispositif à financer des projets de rénovation chez les ménages précaires. Le **Chapitre 2** montre que cette réforme a fonctionné, les ménages du premier quartile de revenu ont reçu en moyenne 100 € du dispositif en 2019, tandis que pour les 50% les plus aisés, le dispositif a représenté un coût de 26€. A partir de données agrégées par code NAF à l'échelle nationale, le **Chapitre 3** évalue l'effet du dispositif CEE sur l'emploi dans la rénovation énergétique. L'analyse recourt à une méthode de groupe de contrôle synthétique développée par Abadie et Gardeazabal (2003). Les résultats sont statistiquement positifs, 15 000 emplois ont été créés par la politique en 2019-2020 soit environ 7.5 emplois par millions € investi.

Cette thèse remet sensiblement en question les effets de la rénovation des bâtiments sur la consommation d'énergie. Dans le cas français, des problèmes de gouvernance entravent la qualité moyenne des travaux réalisés. Régler ces problèmes de qualité est d'autant plus primordial que mes travaux montrent que les politiques de rénovation énergétique ont des effets redistributifs et génèrent des emplois.

MOTS CLÉS

Economie de l'Energie, Politiques Publiques, Econométrie Appliquée, Certificats d'Economie d'Energie

ABSTRACT

This thesis explores the impact and effectiveness of energy efficiency investments and related public policies in the French residential sector. It is based on three empirical analysis that focus on energy expenditures, carbon emissions, distributional effects and jobs development.

Relying on panel micro data covering year 2000 to 2013, **Chapter 1** examines the impact of residential energy retrofit on energy expenditures and carbon emissions in France. Since there is treatment timing variation, I use an estimator à la de Chaisemartin and d'Haultfoeuille (2021). The endogeneity of the investment decision is addressed with placebo tests validating the ex-ante parallel trend assumption and household fixed-effects. I find significant but mild effects. My best estimate is that the average retrofit reduces energy expenditures by 4.97%. Put differently, an investment of EUR 1,000 leads to an annual saving of EUR 17 on energy expenditures. I find that the main French energy retrofit policy, the CEE program, overestimates by 40% the effect of the operations it subsidizes. Carbon emissions decrease a little bit more, with a 5.52% reduction for each EUR 1,000 invested. **Chapter 2** assesses the potential distributional effect of Energy Efficiency Obligations programs. In particular, I assess the impact of a 2016 regulatory change in the CEE scheme that was made to target low-income households. Obligated parties were required to support energy retrofits of dwellings occupied by lower-income households. I find that it worked. According to my estimates, it resulted in an average net annual cost of EUR 26 for households from the third and fourth income quartiles, while households from the first quartile benefit a net EUR 100. Using aggregate employment data by sector in France, **Chapter 3** assesses the effect of the CEE policy on employment in the energy retrofit industries. I use a synthetic control group method, originally developed by Abadie and Gardeazabal (2003) and Abadie et al. (2010). I find a statistically significant impact on employment. I estimate that at least 15,000 jobs were created thanks to the policy, equivalent to 7.5 direct jobs created per million euros invested annually.

This dissertation questions the actual energy retrofit impact on savings. In the case of France, this thesis points out several problems of governance that hamper the quality of achieved works. Addressing these problems appears all the more paramount since my work demonstrates energy retrofit policy might engender several positive spillovers such as distributional effect and job creations.

KEYWORDS

Energy Economics, Public Policies, Applied Econometrics, Energy Efficiency