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Does social housing mitigate fuel poverty?

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Abstract

Fuel poverty in developed countries is a growing concern as between 50 and 125 million Europeans are unable to afford the energy needed for adequate heating, cooking, light, and use of appliances in the home. Tackling fuel poverty has thus become a public policy challenge. The literature reports that rising fuel prices, low incomes, and energy-inefficient housing are the main causes of fuel poverty. However, existing public policies focus mainly on price- and income-based measures to reduce fuel poverty. One government policy, social housing, impacts all three causes of fuel poverty. Since it is highly regulated and heavily influenced by government policies, social housing might be a powerful policy instrument to reduce fuel poverty. Social housing has the potential to fight housing energy inefficiency, which is one cause of fuel poverty, especially as governments promote the construction and renovation of social housing. In this paper, we assess the effectiveness of such measures through matching methods and find that living in social housing decreases fuel poverty by 4.1% to 8.5%, depending on the definition of fuel poverty.

Keywords: Fuel poverty; social housing; social energy subsidy; indoor pollution; matching method

JEL codes: Q41, C52, Q51

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Introduction

An estimated 50 to 125 million people in Europe are fuel poor[4] (Bird et al., 2010; European Fuel Poverty and Energy Efficiency, 2006), and 8.8% of EU27 households were in arrears on their utility bills in 2011 (European University Institute, 2011). These households lack the means to improve the energy efficiency of their often substandard homes: financial hardships are often combined with low energy efficiency of the home and can lead to heating restriction behavior to meet household budget constraints.

Several causes combine to create this fuel poverty situation, even though this phenomenon continues to be treated as solely a monetary problem. Three factors are identified as fuel poverty causes in the literature: rising fuel prices, low incomes, and energy-inefficient housing (EPEE, 2006; IEA, 2011; Rappel, 2011; Palmer et al., 2008). Poor housing conditions such as noise or damp (EPEE, 2006; Phimister et al., 2015) impact well-being at home, and when combined with rising fuel prices, lead to increasing energy bills and problems paying them. Our objective is to assess the effectiveness of social housing on fuel poverty, because social housing is intended to impact the energy efficiency of housing.

Three different approaches are used to measure the phenomenon. First, fuel poverty can be measured as the ratio of energy expenditures to household income. A household can be defined as experiencing fuel poverty if its energy expenditures make up more than 10% of its income (Hills, 2011; Hills, 2012). The second approach is very similar to the well-known indicator of relative poverty: the fuel poor are those with a residual income (i.e. after housing and fuel costs) below a poverty line defined as 60% of the median national equalised income. Finally, “the low income high cost approach” covers households with both low income (residual income below 60% of the national median level) and relatively high energy needs (energy expenditures above the national median level).

Fuel poverty and monetary poverty are inextricably linked: according to Palmer et al. (2008), nearly three-quarters of the fuel poor in England in 2005 were also income poor, showing the multidimensional aspect of poverty. The current French fuel poverty policy was established in

[4] Fuel poverty occurs when a household is unable to afford the most basic levels of energy for adequate heating, cooking, light, and use of appliances in the home.

2010 during the French environment roundtables called ‘‘Grenelle de l’environnement’’, resulting in the law “Grenelle 2” n° 2010-788[5]. The law defines a person suffering from fuel poverty as *“*anyone who encounters, in their home, particular difficulties in obtaining the energy required to meet their basic energy needs due to insufficient resources or housing conditions”.

Three types of policies are commonly cited as measures to reduce fuel poverty: price-based, income-based and energy-efficiency improvement policies (Legendre and Ricci, 2015). Price-based policies consist of social energy subsidies. These were introduced to offer discounted energy bills to those vulnerable to or already in fuel poverty, with special price plans from individual energy suppliers. Price-based policies have given these households the right to a reduction in electricity bills since 2005 and natural gas bills since 2008. This policy is expected to bring some households out of fuel poverty by reducing the relative cost of their consumed energy. Poorer households can also receive income-based assistance in the form of allowances to help them cover their expenditures on housing (housing allowances), energy, and water.

Implementing these price- and income-based policies is supposed to reduce fuel poverty by impacting the two first causes of fuel poverty identified in the literature: rising fuel prices and low incomes (Keirstead, 2008). As previously noted in the literature, however, such measures have only a one-off impact on fuel poverty unless repeated. Energy-efficiency policies, on the contrary, aim to decrease energy consumption in order to reduce vulnerable households’ energy bills and thus reduce exposure to fuel poverty over the long term.

Another public policy, less commonly cited as a measure to reduce fuel poverty, is the development of social housing. Many years ago, the French government began to develop policies to support low-income households and help them to live in decent housing by providing social housing. This measure is primarily seen as a social policy designed to reduce the vulnerability of low-income earners, especially given the weight of housing expenditures in the households’ budget.

However, social housing may also reduce fuel poverty, which results from both a lack of resources and unfavorable housing characteristics. In France, 70% of the households experiencing fuel poverty belong to the lowest quartile of standard of living, and 87% were

[5] Loi n° 2010-788 du 12 juillet 2010 portant sur l’engagement national pour l’environnement [Law passed on July 12, 2010 defining France’s commitment to the environment].

private housing tenants in 2015 (*Ministère de l'Environnement de l'Énergie et de la Mer,* 2015). Social housing is consequently intended to aid these households by impacting the third cause of fuel poverty, energy-inefficient housing. Social housing could be a powerful policy instrument in reducing fuel poverty as this housing sector is highly regulated and heavily influenced by government policies (Reeves et al., 2010).

This article investigates whether social housing significantly impacts fuel poverty in France, assuming this policy affects the three causes of this phenomenon identified in the literature. Based on an innovative recent French survey specially dedicated to energy consumption (PHEBUS), this assessment of public housing policy in keeping poor households out of fuel poverty is conducted using matching methods. Considering that fuel poverty still lacks a commonly agreed-upon definition, we use different measures of fuel poverty[6].

The rest of the paper is organized as follows: the first part discusses social housing in France and the second presents the data used. In the third part, we explain our method. Finally, the results are reported and analyzed in the last part before concluding.

I. Social housing in France

Social housing in France offers decent, low-rent housing to persons whose income does not exceed certain thresholds. Rented public housing units can be created following a public or private initiative. More than 10 million French people are tenants in the 4.7 million public housing units (*Ministère du logement et de l'habitat durable*, 2015). In France there are 69.2 social housing units for every 1,000 inhabitants, but large disparities exist among European countries, such as Spain with 3 social housing units for every 1,000 inhabitants or Netherlands with 147 social housing units for every 1,000 inhabitants (J.CH, 2008).

Social housing is likely to pollute less than private rental housing. Some studies have indeed demonstrated that social housing offers better energy performance (Devalière et al., 2011)

[6] We exclude from the sample households using a collective heating system and which do not declare the amount of their collective charges dedicated to heating system or hot water use. Indeed, we cannot calculate an accurate energy expenditure for these households. Consequently, we slightly underestimate households using a collective heating in our sample (in France 46% of tenants living in social sector have a collective heating (against 32,4% in our sample) and 19% of tenants living in private sector (against 17,5% in our sample) (Devalière et al. 2011)

because it is managed by public policies (Keirstead, 2008) and thus offers better opportunities for carbon reduction (Teli et al., 2015) or installation of energy-saving devices (Reeves et al., 2010). Social housing thus has the potential to fight housing energy inefficiency, which is one cause of fuel poverty.

In its investment plan for housing, the French government committed to introducing financial support (such as a reduced rate of value-added tax on the construction of social housing) in order to promote the construction and renovation of social housing. The objective is set at 150,000 new social housing units and 120,000 renovations a year by 2017. Given the cost and the potential extensions of this social policy, our objective is to assess its effectiveness in mitigating fuel poverty, in terms of its effect on fuel poverty causes.

II. Data

i. Data description

To study the effect of social housing on fuel poverty, we use the 2013 *PHEBUS* (*Housing performance, equipment, needs, and uses of energy survey*) database.

The *Housing performance, equipment, needs, and uses of energy survey* is a new French government survey[7]. This random survey consists of two parts conducted separately: a face-to-face interview with the occupants of the home about their energy consumption expenditures and attitudes, and an energy performance diagnosis of the housing[8]. The survey aims to provide information about the energy performance of the housing stock, allowing for analysis according to household characteristics (such as disposable income per adult equivalent or household size) and household appliances, as well as their energy use and consumption. Attitudes towards energy consumption are also available through this survey (we know, for example, the household's indoor temperature and the beginning and the end of the heating period).

[7] The Operation Managers of the survey are: Ministry of Ecology, Sustainable Development and Energy (MEDDE); General Commission for Sustainable Development (MEDDTL); Service Observation and Statistics (SOeS); under the direction of housing and construction statistics; under the direction of energy statistics

[8] The energy performance diagnosis is a document that provides an estimate of the energy consumption and greenhouse gas emissions of a dwelling, and gives it an energy label. It is part of the technical diagnostics record, which also includes asbestos diagnostics, termites, lead, and the status of indoor facilities for electricity and gas. This diagnosis has been mandatory since 1 November 2006 when a dwelling is sold and since 1 July 2007 when a unit is leased. The display of the unit's energy performance rating in real estate agencies has been mandatory since 1 January 2011. The diagnosis, which is valid for 10 years, was provided free to the participant at the end of the survey.

This survey provides very detailed information on energy consumption by type of fuel, energy costs, and energy tariffs. We know if households live in social or private housing and if they are eligible for a social energy subsidy for gas and electricity.

We group variables into 3 main categories: socio-demographic household characteristics (socio-professional category, disposable income, and behavioral and preference variables), building characteristics (period of construction, type of housing, type of heating system, type of fuel, and renovations), and location (climate area and urban area size).

The present paper studies fuel poverty using not only disposable income but also information about energy expenditures and attitudes towards energy consumption. To our knowledge, this dataset is one of the most precise and richest surveys in this field of research. Our sample contains 993 tenants[9] and is representative of the French population (the sample is weighted to ensure representativeness).

ii. Fuel poverty and descriptive statistics

A widely used measure of fuel poverty is the energy-income ratio (De Quero and Lapostolet, 2009). Boardman (2010) considers that a "household is in fuel poverty if it needs to spend more than 10% of its income on fuel to maintain a satisfactory heating regime and all other energy services". Today, while there are numerous criticisms of this 10% ratio approach and more generally to the exclusive cost/income approach, these definitions remain commonly used.

The *Low Income-High Costs* (LIHC) indicator is an alternative measurement framework focusing on the overlap of high costs and low income (Hills, 2011). This definition is the one used by French national entities such as *ONPE (Observatoire National de la Précarité Energétique)*. According to the low income high costs approach, a household is considered energy poor if (i) its income minus housing and energy expenditures per adult equivalent is below 60% of the national

[9] We exclude from the sample households using a collective heating system and who thus do not declare the amount of their collective charges dedicated to heating or hot water use. Indeed, we cannot calculate accurate energy expenditures for these households. Consequently, we slightly underestimate households using collective heating in our sample: in France 46% of tenants living in social housing have collective heating (against 32,4% in our sample), as do 19% of tenants living in private sector (against 17,5% in our sample) (Devalière et *al*. 2011)

median level, and (ii) its energy expenditure per square meter is higher than the national median level. In our analysis, we retain these two definitions.

The main summary statistics about fuel-poor households according to each definition are presented in Table 5 of Appendix A. In France, the percentage of fuel poor according to the 10% ratio approach is 9.85%; 18.49% according to the Hills definition, while 6.29% of French households are considered fuel poor if we consider both definitions[10]. Fuel-poor households restrict their energy consumption to reduce their bills (45% on average vs. 33% for the total sample). Their disposable income is almost two times lower than the average (around €15,000 a year vs. €27,000). More than the half of fuel-poor households live in the coldest climate area (area H1) and prefer saving energy rather than using their heating system to obtain a comfortable temperature, which seems to be consistent with their financial situation.

In the database, 37.2 % of tenants live in social housing (or 422 households). The rent is on average €391.30 (or €5.90 per square meter) a month as opposed to €558.80 (or €10.50 per square meter) for tenants in the private sector. Moreover, 2.8% of households (or 108 households) are eligible for a social energy subsidy for gas or electricity. The amount of the deduction due to the social energy subsidy is 118.40 €/year, which represents 14.6% of the total energy bill of eligible households in our data. We remove the sample households that benefited from two policies: social housing and social energy subsidies (74 households)[11], in order to isolate and measure the effect of social housing on fuel poverty. This means that the 422 tenants living in social housing in our sample do not receive the social energy subsidy.

Generally speaking, households who are eligible for social housing are blue-collar workers or office workers with low disposable income, and they live in big cities. The profile of households who are eligible for both social housing and social energy subsidies is generally the same, except that their social housing tends to be newer (see table 6 in Appendix A). Overall, on average, households who live in social housing live in more recent units than tenants living in private housing (Figure 1), which is consistent with the literature (Keirstead, 2008). Energy expenditures

[10] The *PHEBUS* survey is conducted one time; therefore we study fuel poverty in one year. We cannot measure the sensitivity of fuel poverty according to the variability of energy prices. However, heating with electricity and gas are the most common in our sample, and the prices of electricity and gas are less variable than that of oil products.

[11] Consequently, we remove from the sample households that do not declare if they benefit from social energy subsidies for electricity or gas.

per square meter are also slightly lower in social housing than for tenants in private housing on average (17.28 €/m^2 vs. 18.78 €/m^2). The share of energy expenditures included in collective charges is higher in social housing (as collective heating is more commonly used).

The percentage of gas in total energy consumption is higher in social housing, whereas the share of fuel oil is significantly lower than tenants in private housing. Gas is the most commonly used energy for heating systems in social housing, while electricity dominates in private housing.

Even though they are low-income households, few households experiencing fuel poverty live in social housing. Only between 9.0% and 14% of fuel-poor households, depending on the definition used, have access to social housing.

Figure 1 Periods of construction and social housing

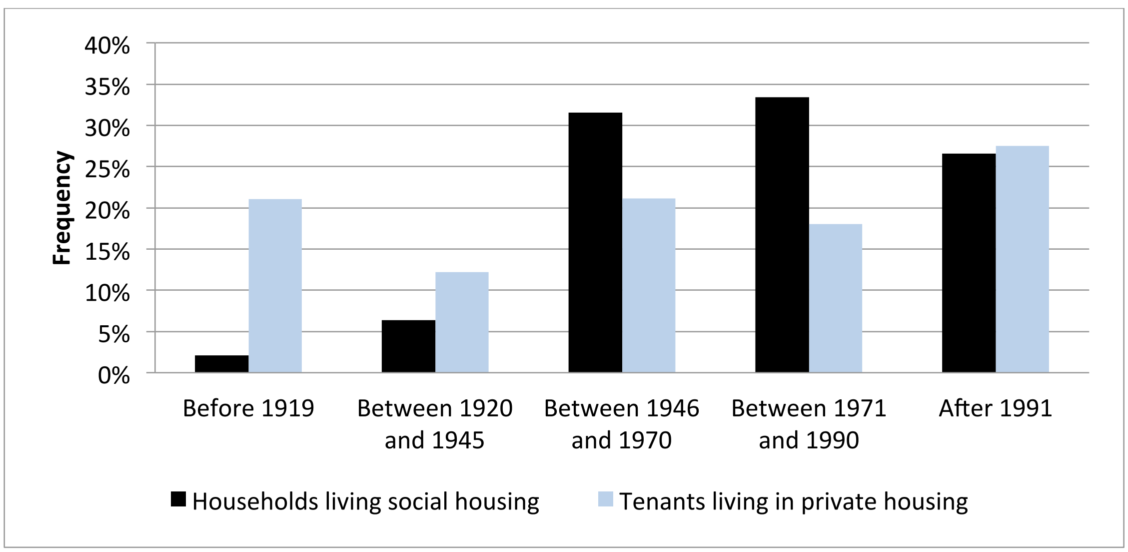

Table 1 Energy expenditures and social housing

	Households living in social housing	Tenants living in private housing
Rent (€/m2)	5.9	10.5
Energy expenditures (in euros)	1,164	1,138
Energy expenditures per square meter (in €/m2)	17.28	18.78
Share of collective charges in energy expenditures (in %)	18.3	4.50
Energy use for heating system		

Electricity	26.1	60.8
Gas	70.4	26.3
Fuel oil	2.9	9.8
Other	2.1	6.8
Observations	422	571

III. Method

We are interested in estimating the causal effect of social housing on fuel poverty. To do this, we use matching methods, which allow us to evaluate the effect after controlling for the observable characteristics of each observation.

A vector x of control variables represents personal attributes and housing characteristics. The binary variable (the treatment variable) denoted R indicates whether the household lives in social housing or not. For the treated sample, $R = 1$ and for the control group, $R = 0$.

Only a perfectly randomized evaluation can avoid selection bias in the estimate. In that case, comparing the outcome variable difference between treated and untreated individuals provides the impact of the treatment (Rubin, 1974). However, in most cases independence between the probability of being treated and personal attributes can absolutely not be assumed. In our case, benefitting from a public policy is undoubtedly strongly linked with household characteristics including housing conditions. The present study is based on non-experimental data, so we use a non-experimental method to estimate the impact of public policies on fuel poverty. The impact of public policy ($\beta(x)$) should ideally be the difference between the outcome variable for the treated households (Y_1) and this variable if the household had not been treated (Y_0):

$$\beta(x) = E[Y_1 / R = 1, X = x] - E[Y_0 / R = 1, X = x] \quad [2]$$

where:

$$Y = RY_1 + (1 - R)Y_0 \quad [3]$$

Y_0 and Y_1 cannot be observed simultaneously. Therefore the counterfactual situation (i.e. $E[Y_0/\ R=1, X=x]$) has to be estimated. We use matching estimators, which requires matching each treated household (which benefits from social housing) with households from the control group (which lacks access to this public policy, i.e. tenant living in private housing). Rubin (1974) proposes matching observations by observable characteristics. Each beneficiary of public policy is matched to a non-beneficiary on the basis of the probability of living in social housing conditionally on the different observed characteristics x. This conditional probability is the propensity score (Rosembaum and Rubin, 1983). Rosembaum and Rubin (1983) show that matching on estimated $R(x)$ is as good as matching on x. Key assumptions for identification of the constraint effect are conditional independence–or *unconfoundedness*--and the presence of a propensity score density common support (Heckman et al., 1999). Under those assumptions, the average treatment effect is then equal to the mean difference in fuel poverty rate, over the common support. We assess the sensitivity of the results compared to the conditional independence assumption in the appendix (part B2).

A nonparametric matching estimator, kernel matching, is used to construct a counterfactual match for each treated unit by using the weighted average of all untreated units. The weights $(\omega(.))$ for kernel matching are given by:

$$\omega(i.j) = \frac{K\left(\frac{P_j - P_i}{a_n}\right)}{\sum_{k \in C}\left(\frac{P_k - P_i}{a_n}\right)} \qquad [4]$$

where P_i is the propensity score for a constrained household and P_j the propensity score for an untreated household included in the control sample (C). K(.) is a kernel function and a_n a bandwidth parameter. Robust standard errors are calculated using bootstrapping, as the estimators are asymptotically linear. Bootstrapping standard errors also takes into account the variance due to the derivation of the propensity score matching and the determination of the common support (Efron and Tibshirani, 1993; Heckman et al., 1997; Horowitz, 2003).

IV. Results

i. Propensity scores

To estimate the effect of this social measure, we first match households from the treated group (households that benefit from social housing)[12] and control group (tenants living in private housing) on the basis of the propensity scores –the probability of living in social housing. We consider in the analysis household characteristics, building characteristics, and location. We estimate these probabilities using logit models; our results are presented in Table 2. Several control variables have an impact on the probability of being eligible for this social policy.

Table 2 Propensity score

	Social housing		
Variables	Marginal effects		Standard errors
Household characteristics			
1st income decile	ref		
2nd income decile	0.0498		0.0467
3rd income decile	-0.0827	*	0.0495
4th income decile	-.01679	***	0.0545
5th income decile	-0.2799	***	0.0456
Number of persons in the household	0.0709	***	0.0157
Building characteristics			
Year of construction before 1945	ref		
Year of construction between 1946-1970	0.4048	***	0.0492
Year of construction between 1971-1990	0.4892	***	0.0441
Year of construction 1991 and after	0.3827	***	0.0506
Renovations in the five last years	0.0906	**	0.0382
Surface area below 80 m2	0.0808	*	0.0417
Location			
Agglomeration size < 2,000 inhbts	ref		
Agglomeration size 2,000 - 99,999 inhbts	0.0891	*	0.0512
Agglomeration size > 100,000 inhbts	0.1585	***	0.0419
Climate area H1 (the coldest)	0.2012	***	0.0333
Climate area H2 and H3	ref		
Number of observations	993		
Number of treated	422		
Correct prediction rate	69.18%		
Pseudo-R2	0.1564		

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

[12] As a reminder, we excluded from the sample households that benefit from both social housing and social energy subsidies in order to measure only the effect of social housing on fuel poverty.

The propensity score of a household living in social housing is significantly influenced by disposable income. The estimate also suggests that period of construction and agglomeration size are strongly significant and positive.
The propensity scores allow us to match a household from the treated group with an equivalent household from the control group. The balancing assumption between characteristics of treated and control groups is valid.

Moreover, to verify that the household characteristics of the treated and control groups are similar after matching, we use two indicators: the standardized percentage bias (Rosenbaum and Rubin, 1983) and overall explanatory power of the propensity score estimates (Table 3)[13]. (i) The overall bias decreases significantly after matching, from 18.1% to 1.9%. The deviation of household characteristics of the control group from those of the treated group, before and after matching, is largely reduced after matching (See Figures 2 and 3 in appendix B1). (ii) We study the overall explanatory power of the propensity score estimates using the likelihood ratio (LR) chi-square test. This test enables us to conclude that before matching, at least one of the regression coefficients in the model is not equal to zero. In contrast, all regression coefficients are simultaneously equal to zero after matching. Considering these results, we can use the matched sample to estimate the effect of social housing.

Table 3 Matching quality

	Standardized percentage bias	**LR χ^2**
Before matching	18.1%	212.74 $p > \chi^2 = 0.000$ ***
After matching	1.9%	1.42 $p > \chi^2 = 1.000$ ns
Number of observations	993	

ii. Causal effects

[13] See appendix B for a more detailed presentation of these indicators.

We first estimate the impact of social housing using the kernel-matching estimator, which enables us to assess the differential of fuel poverty rate between similar treated (i.e. households living in social housing) and control households (Table 4).

Table 4 Causal effect of social housing on fuel poverty, according to definitions of fuel poverty

	Energy expenditure / Income > 10%	**Low income – High cost approach**
Effect of social housing	-0.0410	-0.0852
Standard error	0.0221*	0.0293***
Number of observations	993	
Number of households living in social housing	422	

Note 1: Bootstrapped standard errors are obtained after 10,000 replications.
Note 2: ***significant at 1%; **significant at 5%; *significant at 10%.

Living in social housing led to a 4.10 % decrease in fuel poverty with the 10% ratio approach and an 8.52% decrease with the low income-high cost definition. The sensitivity of the results to a deviation from the assumption of conditional independence of potential outcomes (CIA) is presented in Appendix B2 (Table 7).

Conclusion

In this paper, using an innovative recent French survey specially dedicated to energy consumption (PHEBUS), we empirically evaluated a social public policy, subsidized housing, by estimating its causal effect on fuel poverty. We conclude that social housing is an efficient public policy to tackle fuel poverty. Living in social housing led to a 4.1-8.5% decrease in fuel poverty depending on the fuel poverty definition. Whereas price- and income-based policies suffer from important limitations, social housing seems to be a more complete approach to tackling fuel poverty: it directly impacts housing quality, one cause of fuel poverty, as this housing stock is directly managed by the public sector.

These results could have strong implications: implementing effective policies to reduce fuel poverty could also help reach environmental objectives. Expanding social housing can be a useful measure in tackling fuel poverty through its impact on housing energy efficiency, one cause of fuel poverty.

The Investment Plan for Housing, announced in March 2013 by the President of France, aims to mobilize considerable resources for social housing. The objective is to promote the creation and renovation of social housing. The goal is to renovate 500,000 units per year, including 120,000 social housing units *(République Française*, 2013). If this objective is reached, living in social housing will become a driver of fuel poverty alleviation.

However, for public housing to become an effective alleviator of fuel poverty, the image and social reality of public housing needs to be seriously examined. Social exclusion[14] is a particularly relevant topic in many countries, especially in a period in which there is increased evidence that housing circumstances relate to and contribute to problems of social disadvantage. Housing situations are not simply products of poverty but themselves contribute to the difficulties facing households and affect social integration. Yet some definitions and measures of social exclusion imply that all social housing tenants are necessarily socially excluded, or at least are at particular risk of exclusion (Hills et al., 2010). Given our results, there is an urgent need to rehabilitate the image of social housing. Policy makers cannot afford to exclude a policy instrument that could impact efficiently fuel poverty.

[14] Social exclusion "differs from concepts such as deprivation and poverty because it also incorporates non-material states and processes of disadvantage, including those created through others opinions" (Tucker J. Honourable estates. London: Victor Gollancz Ltd; 1966).

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Appendix

A. Descriptive statistics

Table 5: Characteristics of fuel-poor households

	All Sample		Energy-income ratio > 10%		Low income – High cost	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Annual disposable income in euros	26,916	17,109	14,933	5,598	16,262	6,654
Annual disposable income per adult equivalent (in euros)	18,906	10,164	12,172	3,872	11,484	2,707
Laborer	0.250	0.433	0.215	0.413	0.252	0.435
Employee	0.244	0.430	0.279	0.451	0.420	0.495
Executive or middle manager	0.147	0.354	0.064	0.247	0.073	0.261
Managerial staff	0.111	0.315	0.050	0.220	0.030	0.171
Farmer or craftsman	0.033	0.179	0.074	0.264	0.059	0.236
Retired	0.214	0.411	0.317	0.468	0.167	0.374
Preference for energy savings concerning heating system use	0.476	0.500	0.460	0.501	0.538	0.500
Reported restricted energy consumption	0.326	0.469	0.442	0.500	0.461	0.500
Year of construction before 1945	0.241	0.428	0.313	0.467	0.272	0.447
Year of construction between 1946-1970	0.250	0.433	0.350	0.480	0.286	0.453
Year of construction between 1971-1990	0.238	0.426	0.162	0.370	0.188	0.392
Year of construction 1991 and after	0.271	0.445	0.175	0.382	0.254	0.437
Individual housing unit	0.292	0.455	0.382	0.489	0.268	0.444
Surface (in square meters)	66	27	68	26	57	27
Collective heating system	0.175	0.380	0.095	0.295	0.161	0.369
Heating and hot water expenditures included in collective charges	110.9	290.0	90.1	282.0	96.4	253.7
Energy expenditures (excluding collective charges)	1,046	695	1,920	955	1,241	757
Percent of households using gas	0.405	0.491	0.418	0.496	0.352	0.479
Percent of households using fuel oil	0.046	0.209	0.161	0.370	0.056	0.230
Percent of households using wood	0.186	0.219	0.035	0.185	0.030	0.170
Renovations during the last five years	0.307	0.461	0.321	0.470	0.288	0.454
Agglomeration size < 9,999 inhabitants	0.260	0.439	0.398	0.493	0.260	0.439
Agglomeration size 10,000-99,999 inhabitants	0.207	0.405	0.201	0.403	0.230	0.422
Agglomeration size >100,000 inhabitants	0.533	0.499	0.401	0.493	0.511	0.501
Climate area H1 (the coldest area)	0.601	0.490	0.583	0.496	0.598	0.492
Social energy subsidy	0.028	0.166	0.057	0.233	0.089	0.286
Social housing	0.372	0.484	0.339	0.476	0.291	0.456
Observation	993		84 (or 9.85%)		157 (or 18.49%)	

Note: France is divided into 3 climate areas: H1 is the coldest and H3 the warmest.

Table 6 Pre-treatment characteristics

	Living in social housing unit		Not living in social housing unit		ttest
	Mean	Standard deviation	Mean	Standard deviation	Pr(|T| > |t|)
Annual disposable income in euros	25,333	13,455	27,855	18,896	**
Annual disposable income per adult equivalent (in euros)	16,931	6,181	20,078	11,764	***
Laborer	0.279	0.449	0.233	0.423	ns
Employee	0.295	0.457	0.215	0.411	***
Executive or middle manager	0.096	0.295	0.177	0.382	***
Managerial staff	0.042	0.201	0.151	0.359	***
Farmer or craftsman	0.023	0.151	0.039	0.193	**
Retired	0.264	0.442	0.186	0.389	*
Preference for energy savings concerning heating system use	0.464	0.499	0.483	0.500	ns
Reported restricted energy consumption	0.306	0.461	0.338	0.474	ns
Year of construction before 1945	0.085	0.280	0.333	0.472	***
Year of construction between 1946-1970	0.315	0.465	0.211	0.409	***
Year of construction between 1971-1990	0.334	0.472	0.181	0.385	***
Year of construction 1991 and after	0.266	0.442	0.275	0.447	ns
Individual housing unit	0.233	0.423	0.328	0.470	***
Surface (in square meters)	69	19	65	31	ns
Collective heating system	0.324	0.469	0.087	0.282	***
Heating and hot water expenditures included in collective charges	209.3	362.3	51.3	214.9	***
Energy expenditures (excluding collective charges)	968.7	583.4	1,092.0	750.0	***
Percent of households using gas	0.657	0.475	0.255	0.436	***
Percent of households using fuel oil	0.005	0.070	0.070	0.255	***
Percent of households using wood	0.012	0.109	0.074	0.261	***
Renovations during the last five years	0.367	0.483	0.271	0.445	***
Agglomeration size < 9,999 inhabitants	0.197	0.398	0.298	0.458	***
Agglomeration size 10,000-99,999 inhabitants	0.198	0.399	0.212	0.409	ns
Agglomeration size >100,000 inhabitants	0.605	0.489	0.490	0.500	***
Climate area H1 (the coldest area)	0.693	0.462	0.546	0.498	***
Energy-income ratio > 10%	0.090	0.286	0.104	0.305	*
Low income – High cost	0.144	0.352	0.209	0.407	*
Observation	422		571		

Notes: *** significant at 1%, ** significant at 5%, * significant at 10%, ns non-significant

B. Matching quality

B1: Quality of the propensity score distribution

Figure 2 Propensity score distribution by treatment status

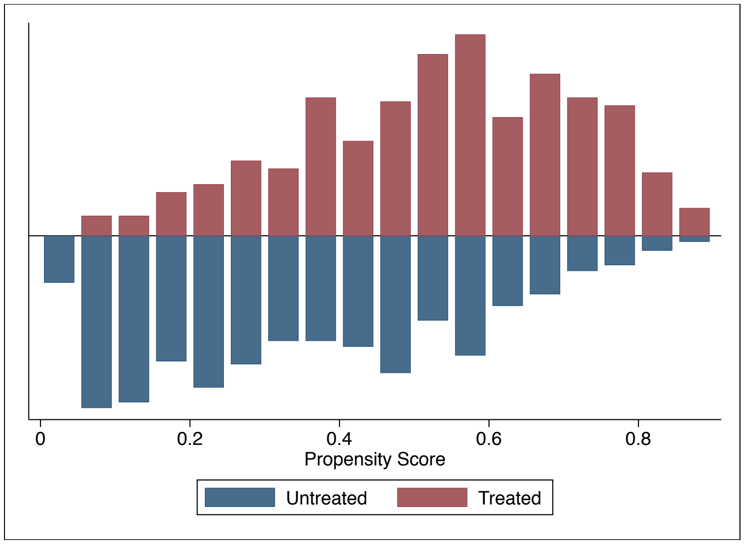
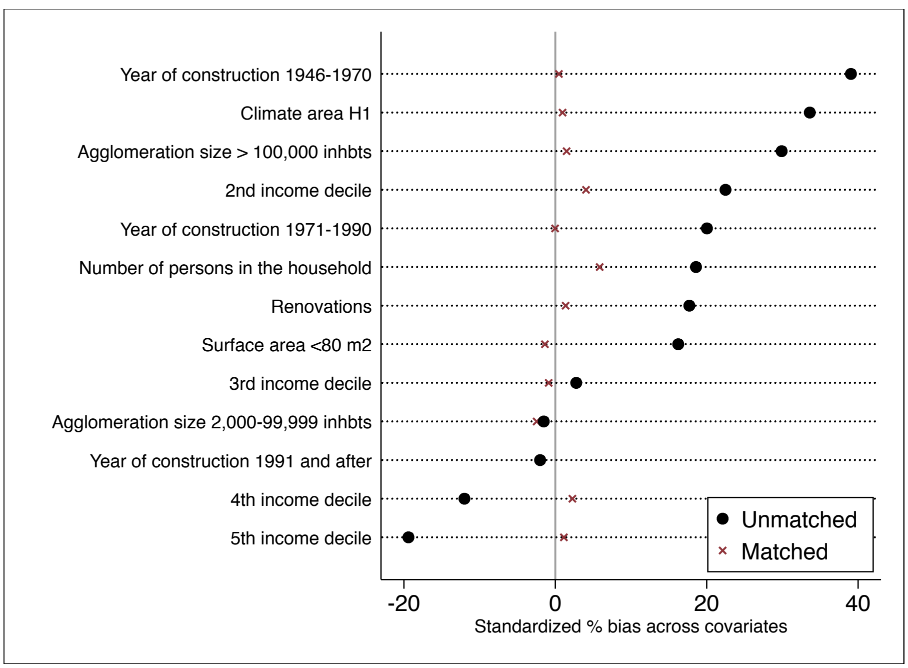


Figure 3 Standardized percentage bias before and after matching



B2: Sensitivity analysis

Matching is based on the conditional independence assumption (CIA), which means that given the observable characteristics, fuel poverty is independent of the probability of living in social housing. This assumption is not satisfied when unobserved characteristics of the treated group differ from unobserved characteristics of the control group. In this section, we observe the sensitivity of the results to a deviation from this assumption. This enables us to appraise the extent to which the results can be altered by unobserved factors.

We use Ichino et al.'s (2008) approach: We test the impact of an unobserved binary variable u that affects the potential outcome Y (i.e. fuel poverty) and eligibility for social housing (T = 1). The conditional independence given the set of variables x is not valid, but this assumption holds given x and u. In other words,

$$Pr(T = 1|Y_0, Y_1, x) \neq Pr(T = 1|x) \quad [5]$$

and

$$Pr(T = 1|Y_0, Y_1, x, u) = Pr(T = 1|x, u), \quad [6]$$

where u is assumed to be binary.

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

$$\Pr(u = 1|T = i, Y = j, x) = \Pr(u = 1|T = i, Y = j) \equiv P_{ij} \quad [7]$$

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

We assign arbitrary values to the parameter Pij. We consider the neutral confounder Pij = 0.5, and then we can let u mimic the behavior of some important covariates. We choose variables that we assume to have an effect on the outcome.

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

Results are presented in the following table. The first four columns contain probabilities Pij. For each value we give at u, the next two columns present, respectively, the outcome effect (i.e., the effect of u on the untreated outcome, controlling for observables x) and the selection effect (i.e., the effect of u on eligibility for social housing, controlling for observables x). When the outcome and the selection effects are higher than 1, this means that u has a positive effect on the probability of being fuel poor, given that households are ineligible for social housing, and a positive effect on the probability of living in social housing. The last column provides the effect and the standard error of social housing, controlling for observable x and unobservable u.

To focus on the effect of social housing on fuel poverty, we assume that u follows the same distribution as the variable "Construction 1991 and after". For the 10 ratio approach, P11 equals 0.18, i.e. 18% of fuel-poor households living in social housing live in dwellings built in 1991 and after. The effect of social housing, controlling for x and u, is close to the situation without a confounder (-0.040). If we consider that u has the same distribution as the "2nd income decile" variable, the impact of social housing is significant and slightly lower than the situation without a confounder reaching -0.038. The sensitivity analysis confirms the robustness of the results concerning the effect of social housing on the fuel poverty rate.

Table 7 Sensitivity analysis – Impact of social housing on fuel poverty

	Fraction *u* =1 by treatment/outcome				**Outcome effect**	**Selection effect**	**Social housing effect**	**SE**
	P_{11}	P_{10}	P_{01}	P_{00}				
Fuel poverty: According to 'Energy expenditure / Income' ratio								
No confounder	0	0	0	0	-	-	-0.041	0.022*
Neutral confounder	0.5	0.5	0.5	0.5	1.038	1.018	-0.039	0.001***
Confounder like:								
2nd income decile	0.32	0.33	0.23	0.24	1.009	1.545	-0.038	0.003***
Construction 1991 and after	0.18	0.27	0.16	0.29	0.515	0.937	-0.040	0.002***
Climate area H1	0.64	0.71	0.59	0.54	1.291	2.073	-0.042	0.006***
Surface area below 80 m^2	0.79	0.76	0.61	0.70	0.728	1.486	-0.036	0.004***
Fuel poverty: According to Low income – High cost approach								
No confounder	0	0	0	0	-	-	-0.085	0.029***
Neutral confounder	0.5	0.5	0.5	0.5	1.057	1.011	-0.080	0.001***
Confounder like:								
2nd income decile	0.05	0.37	0.14	0.26	0.484	1.593	-0.075	0.004***
Construction 1991 and after	0.30	0.26	0.25	0.28	0.868	0.993	-0.080	0.001***
Climate area H1	0.72	0.71	0.56	0.55	1.078	2.006	-0.081	0.006***
Surface area below 80 m^2	0.79	0.76	0.75	0.68	1.614	1.466	-0.082	0.004***