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Sondès Kahouli

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AN ECONOMIC APPROACH TO THE STUDY OF THE RELATIONSHIP BETWEEN HOUSING HAZARDS AND HEALTH: THE CASE OF RESIDENTIAL FUEL POVERTY IN FRANCE

The impact of housing hazards on health outcomes is becoming a major issue especially given the recent and on-going reviews of energy legislation in many European countries. A large body of epidemiological literature argues that fuel poverty – a frequently debated example of a housing hazard involving low indoor temperatures – is associated with heightened health risks.

By using a large scale nationally representative dataset, I seek in this article to delve into this alleged association and uncover a causal relationship between fuel poverty and self-assessed health. Coming from an economics standpoint, I used a panel approach based on an instrumental fixed-effects model which allow me to analyse causality. I used both objective and subjective fuel-poverty indicators.

The results show that there is a significant causal relationship between fuel poverty and self-assessed health status. The estimated causality is exacerbated when subjective fuel-poverty indicators are used. The results also show that the negative impact of fuel poverty on health is deferred, meaning that fuel poverty takes time to manifest itself in terms of poor health.

In policy terms, this study adds to the debate on investing in housing energy-efficiency schemes to reduce fuel poverty and thereby improve health outcomes. It also lends support to the argument according to which improving housing conditions to curb fuel poverty is a lever for reducing public expenditures on health care.

KEYWORDS

Residential fuel poverty, Health, Panel model, Causality, Instrumental variables, France.

JEL CLASSIFICATION

Q40; I10; C23

1 Introduction

Over the past decade, several scientific studies have provided evidence that various aspects of the built environment – the human-modified places where people live, work, play, shop and more – can have significant and directly measurable effects on health outcomes, *i.e.* physical, mental and social well-being (Houd, 2005). Therefore, consideration of the effects that the built environment has on health has been a key driver behind the developments in the field of environmental health. In particular, within the framework of the recurrent debates on the quality of indoor living environments on the one hand, and on socio-economic impacts of energy transition – in particular on residential fuel poverty – on the other hand, many European and other governments worldwide are paying more attention to the health consequences of residential fuel poverty.

Fuel poverty refers to a multidimensional concept that considers three main factors, namely the household’s financial situation, dwelling characteristics (*i.e.* energy efficiency) and energy prices (EPEE (2006), Palmer et al. (2008), Blavier et al. (2011)). A household is considered fuel-poor when it lives in an energy-inefficient dwelling and is unable to heat the home to an appropriate standard level of warmth¹. Therefore, residential fuel poverty takes the form of thermal discomfort and is closely related to housing characteristics, *e.g.* heating system, energy efficiency, dampness, mouldiness.

In Europe, despite the spread of fuel poverty and its recognition by governments as a social, public health and environmental policy issue in a context of ever-increasing energy prices, the European Union (EU) has not yet adopted a common definition nor common indicators to measure it². The UK government was the first to acknowledge the phenomenon and set up measures to fight it. In fact, the fuel poverty concept was born in the UK in the 1970s under the leadership of activist organisations that called the issue to the attention of authorities and the general population in light of the winter mortality induced by the steady rise in energy prices, preventing some households from heating their dwellings to an appropriate standard level of warmth (Dutreix et al. (2014), ONPE (2014, 2015)). Two decades later, Boardman (1991), based on an earlier contribution by Isherwood and Hancock (2016), defined an indicator that has since been used in the 2001 UK Fuel Poverty Strategy to measure fuel poverty (Fahmy et al., 2011).

In France, the official definition of fuel poverty was published in the National Environmental Commitment Act (no. 2010-788 of 12 July 2010, “Loi Grenelle 2”) amending the Housing Rights Act (no. 90-449 of 31 May 31 1990, “Loi Besson”) ³. According to this definition, a fuel-poor household represents a person who has difficulties accessing energy within his/her dwelling to satisfy his/her basic needs, due to insufficient financial resources or inadequate dwelling characteristics *i.e.* energy inefficiency, presence of dampness and rot. In terms of indicators, recently inspired by developments in the UK, the French national observatory of fuel poverty ⁴ suggests using a combination of objective and subjective indicators to measure the magnitude of fuel poverty (ONPE (2014, 2015)).

The recent literature on fuel poverty identifies three types of indicators: objective factual indicators, subjective self-reported indicators and composite indices (Fizaine and Kahouli (2019)).

1. According to the World Health Organization (WHO), an appropriate standard level of warmth is equal to 21°C for the main living area and 18°C for other occupied rooms (ONPE, 2015).

2. However, the European Fuel Poverty and Energy Efficiency (EPEE) project, conducted between 2006 and 2009, used a descriptive approach to analyse fuel poverty in some European countries, *i.e.* Belgium, France, Italy, Spain and the United Kingdom. It was based on three criteria: the ability to pay to keep one’s home warm, the presence of dampness, leaks, mould in the dwelling and arrears on electricity, gas and water bills (EPEE, 2006).

3. The “Loi Besson” no. 90-449 of 31 May 1990 stipulates that anyone encountering difficulties, particularly due to insufficient financial resources or inadequate living conditions, can benefit from public aid, according to the rules defined in the Act, for access to decent and independent housing with water, energy and telephone services - Translated from French (JORF, 1990).

4. “Observatoire National de la Pauvrete Énergetique” (ONPE).

40 Objective factual indicators draw on measurable and observable criteria and are based on consump-
41 tion theory. In particular, objective factual indicators take into account the amount of expenditures
42 devoted to satisfying fuel needs with respect to the total available financial endowments. The lit-
43 erature distinguishes between the 10% indicator, the After Fuel Cost Poverty (AFCP) indicator
44 and the Low-Income/High-Costs (LIHC) indicator. Subjective fuel-poverty indicators are based
45 on personal opinions, interpretations, points of view and judgement. They are usually constructed
46 by referring to households' self-reported answers to questions asked by social investigators in a sur-
47 vey. The most frequently asked questions include “*Do you suffer from thermal discomfort?*”, “*Have*
48 *you had difficulty paying your utility bills (in the past)?*”, “*Can you afford your energy bills?*”, or
49 “*Are you satisfied with your heating equipment?*”. Finally, composite indices were created as a
50 compromise between the simplicity of one-dimensional indicators and the need to account for the
51 multidimensional nature of fuel poverty. They represent an attempt to overcome the shortcomings
52 of one-dimensional indicators and, at the same time, produce a result that condenses the informa-
53 tion into single and easy-to-interpret metrics (Thomson and Snell, 2013).

54 Currently, in the recent context of the creation of the EU Energy Poverty Observatory (EPOV)
55 in January 2018 and increasing debates on the physical and mental health risks of residential fuel
56 poverty, the latter has become a major challenge. In this context, the EU recently developed
57 policies targeting the reduction of fuel poverty, particularly by enhancing the energy efficiency of
58 houses, old and new alike. In this framework, one way to help determine which type of policy
59 measure should be implemented to fight residential fuel poverty is to identify its consequences
60 on health as precisely as possible. Nevertheless, analysing the impacts of residential fuel poverty
61 and identifying transmission channels through which it can affect physical and mental health out-
62 comes has proven to be an enormous challenge, requiring the development of new suitable research
63 paradigms, methodologies, datasets as well as a willingness for cooperation across different aca-
64 demic disciplines (Houd, 2005).

65 Despite the considerable body of interdisciplinary literature in the fields of epidemiology,
66 medicine, environmental health, psychology and psychiatry that have begun to tackle this is-
67 sue, the contribution from the field of economics is still limited. Several papers in economics have
68 already analysed the evidence relating income poverty, or more generally socio-economic status,
69 to health (Thomas and Strauss (1997), Adams et al. (1999), Adams et al. (2003), Currie (2009),
70 Chin (2010), Kuehnle (2014)). Nevertheless, few economics studies have explored the relationship
71 between residential fuel poverty and health, either in terms of correlation or causality (Lacroix and
72 Chaton (2015), Llorca et al. (2018)).

73 Here, based on observational large scale data, I aim to fill this gap in the literature. In par-
74 ticular, I seek to determine whether there are causal effects of fuel poverty on self-assessed health
75 status, rather than focus exclusively on the description of correlations. I used a panel approach,
76 which offers the valuable possibility of conducting a longitudinal analysis, whereas studies on fuel
77 poverty are usually limited to cross-sectional analyses. In an European context astonishingly char-
78 acterised by the absence of specific databases to analyse the question of the relationship between
79 fuel poverty and health, I relied on a nationally representative dataset, namely the Statistics on
80 Resources and Living Conditions (SRCV) database -which is part of the European Union Statis-
81 tics on Income and Living Conditions (EU-SILC) database- to conduct this study. Although these
82 statistics are not specifically devoted to the analysis of the relationship between fuel poverty and
83 health (*cf.* Subsection 3.1.1), they nonetheless offer a unique opportunity to address the causality.
84 Thus, I aim through this study to initiate an incipient understanding of this issue and to open the
85 door for new research prospects. To reliably deal with causality, I used an instrumental fixed-effects
86 model based on the identification of individual-specific instruments. Since, causality is still not

87 unequivocally demonstrated and is still up for discussion even when experimental designs based on
88 based on randomized controlled trial (RCT) are used to clearly identify causal paths, I aim through
89 the use of an instrumental-variables approach and a large scale nationally representative dataset to
90 contribute to this debate. I also aim to point-out the need for more interdisciplinary approach to
91 tackle the more general question of the relationship between housing hazards and health outcomes.

92 The paper unfolds as follows. In Section 2, I give a brief review of the literature on health de-
93 terminants. In Section 3, I present the empirical analysis and discuss findings. Finally, in Section
94 4, I present the policy implications and conclude.

95 2 Literature review on health determinants

96 The literature on health determinants is abundant and remarkably interdisciplinary. It relies
97 on various complementary approaches to deconstruct health determinants. These determinants
98 can be classified into three categories:

- 99
- 100 — individual characteristics, *i.e.* sex, age, socio-economic status, etc.;
- 101 — environmental hazards. Generally speaking, they represent any state, event or substance
102 that has the potential to threaten the surrounding natural environment or adversely affect
103 people’s health, *i.e.* pollution, traffic noise, housing conditions, natural disasters, etc.;
- 104 — other hidden common factors, *i.e.* unobserved genetic heterogeneity, behavioural factors
105 (nutrition, stress, smoking), rational economic decision-making, etc.

106

107 The literature focuses on studying the association (or alternatively, the correlation) and the causal-
108 ity between each determinant and health. Although the association between some determinants
109 – for example, income or housing conditions – and health has been largely acknowledged, demon-
110 strating causality paths is more difficult.

111 Below, I do not intend to give an exhaustive literature review on health determinants; instead,
112 I propose a summary of the literature that takes into account the first two categories of health
113 determinants listed above, namely individual characteristics and environmental hazards. Under
114 the first category, I will briefly focus on the case of socio-economic status as an example of a largely
115 discussed health determinant to which I will refer in the econometric analysis. Under the second
116 category, I take the specific case of residential fuel-poverty as an example of an environmental
117 hazard that impacts health, the aim of this paper. I consider associations and causality issues⁵.

118 2.1 Individual characteristics: the relationship between socio-economic 119 status and health

120 Income is very frequently used as a proxy for socio-economic status and there is a very large
121 body of economics and epidemiological literature studying the relationship between income and
122 health⁶. This body of literature gives evidence that higher income is associated with better health
123 and longer life. It also asserts that this association holds for different eras, places, genders and

5. The premises of a discussion of the relationship between the “the other hidden factors” and health outcomes can be found in Adams et al. (2003).

6. Kitagawa and Hauser (1973), Luft (1978), Hurd (1987), Hurd and Wise (1989), Rodgers (1991), Ettner (1996), Power et al. (1996), Feinstein (1992), Barsky et al. (1997), Bosma et al. (1997), Thomas and Strauss (1997), Backlund et al. (1999), Ecob and Smith (1999), Fitzpatrick and Dollamore (1999), Chandola (2000), Ross and Mirowsky (2000), Seeman et al. (2002), Adams et al. (2003), Adams et al. (1999), Adams et al. (2003), Currie (2009), Chin (2010), Kuehnle (2014).

124 ages⁷. At the same time, although there has been relatively few natural experiments that allow
125 causal paths to be clearly identified⁸, causal links in both directions have been reported (Culter
126 et al. (2006), Deaton (2008)). In a pioneering study, McKeown (1979) asserts that income is
127 the main determinant of health in the history of developed countries, primarily through better
128 nutrition, clothing and housing. Along the same lines, Pritchett and Summers (1996) found that
129 economic growth in developing countries led directly to reductions in infant mortality rates and
130 improvements in life expectancy. The underlying assumption is that health improvement is a
131 direct by-product of higher income levels through nutritional factors, as well as the fact that higher
132 income enables the provision of public health infrastructures. More recently, in a literature review
133 conducted in an epidemiological causal framework, Pickett and Wilkinson (2015) asserts that there
134 is strong evidence that income inequality affects population health and well-being. Further, of the
135 small number of studies that find no causality, most can be explained by income inequality being
136 measured at an inappropriate scale, the use of mediating variables as controls, the use of subjective
137 rather than objective measures of health or follow-up periods that are too short.

138 2.2 Housing hazards

139 Housing hazards is a specific case of environmental hazards and includes important determi-
140 nants of health. They refer to any risk of harm to the health or safety of an actual or potential
141 occupier that arises from a deficiency⁹. Below, I first focus on the case of the impact of housing
142 conditions on health outcomes. Then, I consider the more specific example of the fuel-poverty
143 housing hazard. I summarised two types of studies: studies that analyse the impact of housing
144 conditions – not just the effects of residential fuel poverty – on health (Subsection 2.2.1) and stud-
145 ies that analyse the impact of residential fuel poverty as the only considered housing condition on
146 health (Subsection 2.2.2). In this latter type of study, the evidence of any link between residential
147 fuel poverty and health outcomes can be divided into two broad categories: the impact of low
148 indoor temperatures, *i.e.* thermal discomfort, and the impact of dampness and/or mould growth.
149 I considered only the negative effects of housing on health outcomes that deal with physical and
150 mental health. Some studies also consider the effect on social life and well-being.

151 2.2.1 Literature focusing on housing conditions

152 There are a large number of articles, books and reports that focus specifically on housing and
153 health¹⁰. Similarly, there are extensive studies that explore the multi-faceted links between poor
154 socio-economic status and poor health (and educational status) and directly implicate poor hous-
155 ing as a determinant¹¹.

156 Interestingly, there are comprehensive reviews summarising this literature on housing and

7. Goldman (2001), Currie and Stabile (2003), Propper et al. (2007), Cunha and Heckman (2007), Currie et al. (2008), Jones and Wildman (2008), Khanam et al. (2009), Currie (2009), Chin (2010), Reinhold and Jürges (2012), Kurk (2012), Apouey and Geoffard (2013), Kuehnle (2014), Pickett and Wilkinson (2015).

8. Evans (1978), Felitti et al. (1978), Fox et al. (1985), Dohrenwend et al. (1992), Goldman (1994), Chapman and Hariharran (1994, 1996), Kelley et al. (1997).

9. In UK, the health risk-assessment procedure, named Housing Health and Safety Rating System (HHSRS), that measures the risks within the home identifies a series of 29 potential housing hazards. They cover indoor pollution, hygiene, structural safety, temperatures, damp and mould growth, etc. For an exhaustive list of hazards, please visit: <http://www.communities.gov.uk/publications/housing/hhsrsoperatingguidance>. Source: Marmot Review Team (2011).

10. Ranson (1991), Burridge and Ormandy (1993), Ineichen (1993), Ambrose et al. (1996), BMA (2003), Howden Chapman and Carroll (2004), Bonnefoy et al. (2004), Bonnefoy et al. (2007), Ezratty et al. (2009).

11. Marmot et al. (1991), Syme (1994), Sandel et al. (1999), Airey et al. (1999), Graham (2000), Graham (2000), Attanasio and Emmerson (2001), Gravelle and Sutton (2001), Jefferis et al. (2002).

157 health¹². Some of these reviews focus on the more general literature reporting associations be-
158 tween poor housing and poor health. Taking a different tack, others attempt to look at health gains
159 following home improvements¹³. Other systematic reviews focus on the impact of housing-related
160 interventions¹⁴, smoke alarms and house dust mite reduction measures¹⁵.

161 Although this body of literature shows that there is no doubt about the link between poor hous-
162 ing and health, it reveals that the research required to demonstrate this linkage is not easy to carry
163 out. For instance, Thomson et al. (2002) argue that although there are many thousands of studies
164 linking housing improvement to health gains, only a handful have offered robust evidence on a
165 before-and-after renewal benefit (Roys et al., 2010). Conversely, although not focusing directly on
166 the residential fuel poverty issue, a number of these studies have shown that residential fuel poverty
167 has a harmful impact on health outcomes. For example, Wilkinson et al. (1998) show that the
168 seasonal mortality variations in the UK are related to indoor (rather than outdoor) temperature
169 and that this annual variation can be reduced by helping residents protect themselves from cold
170 weather conditions in their homes. In the same context, based on an epidemiological approach, the
171 Large Analysis and Review of European Housing and Health Status (LARES) study¹⁶ shows that
172 there is a significant relationship between dwelling energy efficiency and physical health (Bonney
173 et al. (2007), Ezratty et al. (2009)). This relationship takes the form of a negative link between
174 thermal discomfort and the risk of respiratory and cardiovascular diseases, hypertension or the
175 presence of digestive disorders. LARES also shows the same type of negative link between thermal
176 discomfort and mental and social well-being.

177 2.2.2 Literature focusing on residential fuel poverty

178 Table C.1 of Appendix C summarises and supplements the content of this paragraph.

179 When examining the literature on the health effects of residential fuel poverty, I considered
180 the two main features of residential fuel poverty, namely thermal discomfort and damp and mould
181 growth.

182 There has been much research on the effects of indoor thermal discomfort, *i.e.* low temper-
183 atures, on health since the pioneering assessment of the cost of indoor cold and the definition
184 of the 10% fuel-poverty indicator by Boardman (1991). For instance, Baker (2001) produced a
185 review of the evidence on the link between living in a fuel-poor dwelling and the increased risk of
186 illness. This study showed in particular a strong association between low indoor temperatures and
187 increased risk of strokes, heart attacks and respiratory illness. Other evidence shows cold stress
188 causing cardiovascular strain and increased incidence of dust mites in poorly ventilated homes –
189 in turn affecting asthma and eczema, especially in children. Baker (2001) review evidence on the
190 negative effect of the presence of damp and mould growth in the home on mental and physical
191 health. In the same context, Peat et al. (1998) reviewed literature over 15 years that linked damp

12. Raw and Hamilton (1995), Peat et al. (1998), Wilkinson (1999), Fuller-Thomson and Hwang (2000), Thomson et al. (2002).

13. Wilkinson (1999), Fuller-Thomson et al. (2000), Thomson et al. (2002).

14. Intervention studies refer to studies on heating and insulation improvements that were carried out and impacts on well-being that were assessed.

15. DiGuseppi and Higgins (2000), Hammarquist et al. (2000).

16. LARES is a pan-European housing and health survey that was undertaken from 2002 to 2003 in eight European cities at the initiative of the WHO European Housing and Health task force. It was designed to achieve the following objectives:

- to improve knowledge on the impacts of existing housing conditions on health and mental and physical well-being;
- to assess the quality of the housing stock in a holistic way and to identify housing priorities in each of the surveyed cities;
- to develop an “easy-to-use” tool to assess the impact of housing on health in any city in Europe.

192 and mould in the home with respiratory health and concluded that building homes designed to
193 prevent the proliferation of indoor allergens would reduce the risk of respiratory symptoms.

194 Wilkinson et al. (2001) showed that there is a credible chain of causation that links low indoor
195 temperatures due to energy inefficiency to cold-related deaths. In particular, there is a 23% excess
196 of deaths from heart attacks and strokes. Indoor temperatures below 16°C are a particular risk
197 and are most likely to affect old and poorly heated housing with low-income residents. Rudge
198 (2001) has been active in developing a methodology to assess the cost-effectiveness of investment
199 in warmer homes. This approach seeks to correlate data on low income, building characteristics
200 and admissions to hospital. Also, Howden-Chapman et al. (2005) focused on analysing the con-
201 sequences of insulation measures¹⁷ on health, the well-being of the occupants, as well as on their
202 utilisation of health care.

203 By considering a discursive approach, Ezratty (2010) and Ormandy and Ezratty (2012) argue
204 that fuel poverty and housing conditions considerably affect physical and mental health as well as
205 social well-being. In particular, they explain that there are different methods for measuring ther-
206 mal comfort, *i.e.* air temperature, residents' perceptions, satisfaction prediction, and argue that,
207 regardless of the method, thermal discomfort has negative direct, *i.e.* cardiovascular and respira-
208 tory disease, asthma, etc., and indirect, *i.e.* risk of carbon monoxide poisoning, effects on health.
209 In the same context, Liddell and Guiney (2015), based on a literature review of nine intervention
210 studies that outline the current prevailing framework for understanding mental well-being in the
211 fields of psychology and psychiatry, argue that living in cold and damp housing contributes to a
212 variety of different mental health stressors, including persistent worry about debt and affordabil-
213 ity, thermal discomfort and worry about the consequences of cold and damp for health. Lacroix
214 and Chaton (2015) rely on an economic approach and use subjective indicators for fuel poverty to
215 analyse whether the latter is a determinant of perceived health in France. In particular, they used
216 self-reported perceptions of feeling cold (thermal discomfort) as a proxy for fuel poverty and the
217 answer to the question "*How is your general health?*" as a proxy for health status. By estimating
218 a binary probit model, they showed that a person in fuel poverty is 2.36 percentage points more
219 likely to report poor or fair health status than a person who is not in fuel poverty.

220 More recently, Llorca et al. (2018) studied determinants of self-assessed health in Spain using
221 objective and subjective fuel poverty indicators. They however focused on "purging" the influence
222 of the objective measure of fuel poverty on self-assessed health. Their results show that poor hous-
223 ing conditions, fuel poverty and material deprivation have a negative impact on health. Within
224 the framework of a different approach, Robić and Antčić (2018) studied the health consequences
225 of living in fuel poverty in Croatia. They used a sample of 394 households and with four groups
226 of fuel-poverty indicators¹⁸ and showed that those who are affected by energy poverty live in in-
227 adequate conditions and face adverse impacts on their health.

228

229 In summary, economics and non-economics interdisciplinary studies, although using different
230 approaches, provide vast evidence that housing hazards, particularly residential fuel poverty, have
231 negative impacts on physical and mental health, as well as on social life and well-being. Income is
232 clearly a crucial determinant of health outcomes. Housing hazards, and in particular fuel poverty,
233 can be seen as a transmission mechanism through which income impacts health outcomes (Kuehnle,
234 2014).

17. Insulation measures affect indoor temperature, humidity, energy consumption and mould growth.

18. The subjective qualitative assessments by the affected persons, the subjective qualitative assessments by others, the objective non-expenditure-based indicators and the expenditure-based indicators.

235 3 Econometric analysis

236 I present my econometric analysis in two steps. I first present the data and summary statis-
237 tics (Sub-section 3.1). Then, I present the econometric estimations used to determine if there
238 any correlations and causality relationships between fuel poverty and self-assessed health status
239 (Subsection 3.2).

240 3.1 Data and summary statistics

241 3.1.1 Database

242 I used the Statistics on Resources and Living Conditions (SRCV)¹⁹ database published by the
243 French National Institute of Statistics and Economic Studies (INSEE)²⁰. This database is a part of
244 the European Union Statistics on Income and Living Conditions (EU-SILC). The EU-SILC is the
245 EU reference source for comparative statistics on income distribution and social exclusion at the
246 European level, particularly in the context of the “Programme of Community action to encourage
247 cooperation between Member States to combat social exclusion” and for producing key policy
248 indicators on social cohesion for the follow-up of the main EU 2020 target on poverty and social
249 inclusion. It provides two types of annual data. First, it provides a cross-sectional data pertaining
250 to a given time or a certain time period with variables on income, poverty, social exclusion and other
251 living conditions. Second, it provides longitudinal data pertaining to individual-level changes over
252 time. The cross-sectional data is collected in two stages. An early subset of variables collected via
253 registers or interviews to assess as early as possible poverty trends. A full set of variables provided
254 along with the longitudinal data help to produce main key policy indicators on social cohesion. The
255 longitudinal data aim to identify the incidence and dynamic processes of the persistence of poverty
256 and social exclusion among subgroups in the population. For the cross-sectional and longitudinal
257 components, all household and personal data are linkable. I used the longitudinal component of
258 the SRCV, in particular, the waves going from 2004 to 2015²¹. Given that the SRCV does not
259 aim to address questions of fuel poverty and its relationship to health status, the quality of data
260 on fuel poverty and health is not as good as one would hope. However, these data still provide
261 the valuable opportunity to conduct a longitudinal study to at least approach this issue and then
262 open new prospects for further investigations.

263 3.1.2 Data on fuel poverty, health status and controls

264 Based on the fuel-poverty literature and bearing in mind the weak points of various fuel-poverty
265 indicators (Fizaine and Kahouli, 2019), I used two classes of indicators of fuel poverty: objective and
266 subjective. For the objective indicator, I used the 10% indicator and for the subjective indicator, I
267 first used the financial ability of a household to heat its dwelling and then used the difficulty that a
268 household can encounter to heat its dwelling due to financial constraints or dwelling characteristics.

269 I calculated the 10% indicator following formula (Hills (2011, 2012)):

$$I = \frac{\text{Equivalent fuel costs}}{\text{Equivalent disposable income (before housing costs)}} \quad (1)$$

19. In French, *Statistique sur les Ressources et Conditions de Vie*.

20. In French, *Institut National de la Statistique et des Études Économiques*.

21. For more information on the methodological and practical framework for the computation and production of the EU-SILC database, as well as information on quality and methodological limitations, interested readers can consult <http://ec.europa.eu/eurostat/statistics-explained/i>. French data in the EU-SILC database are available for free upon request from the French *Quetelet* network, accessible at the following address: <https://quetelet.casd.eu/en/utilisateur/connexion>.

270

271 — if $I > 10\%$ the household is fuel-poor.

272

273 One drawback of this formula is that the 10% indicator overestimates the extent of fuel poverty
274 within the general population by including households with a high level of income. To counter this
275 criticism, the ONPE (2014, 2015) studies suggest including in the calculation only those households
276 having an income (cu) lower than the threshold of the third decile of income (cu). Therefore, in
277 this study, only households having an income (cu) level lower than this threshold were considered
278 as fuel-poor.

279 Thus, a household is fuel-poor if:

$$\frac{\text{Equivalised fuel costs}}{\text{Equivalised disposable income}} > 10\% \quad (2)$$

280 and

$$\begin{aligned} \text{Equivalised disposable income} &= \frac{\text{Disposable income}}{\text{Number of consumption units}} & (3) \\ &< \text{Threshold of the third decile of income} \end{aligned}$$

281 Note that:

$$\text{Equivalised fuel costs} = \frac{\text{Fuel costs}}{\text{Number of consumption units}} \quad (4)$$

282 Regarding the subjective indicators of fuel poverty, the first indicator corresponds to the house-
283 hold's answer to the following question in the EU-SILC database:

284

285 — “Is your dwelling difficult or too expensive to heat to suitable level of warmth?” (“Yes” or
286 “No”).

287

288 The second indicator corresponds to the answer to the following question:

289

290 — “Are you financially able to maintain an adequate temperature in the dwelling?” (“Yes” or
291 “No”).

292

293 The difference between these two indicators is that whereas the first refers to dwelling character-
294 istics, the second is related to the household's financial situation.

295 Although the use of the objective consumption expenditures (the 10% indicator) has been well-
296 accepted since the Boardman (1991) study, the use of subjective indicators is less consensual due to
297 their lack of consistency across respondents. For instance, Hills (2012) suggests that an overlapped
298 mix of cultural, generational and demographic factors influence participants' responses. Thomson
299 et al. (2017b) add that there are also risks associated with potential errors of exclusion and biases.
300 Nevertheless, Fahmy et al. (2011) and Koh et al. (2012) argue that subjective measures provide
301 a more nuanced perspective of energy poverty, capturing real experiences and needs in a manner
302 that cannot be captured by objective measures. In this context, Price et al. (2012) argue that
303 the overlap between objective indicators, in particular the 10% indicator, and subjective indica-
304 tors, which are based on an individual's self-reported perceptions of household heating difficulties,

305 is minimal. Amongst households that felt that they had problems in maintaining warmth, fewer
306 than half show expenditures that would classify them as fuel-poor. Therefore, subjective indicators
307 affect the measurement of fuel poverty just like any objective indicator by providing additional in-
308 formation that may enhance the comprehension of households' situations. Advocates of subjective
309 measures also argue that they are better able to capture the wider social exclusion and material
310 deprivation elements associated with energy poverty than objective expenditure-based measures
311 (Healy, 2004). Therefore, in this study, I considered that combining the use of objective and sub-
312 jective indicators leads to a more exhaustive understanding of the multidimensional character of
313 fuel poverty. The two types of indicator capture different aspects of fuel poverty.

314 In comparison with the existing literature, using the subjective indicator related to the difficulty
315 to heat dwelling "*Is your dwelling difficult or too expensive to heat well?*", I followed Chaton and
316 Lacroix (2018) who defined fuel poverty in a similar way as in the French National Environmental
317 Commitment Act (no. 2010-788 of 12 July 2010, "Loi Grenelle 2"). Under this Act, a fuel-poor
318 household is a person who has difficulties within his/her dwelling to access energy to satisfy his/her
319 basic needs due to insufficient financial resources or inadequate dwelling characteristics (see Sec-
320 tion 1). Similarly, by using the other subjective indicator, which relates to a household's finances
321 "*Are you financially able to maintain an adequate temperature in the dwelling?*", I also adopted
322 the definition of the National Environmental Commitment Act and went along the same lines as
323 several studies conducting comparative analyses of fuel poverty across Europe (Healy and Clinch
324 (2002), Healy (2004), Thomson and Snell (2013), Liddell et al. (2016), Dubois and Meier (2016),
325 and Bouzarovski and Tirado Herrero (2017)). In particular, Thomson and Snell (2013) used the
326 indicator "*Can the household afford energy if they want it?*" or equivalently "*Can they keep the
327 home adequately warm?*".

328 For health data, I used the answer to the following question in the EU-SILC database, which
329 represents self-reported health status:

330

331 — "*How is your general health status?*" ("Very good", "Good", "Fairly good", "Bad", "Very bad"),
332

333 According to the ODPM (2006), health status represents the individual's state of physical, mental
334 and social well-being. It is not limited to the presence or absence of disease, infirmity or physical
335 injury, but includes psychological injuries and distress²².

336 To be consistent with previous studies, I generated a binary indicator for the self-reported health
337 status variable. It takes the value of 1 if the respondent's answer is "Very good", "Good", or "Fairly
338 good" and 0 when it is "Very bad" or "Bad" (Healy (2004), Eurofound (2012)). Although criticised
339 due to the risk of subjective biases, self-reported health status is a well-established indicator that
340 has been extensively used in public health and epidemiological research as well as in economic
341 research²³. Moreover, existing evidence suggests that it is a reliable and valid measure of health
342 status (Lundberg and Manderbacka (2012), Mishra and Carleton (2015)), and can predict future
343 health outcomes (Mossey and Shapiro (1982), Miilunpalo et al. (1997), Thomson et al. (2017b)).

344 In addition to fuel-poverty and health status variables, based on insights detailed in Sub-
345 section 2, I incorporated the following exogenous control variables classified into three homogeneous
346 families:

22. However, I note that in a specialised health surveys and in general surveys of the population, the answer to the question "*How it is your general health status?*" is not devoted to giving specific information about mental health, but to how an individual perceives his/her health in its three dimensions: physical, mental and social well-being. Information about mental health is generally determined through other more targeted questions, such as "*Are you satisfied with your life?*" or "*Overall how would you rate your mental health?*".

23. Chin (2010), Eurofound (2012), Mulinari et al. (2015), Lacroix and Chaton (2015), Artazcoz et al. (2016), Llorca et al. (2018).

- 347 — household characteristics: sex (*SEX*), marital status (*MAR*), household size (*HSIZE*)
- 348 and disposable income (*INC*);
- 349 — dwelling characteristics: dwelling type (*DWTY*), presence or absence of roof leaks, damp
- 350 walls/floors/foundations, rot in window frames or floor (*LEAK*), and exposure and daylight
- 351 (*DARK*), surface (*SURF*), dwelling age (*DWAGE*), and urban characteristics (*RURAL*).
- 352 The variable dwelling age was used as a proxy for the energy-efficiency level of the dwelling.
- 353 In particular, dwellings built before the first French thermal regulation in 1974 are assumed
- 354 to be less energy efficient;
- 355 — Climate characteristics (*CLIMHFR*): (inner) Paris (*CLIMFR1*), Parisian (*CLIMFR2*),
- 356 East and Centre-East (*CLIMFR3*), North and South (*CLIMFR4*), and West, South-West
- 357 and Mediterranean (*CLIMFR5 – 8*) regions.

358
 359 For the *CLIMHFR* variable, I adopted the official classification of France into eight zones having
 360 different climate characteristics, *i.e.* *FR1* to *FR8* (see Table 1).

361 All control variables were extracted from the EU-SILC database. By incorporating them in
 362 estimations, I help control for factors that may confound or mediate the relationship between
 363 health and fuel poverty. In this context, in addition to the impact of fuel poverty, I paid particular
 364 attention to the effect of income on self-assessed health outcomes because such effects have been
 365 extensively analysed in the literature.

366 Finally, I also incorporated two other variables in the estimations called instrumental variables:

- 367
- 368 — Housing retrofit subsidy (*RETRO*);
- 369 — Energy prices (*P*).

370
 371 I discussed in detail the issues with these two variables in Sub-section 3.2.1.

372
 373 I ran all estimations on unbalanced samples to obtain the maximum number of observations.
 374 After merging, the sample contained 62,538 individuals older than 16 years observed from 2004
 375 to 2015 for up to 9 years (rotating panel), corresponding to 242,424 observations. Because there
 376 are usually several individuals per household, for each household, I kept only the individual who
 377 answered the survey to avoid subjective bias. Therefore, the final sample was composed of 29,681
 378 individuals, corresponding to 122,328 observations. All non-dummy variables used in estimations
 379 were log-transformed.

380 Variables and data sources are summarised in Table 1.

Table 1 – Presentation of variables and data sources

Variable	Header	Description	Source
Health status	<i>HEALTH</i>	Endogenous variable Dummy: 1 if “Very good”, “Good” or “Fairly good”, 0 otherwise	EU-SILC
10% indicator	<i>FPOV</i>	Exogenous variables Fuel-poverty indicators	Author calculation. 3.1.2
Financial ability to maintain an appropriate level of warmth	<i>TEM</i>	Dummy: 1 if yes, 0 otherwise	EU-SILC
Dwelling difficult to heat	<i>DIFDH</i>	Dummy: 1 if yes, 0 otherwise	EU-SILC
Sex	<i>SEX</i>	Controls: household characteristics Dummy: 1 if male, 0 otherwise	EU-SILC
Marital status	<i>MAR</i>	Dummy: 1 if single, 0 otherwise	EU-SILC
Household size	<i>H SIZE</i>	Number of consumption units (<i>cu</i>)	EU-SILC
Disposable income	<i>INC</i>	€	EU-SILC
Dwelling type	<i>DW TY</i>	Controls: dwelling characteristics Dummy: 1 if apartment, 0 otherwise	EU-SILC
Leaks, damp and rot	<i>LEAK</i>	Dummy: 1 if yes, 0 otherwise	EU-SILC
Exposure and natural lighting	<i>DARK</i>	Dummy: 1 if dark, 0 otherwise	EU-SILC
Dwelling surface area	<i>SURF</i>	Surface in m^2	EU-SILC
Dwelling construction date	<i>DWAGE</i>	Dummy: 1 if post-1974 building ^a , 0 otherwise	EU-SILC
Rural commune	<i>RURAL</i>	Dummy: 1 if < 2000 inhabitants, 0 otherwise	EU-SILC
Climate zone FR1	<i>CLIMFR1</i>	Controls: climate characteristics Dummy: 1 if located in Paris, 0 otherwise	Official definition ^b
Climate zone FR2	<i>CLIMFR2</i>	Dummy: 1 if located in Parisian region, 0 otherwise	Official definition ^b
Climate zone FR3	<i>CLIMFR3</i>	Dummy: 1 if located in North, 0 otherwise	Official definition ^b
Climate zone FR4	<i>CLIMFR4</i>	Dummy: 1 if located in the East or Center-East, 0 otherwise	Official definition ^b
Housing retrofit subsidy	<i>RETRO</i>	Instruments Dummy: 1 if yes, 0 otherwise	EU-SILC
Energy prices	<i>P</i>	—	Author calculation. Cf. Appendix B

^a. 1974 corresponds to the date of the first thermal regulation in France.

^b. <https://ec.europa.eu/eurostat/fr/web/nuts/local-administrative-units>

381 3.1.3 Summary statistics

382 In this section, I describe the summary statistics for the central variables, *i.e.* self-assessed
383 health status and fuel poverty. Below, I give the descriptive figures and provide the associated
384 tables in Appendix A. First, I describe the composition of the sample of households according to
385 the levels of the categorical health and fuel-poverty variables. Second, I describe the household
386 transition from one health and fuel-poverty status to another to ensure that there is a sufficient
387 intra-individual variability in these variables. The latter is important to verify when working with
388 panel data. I already verified that there is sufficient variation over time in self-assessed health-
389 status and fuel-poverty variables to ensure that it is suitable to use panel data methodology.

390 Figure 1(a) shows that 25.92% of households in the sample declared that their health status is
391 “Fairly good”. It also shows that 9.49% of households declared that they have a “Bad” or “Very
392 bad” health status, whereas 64.59% of them declared that they have a “Good” or “Very good”
393 health status. Regarding the intra-individual variation in the self-assessed health status, in partic-
394 ular health improvement over time, Figure 1(b) shows for example that from year to year, 18.94%
395 of households declaring that they have a “Fairly good” health status declared that they have a
396 “Good” health status the following year. Similarly, 36.51% of households declaring that they have
397 a “Good” health status declared that they had a “Very good” health status the following year. I
398 observed the same transition rates for improvement when considering other health status levels.
399 The same is also true in the opposite direction, with health status worsening. For example, 11.65%
400 of households declaring that they have a “Fairly good” health status declared that they have “Bad”
401 or “Very Bad” health status the following year.

402 Regarding the subjective fuel-poverty variables, Figure 1(c) shows that 25% of households de-
403 clared that they have difficulty heating their dwelling and that one-third of households declared that
404 they encounter financial difficulties to satisfy their heating needs. Regarding the intra-individual
405 variation in subjective fuel poverty, Figure 1(d) shows that almost 14% of households declaring for
406 a given year that they had no difficulty heating their dwelling, declared that they had problems
407 the following year. Similarly, almost 43% of households declaring for a given year that they had
408 difficulty heating their dwelling declared that they did not encounter this difficulty the following
409 year. For the second subjective indicator of fuel poverty “*Are you financially able to maintain an*
410 *adequate temperature in the dwelling?*”, Figure 1(e) shows that 39% of households declaring that
411 they have financial difficulty in a given year did not have the same problem the following year.
412 Their situation was therefore better. Conversely, almost 19.71% of households declaring at a given
413 year that they had no financial difficulty to heat their dwelling saw their situation worsen the
414 following year.

415 For the objective indicator of fuel poverty, *i.e.* the 10% indicator, calculations show that there
416 are 10.21% of fuel-poor households in the sample. Of these, Figure 1(f) shows that 19.71% de-
417 clared that they were fuel-poor during a given year, but became non-fuel-poor the following year.
418 Further, 12.43% declared that they were not fuel-poor in a given year, but became fuel-poor the
419 following year.

420 Interestingly, regarding the overlap between three measures of fuel poverty, statistics across fuel-
421 poverty indicators show that 26.32% of individuals encounter at least one of the three fuel-poverty
422 problems, *i.e.* being fuel-poor, declaring having financial ability to maintain an appropriate level
423 of warmth, or declaring having a dwelling difficult to heat. They also show that 8.29% have two
424 problems, and only 2.48% have the three problems at the same time.

425

426 In sum, in addition to giving a preliminary overview of the composition of the study sample,

427 the summary statistics mainly show that, from an econometric point of view, there is a sufficient
 428 variability in central variables to use the panel-data methodology.



Figure 1. (a) Summary statistics for the self-assessed health status variable. Blue: frequency, Orange: percentage; (b) Intra-individual variation in the self-assessed health status. Each bar in each block of bar graphs represents one level of the self-assessed health status variable and gives the percentage of households that change levels, *i.e.* the intra-individual variation in health status from one year to the next; (c) Summary statistics for fuel poverty as approximated by “dwelling difficult to heat” and “household financial ability to heat its dwelling”. Each bar gives the percentage of households declaring that they have a dwelling difficult to heat or that they have financial difficulties to heat their dwelling to an adequate temperature; (d) Intra-individual variation in fuel poverty as approximated by the variable “dwelling difficult to heat”. Each bar in each block of bar graphs represents one level, *i.e.* “Yes” or “No” of the fuel-poverty variable and gives the percentage of households that change levels, *i.e.* the intra-individual variation; (e) Intra-individual variation in fuel poverty as approximated by the variable “household financial ability to heat its dwelling”. Each bar in each block of bar graphs represents one level, *i.e.* “Yes” or “No” of the fuel-poverty variable and gives the percentage of households that change levels, *i.e.* the intra-individual variation in the household financial ability to heat its dwelling; (f) Intra-individual variation in the (objective) 10% indicator of fuel poverty.

429 3.2 Econometric specifications and findings

430 3.2.1 Is there any correlation between fuel poverty and self-assessed health status?

431 I start by studying the association between fuel poverty and self-assessed health status. I
432 estimated a fixed-effect model based on the following specifications:

$$\Delta y_{it} = a_i + \mu_t + \alpha \Delta x_{it} + \beta \Delta z_{it} + \Delta \epsilon_{it} , \quad (5)$$

433 where y_{it} is health outcome, a_i represents unobserved individual fixed factors that are assumed to
434 affect health outcome, μ_t are time-specific effects, x_{it} is a fuel-poverty indicator (the treatment), z_{it}
435 denotes the vector of other exogenous control variables, and ϵ_{it} is an independent and identically
436 distributed (i.i.d.) disturbance term. α and β are the vectors of coefficients respectively associated
437 with fuel poverty and control variables.

438 The model is estimated using the time first-difference estimator to remove individual hetero-
439 geneity and, thus, its correlation with some explanatory variables. In particular, individuals do not
440 all have the same scale of perception when assessing their fuel-poverty and health statuses. Their
441 pessimism may be reflected in their answers to questions, thereby creating an endogeneity bias in
442 the estimates. Given that the most likely excluded variables that could cause a merely associative
443 relationship are time-persistent, especially relative to fuel-poverty changes, the first-difference es-
444 timation should reduce the effect on the fuel-poverty estimates of excluded variables. In terms of
445 interpretation, the estimation of this specification determines, for a given individual, the impact
446 of variation of the fuel-poverty status between $t - 1$ and t on the variation of his/her self-assessed
447 health status between $t - 1$ and t .

448 Table 2 gives the results of the estimation. As for all estimations presented throughout
449 this paper, Models 1 to 4 differ according to their fuel-poverty indicator. In Model 1, I used the
450 objective 10% indicator as calculated in Section 3.1.2. In Models 2 and 3, I used the two subjective
451 indicators, namely “*Are you financially able to maintain an adequate temperature in the dwelling?*”
452 and “*Is your dwelling difficult or too expensive to heat to suitable level of warmth?*”. Finally, in
453 Model 4, I simultaneously included all three fuel-poverty indicators.

454 Models 1 to 3 show that there is a significant negative correlation between fuel poverty and
455 self-assessed health status. In terms of magnitude, the fuel-poverty coefficients associated with
456 subjective indicators were higher than those associated with the objective indicator, *i.e.* -4.4%
457 versus -6.4%. Model 4 confirms that the magnitude of the impact of fuel poverty is greater when
458 the objective 10% indicator is used *i.e.* -5% versus -2.9%. Most likely, the subjective dimension
459 in households’ appreciation of their fuel-poverty situation exacerbates the magnitude of the ef-
460 fect of fuel poverty on self-assessed health state. Regarding the control variables, results of the
461 three models were quite similar. They showed a significant positive correlation between income
462 on self-assessed health status. In particular, individuals with high income, usually having a high
463 socio-economic standing, are expected to suffer less from fuel poverty because they can either af-
464 ford energy or make their home more energy-efficient, and in turn their health is less affected.
465 This corroborates statements of previous studies. In fact, although the many studies examining
466 income inequality with regard to health interpreted the evidence differently, the large majority of
467 studies report that health tends to be worse in more unequal societies (Pickett and Wilkinson,
468 2015). Regarding dwelling characteristics, the results show that there is a significant and cor-
469 rectly signed correlation between dwelling characteristics – in particular the presence or absence
470 of leaks/dampness and darkness – and dwelling energy efficiency, as assessed by dwelling age. The
471 remaining variables, *i.e.* dwelling type, surface and dwelling setting (urban or rural) are statically

472 non-significant. Finally, the results show that climate characteristics are significantly correlated
 473 with self-assessed health status. In particular, living in (inner) Paris, the Parisian Region or the
 474 North (where it's colder) is negatively correlated with self-assessed health status.

Table 2 – Results of the estimation of fixed-effect models (1)

	Model 1	Model 2	Model 3	Model 4
<i>c</i>	2.321 (2.821)*** ^a	2.234 (3.029)***	5.032 (4.201)***	4.231 1.384
Fuel poverty indicators				
<i>FPOV</i>	-0.044 (-3.210)***	—	—	-0.050 (-8.340)***
<i>TEM</i>	—	0.055 (3.011)***	—	0.021 (4.110)***
<i>DIFFH</i>	—	—	-0.064 (-8.671)***	-0.029 (-1.982)**
Control variables: household characteristics				
<i>SEX</i>	0.030 (0.920)	0.002 (1.300)	0.003 (1.901)*	0.011 (1.981)**
<i>MAR</i>	-0.247 (-1.340)	-0.239 (-0.893)	-0.897 (0.130)	-0.364 (0.030)
<i>H SIZE</i>	0.302 (0.011)	0.138 (0.282)	0.932 (0.021)	0.645 (1.021)
<i>INC</i>	0.031 (4.111)***	0.036 (5.033)***	0.021 (12.330)***	0.012 (2.837)***
Control variables: dwelling characteristics				
<i>DWTY</i>	0.339 (0.112)	0.122 (0.291)	0.404 (0.910)	0.212 (1.721)*
<i>LEAKS</i>	-0.033 (-13.240)***	-0.0352 (-4.321)***	-0.040 (-9.000)***	0.017 (-3.421)***
<i>DARK</i>	-0.204 (-0.041)	-0.165 (-0.829)	-0.032 (-0.140)	0.922 (0.002)
<i>SURF</i>	-0.006 (-2.210)**	-0.001 (-1.281)	-0.003 (-1.020)	-0.005 (-1.991)**
<i>DWAGE</i>	0.003 (2.276)***	0.003 (3.362)***	0.062 (2.237)**	0.0238 (4.239)***
<i>RURAL</i>	-0.231 (-0.040)	0.322 (0.280)	0.391 (0.032)	-0.094 (-0.001)
Control variables: climate characteristics				
<i>CLIMFR1</i>	-0.002 (-12.240)***	-0.002 (-19.903)***	-0.005 (-14.132)***	-0.001 (-8.389)***
<i>CLIMFR2</i>	-0.001 (-4.212)***	-0.003 (-9.123)***	-0.001 (-3.192)***	-0.004 (-3.099)***
<i>CLIMFR3</i>	-0.021 (3.370)***	-0.4352 (-0.030)	-0.203 (1.231)	-0.023 (4.427)***
<i>CLIMFR4</i>	-0.322 (-0.200)	-0.676 (-0.903)	-0.982 (-1.102)	-0.351 (-0.244)
<i>R²</i>	0.323	0.402	0.490	0.389
Number of observations	102 041	102 129	101 876	101 299
Year fixed effects	Yes	Yes	Yes	Yes

a. *** denotes significance at 1%, ** 5%, and * 10%.

475

476 3.2.2 What's about causality between fuel poverty and self-assessed health status?

477 The estimation of the fixed-effects model shows that there is a significant correlation between
 478 fuel poverty and self-assessed health status, but is not enough to study the causal relationship
 479 between these two variables. Moreover, another limitation in the use of a fixed-effects model is

480 that it does not take into account the endogeneity bias, which refers to the fact that some time-
481 varying observed or unobserved events that occur during a specific year may simultaneously affect
482 fuel poverty and health status. More specifically, the main requirement for consistent estimation
483 of α within a standard regression analysis of Eq. (5), the condition that $\text{Cov}(x_{it}, \epsilon_{it} | z_{it}, \mu_t) = 0$,
484 is unlikely to be met. Factors influencing fuel-poverty, such as individuals' expectations regarding
485 income or job loss, may also influence health, but were not observed and may bias estimates of α
486 because these factors can have a direct effect on health in addition to their effect on fuel poverty.
487 The estimation of α requires an instrument that predicts fuel poverty, but conditional on covari-
488 ates, is not correlated with health outcome. Likewise, it is necessary to eliminate the unobserved
489 time-invariant individual-specific fixed effects a_i , and any time-varying unobserved effects μ_t that
490 might affect health as well as fuel poverty. Therefore, to tackle with these challenges, I propose
491 the use of an instrumental fixed-effect specification of Eq. (5):

$$\Delta y_{it} = \alpha \Delta x_{it} + \beta \Delta z_{it} + \Delta \epsilon_{it} \quad (6)$$

493 Therefore, instrumental variables (IV) are used to predict changes in fuel-poverty variables,
494 Δx_{it} . The combination of IV and fixed-effects estimation eliminates both potential sources of
495 endogeneity – fixed individual characteristics that affect both health and fuel poverty in Eq. (5)
496 and time-varying influences that affect both health and fuel poverty net of the influences of fixed
497 characteristics – and, conditional on the assumptions of the model holding, the instrumental fixed-
498 effects approach allows an unbiased estimation of the effect α of fuel poverty on health in Eq. (5).

499 A credible instrument must satisfy two conditions. First, it must be relevant – which means that
500 it must affect the probability of the treatment, *i.e.* fuel poverty. In a regression of the treatment
501 on the instrument, *i.e.* the first-stage equation, the coefficient of the IV must be sufficiently strong.
502 In our case, this means that the instruments must be significantly correlated with fuel poverty as
503 measured by objective or subjective indicators. Second, the instrument should satisfy the exclusion
504 restriction, which means that the instrument should affect the outcome, *i.e.* self-assessed health
505 status, exclusively through its effect on the treatment. When these two conditions are satisfied,
506 instruments give precise estimates of direct causal effects (Angrist et al. (1996), Heckman (2000,
507 2001), Adams et al. (2003)).

508 The choice of instruments often leads to debates due to the weak associations between the
509 treatment and the chosen instrument. It can thus be difficult to obtain precise estimates of direct
510 causal effects (Staiger and Stock, 1997). Instruments should therefore be carefully chosen, although
511 remarkably there is a consensus that proper instruments are very hard to find (Adams et al., 2003).
512 Ideally, they can be obtained through designed experiments, where random treatment assignment
513 precludes the possibility of confounding by common factors, provided recruitment and retention
514 of experimental subjects does not re-introduce confounding. In this study, economic events that
515 impact individuals differently and that are not related to their prior fuel poverty or health are po-
516 tentially proper instruments. Table 3 presents some examples of instruments that have been used
517 in the health and development economics literature to study the question of the causality between
518 income (or alternatively wealth or socio-economic status) and health. Based on this literature, I
519 relied on the following two individual-specific instruments:

520

521 — IV(1): Housing retrofit subsidy²⁴

522 Retrofit actions may not be exclusively devoted to enhance housing energy efficiency, and

24. In the EU-SILC database, this variable is called “Exceptional financial resources: receipt of housing retrofit subsidy”.

523 are not necessarily a lever to fight residential fuel poverty. However, even though there is no
524 information in the EU-SILC database about how much of this subsidy was devoted to help
525 to improve energy efficiency, I assumed that it was primarily devoted to improving housing
526 energy efficiency. ADEME (2018)²⁵ argues that improving housing energy efficiency is the
527 foremost rationale for a household to undertake housing retrofit actions in France, and that
528 the most frequent housing retrofit actions by French households are housing insulation, *i.e.*
529 roof, walls, openings (windows and French window), and increasing the energy-efficiency of
530 the heating system. Moreover, ADEME (2018) adds that 83% of French households declare
531 that the retrofit actions undertaken indeed improved their housing thermal comfort. On
532 the other hand, the housing retrofit subsidy exogenously affects fuel poverty because its
533 amount does not depend on income (which enters in the calculation of the 10% objective
534 fuel-poverty indicator). In particular, in France, one of the most efficient energy retrofit
535 measures, the Tax Credit for Energy Transition²⁶ – which is a tax provision that allows
536 households to reduce their income tax by up to 30% of the expenditures made to undertake
537 actions devoted to improve energy efficiency of the dwelling – is distributed by the govern-
538 ment independently of income level (ADEME, 2018).

539 Based on this, I conjecture that the housing retrofit subsidy is a relevant instrument (ex-
540 ogenously affecting fuel poverty) and satisfies the exclusion restriction (its effect on health
541 is only indirect and goes through fuel poverty).

542
543 — IV(2): Energy prices

544 In previous studies dealing with the causality between health and income, “Food prices” and
545 – more generally – “Commodity prices” have usually been used as instruments (Thomas and
546 Strauss (1997) and Brückner and Ciccone (2007). *Cf.* Table 3). By analogy and in the con-
547 text of residential energy (heating) demand and the associated fuel-poverty issue, I propose
548 energy prices as an instrument. I conjecture that an exogenous increase in energy prices,
549 in particular gas and electricity²⁷ engenders an increase in residential energy expenditures,
550 thus, in the probability to be pushed into fuel poverty. Thus, there is a direct link between
551 energy prices and fuel poverty and energy prices are a relevant instrument (condition 1).

552 As for the exclusion condition (condition 2), it may likely be violated because health out-
553 comes can be directly and negatively affected by an increase in energy prices. A channel for
554 such negative effects goes through the competition between energy and health expenditures
555 that an increase in energy prices may trigger: after a shock in energy prices, there will be
556 less money for energy and health. Two assumptions are possible²⁸:

557
558 — Assumption 1: there is less money for residential energy. The individual decides to
559 reduce his/her residential energy consumption to maintain his/her health (and other)

25. Based on the results of the “Energy retrofit actions for independent dwelling” survey dealing with the 2014-2016 period (Enquête “Travaux de Rénovation Énergétique des Maisons Individuelles” (TREMI)).

26. Le Crédit d’Impôt pour la Transition Énergétique (CITE).

27. Gas and electricity are the main sources of energy used for residential heating in France. For example, in 2015, 39% of households used gas and 35% used electricity (INSEE, 2017).

28. The distribution of total budget to different item of expenditures, in particular residential heating and health depends on several determinants, particularly income. After an increase in energy prices, a poor individual will probably quickly change his/her habits and reduce his/her energy consumption to cope with high heating expenditures. However, an affluent individual will look for more energy-efficient equipment to maintain his/her thermal comfort and also reduce his/her medium- and long-term heating expenditures. In all cases, the trade-off between residential energy and health expenditures is a complex process and goes beyond the aim of this paper. For this reason, assumptions 1 and 2 below should be considered bearing in mind that they correspond to a simplified framework to look at possible trade-off between residential energy and health expenditures. I note that, unless I’m mistaken, there is currently no published study on the effect of the competition between energy and health expenditures.

560 expenditures. This can engender an energy deprivation situation leading to fuel poverty,
561 which itself can induce a negative effect on health outcomes. In this case, the effect of
562 an increase in energy prices on health is indirect and goes through fuel poverty. The
563 instrument satisfies the exclusion condition.

564 — Assumption 2: there is less money for health costs. The individual prefers thermal com-
565 fort to the detriment of health. Then the effect of an increase in energy prices on health
566 will not go through fuel poverty. It will be direct and takes the form of a reduction
567 in the demand for health care services, which can itself generate an additional stressful
568 situation that can exacerbate the negative impact of energy prices on health. In this
569 case, the exclusion condition is violated.

570
571 Which assumption is more realistic? Answering this question is difficult, although intuitively
572 individuals may be expected to reduce their heating expenditures rather than their health
573 expenditures. On the other hand, the direct and immediate effect of an increase in energy
574 prices on health will operate through stress – whose consequences on health and health
575 expenditures take time to manifest themselves – rather than a reduction in the demand for
576 health care services, and thus health expenditures. Thus, assumption 2 is not applicable.
577 Although this statement is still hypothetical, official French statistics from the INSEE ²⁹
578 show that the weight of health expenditures in the household budget has quadrupled over
579 the last 60 years due to a sharp increase in overall health expenditures (caused, inter alia, by
580 the ageing of the population) and to the decline in health expenditures ensured by society
581 at large ³⁰. Moreover, the same official statistics show that, while between 1960 and 2017
582 residential expenditures, including energy expenditures, have increased by 3.1%, health ex-
583 penditures have increased by 4.9% ³¹.

584
585 By considering these points, I reasonably assume that Assumption 1, according to which
586 the instrument satisfies the exclusion condition applies: the effect of energy prices' increase
587 on health outcomes is indirect and goes through fuel poverty.

588

29. <https://www.insee.fr/fr/statistiques/3303442?sommaire=3353488>. “Institut National des Statistiques et des Études Économiques” (INSEE).

30. https://www.lafinancepourtous.com/decryptages/finance-perso/revenus/consommation/evolution-consommation_menages/.

31. Although these aggregated statistics can be insightful, they should be interpreted with caution because they hide several economic, geographical and gender disparities.

Table 3 – Examples of instruments used in health and development economics literature

Reference	Topic	Instrument(s)
Pritchett and Summers (1996)	Relationship between income and health (country level). — Outcome: health — Treatment: income	1) Terms of trade, 2) Investment ratio, 3) Black market premium, 4) Price level distortion.
Ettner (1996)	Relationship between income and health (individual level). — Outcome: health — Treatment: income	1) State unemployment rate, 2) Work experience, 3) Parental education, 4) Spousal characteristics.
Thomas and Strauss (1997)	Relationship between health of wages for men and women. — Outcome: wages — Treatment: health indicators	1) Relative food prices, 2) Non-labour income.
Meer et al. (2003)	Relationship between health and wealth (individual level). — Outcome: health — Treatment: wealth	1) Inheritances.
Adams et al. (2003)	Causal paths between health and socio-economic status (individual level). — Outcome: health — Treatment: socio-economic status.	1) Economic events that impact individuals differently and that are not related to their prior socio-economic status or health, <i>i.e.</i> a tax change that affects wealth differently, 2) Change in mandated Medicaid coverage that has a differential impact across States, 3) Individual events such as receipt of inheritances ^a .
Brückner and Ciccone (2007)	Relationship between growth, democracy, and civil war (country level). — Outcome: civil wars — Treatment: economic growth	1) Growth rate of current and lagged rainfall, 2) Commodity price index growth rate.
Chin (2010)	Relationship between income, health, and well-being (individual level). — Outcome: health and well-being — Treatment: income	1) Interaction between the price of salt and the number of household members, 2) Interaction between regional rainfall and a binary variable of individual land ownership, 3) A variety of alternative instrumental variables: interactions, lags, and non-linear transformations of rainfall levels, rainfall growth, rainfall levels in the lowest 10 th and 25 th percentiles of total rainfall, number of “economically productive” male and female children (ages 10-49), their mortality and sex-ratios by household.
Kuehnle (2014)	Causal effect of family income on child health (individual level). — Outcome: health — Treatment: income	1) Local unemployment rate, 2) Lagged local unemployment rate (by one year), 3) Average local unemployment rate (averaged over available waves), 4) Business growth rate and regional GDI (gross domestic income per head), 5) Local unemployment rate, business growth rate and regional GDI, 6) Average local unemployment rate, business growth rate and regional GDI.

^a. However, they should not be anticipated and the probability of their occurrence should not be linked to health status (Meer et al., 2003)

589 The instrumental fixed-effect model was estimated in two steps. The first-stage least squares
 590 estimation model is defined as:

$$x_{it} = b_i + \eta_t + \gamma I_{it} + \delta z_{it} + \xi_{it} , \quad (7)$$

591 where b_i represents unobserved time-invariant fixed factors, which may be correlated with the fixed
 592 unobserved characteristics a_i in Eq. (5), and that affect an individual's fuel-poverty situation,
 593 η_t are unobserved time-varying factors that affect instrument(s) and income, x_{it} is a measure
 594 of fuel poverty, I_{it} is a vector of instruments that directly affects fuel poverty and indirectly
 595 affects the second-stage health outcome y_{it} and z_{it} is a vector of individual, housing and climate
 596 characteristics. Finally, ξ_{it} denotes unobserved factors that are uncorrelated with z_{it} and the
 597 second-stage error term ϵ_{it} in Eq.(5). The fixed-effects estimation is applied to Eq. (7) to control
 598 for both the time-varying unobserved factors η_t and unobserved fixed factors b_i :

$$\Delta x_{it} = \alpha \Delta I_{it} + \beta \Delta z_{it} + \Delta \xi_{it}. \quad (8)$$

599 Thus, the excluded variable bias arising from the potential correlation between the instruments
 600 I_{it} and the individual-specific time-invariant unobservables b_i is adequately addressed by fixed
 601 effects because the change in instruments must be exogenous.

602 Table 4 presents the results of the first-stage regression. I report only results showing the
 603 statistical significance of the IV, because they are the main interest in this first-stage regression.
 604 They show that there is a significant correlation between the instruments and fuel poverty. I
 605 expected credible estimates of direct causal effects with these instruments. I conclude that the
 606 instruments are sufficiently strong that I can implement an IV strategy to estimate the direct
 607 causal effects of fuel poverty on self-assessed health status (Angrist et al. (1996), Staiger and Stock
 608 (1997), Heckman (2000, 2001)).

609 Table 5 gives the results of the instrumental fixed-effects model. The results of the four models
 610 show that fuel poverty has significant negative effects on self-assessed health status. In particular,
 611 this effect ranges from -10.90% to -13% depending on which fuel-poverty indicator is used. A
 612 10% increase in the objective fuel-poverty indicator induces a 10.9% decrease in the number of
 613 households declaring that they have a very good general health status. For the subjective fuel-
 614 poverty measures, the results show that a 10% increase in the number of households declaring that
 615 they are financially able to satisfy their heating needs (see Model 2) engenders a 13% decrease in
 616 the number of households declaring the they have a very good general health status. Thus, the
 617 negative effect is greater when fuel poverty is approximated using subjective indicators. When
 618 using the three fuel-poverty indicators in the same regression (Model 4), the results show that
 619 estimation of fuel-poverty effect is still higher in the case of subjective indicators. Based on
 620 previous literature, I again conjecture that the estimated effect of fuel poverty on self-assessed
 621 health status is slightly exacerbated when indicators are based on personal opinions, standards
 622 and judgement. In particular, Llorca et al. (2018) argue that individuals who rate themselves as
 623 fuel poor tend to report poorer health status. Lacroix and Chaton (2015) add that a person in fuel
 624 poverty is (2.36 percentage points) more likely to report poor or fair health status than a person
 625 who is not in fuel poverty.

626 When looking at control variables, the results of the four models support similar conclusions.
 627 The results from Model 1, in which the objective measure of fuel poverty is used, show that there
 628 is a negative causality between sex and self-assessed health status. The same holds when looking
 629 at the impact of household size and self-assessed health status. Interestingly, results also show

630 that an increase in income has a positive impact on self-assessed health status which corroborates
631 previous results (see Section 2). As explained above, this effect is more stronger when the objective
632 fuel-poverty indicator is used (Model 1).

633 Considering dwelling characteristics, variables describing home dampness and leaks negatively
634 impact self-reported health status, whereas dwelling energy efficiency operates in the opposite
635 direction. The results of Models 2 and 3 give the same results as Model 1. Finally, regarding climate
636 characteristics, results generally show some evidence of a negative and statistically significant effect
637 of living in a cold region and self-assessed health status (in particular in Models 1 and 4) (Charlier
638 and Kahouli, 2019).

639 Since it is well-established that the effect of fuel poverty on health is not immediate, manifesting
640 itself on the medium or long term, I re-estimated the previous instrumental fixed-effects model
641 by modifying the date at which the fuel-poverty variable is observed. I note that through this
642 additional specification, I aim to test the assumption according to which the negative impact of
643 fuel poverty on health is not immediate. It takes time to manifest itself in terms of poor health. By
644 extension, I also aim to link, even implicitly, this analysis to the literature dealing with scarring
645 effects which means that the longer the duration of time spent in fuel poverty the greater the
646 potential effect on health (Roberts et al., 2015)³².

647 The lagged specification is written as follows:

$$\Delta y_{it} = \alpha \Delta x_{i(t-k)} + \beta \Delta z_{it} + \Delta \epsilon_{it}. \quad (9)$$

648 The variables in Eq. (9) are defined as in Eq. (6) except the variable $x_{i(t-k)}$, which denotes
649 henceforth the lagged fuel-poverty variable. In other words, I estimated the model by considering
650 the contemporary and lagged impact of fuel poverty on self-assessed health status. I ran several
651 estimates, but only report results from estimations with the impact of fuel poverty at periods (t)
652 and ($t - 1$) on self-assessed health status at period (t).

653 I note that some variables related to household and dwelling characteristics were not statistically
654 significant in the previous estimation (Table 5), as in the preliminary estimation of correlations
655 (Table 2), *i.e.* marital status, dwelling darkness and urban setting. Therefore, I removed these
656 variables from the lagged IV estimation.

657 Table 6 presents the results of regressing fuel poverty at periods (t) and ($t - 1$) on self-assessed
658 health status at period (t). Interestingly, they now show that the coefficients associated with fuel-
659 poverty indicators at period (t) are statistically non-significant although correctly signed. However,
660 they are statistically significant at period ($t - 1$). This means that the effect of fuel poverty is de-
661 ferred (not immediate). Fuel poverty takes time to translate into negative health consequences. For
662 the objective indicator of fuel poverty, *i.e.* the 10% indicator, the impact of fuel poverty is slightly
663 lower than for the subjective indicators. More specifically, while for the objective indicator a 10%
664 increase of fuel poor households induces a 14.1% decrease in the number of households declaring
665 that they have a good or very good self-assessed health status, it induces 21.1% decrease in the
666 number of households declaring that they have a good, very good or fairly good health status when
667 the financial ability to maintain an appropriate level of warmth is used as fuel poverty indicator.
668 When considering the regression containing the three fuel-poverty indicators, the causal impact of
669 fuel-poverty on self-assessed health status is still significant for each of the three indicators, but
670 more important when the subjective indicators are used. The effects of the control variable are

32. Although the model that I propose does not permit to analyse the dynamic aspect related to scarring effects and how the exit and re-entry into fuel poverty are influenced by housing and household characteristics, it is important to bear in mind that a reliable medium or long-term analysis of consequences of fuel poverty on health outcomes should take into account household fuel poverty situation at different time periods.

671 relatively similar to those in the non-lagged model.

672 In summary, in light of my main question, the causality analysis based on the instrumental
 673 fixed-effects model shows that there is a significant causal relationship between fuel poverty and
 674 self-assessed health status. The magnitude of this causality, even small, appears to be more im-
 675 portant when a subjective fuel-poverty indicator is used. It also shows that the negative impact of
 fuel poverty on health is deferred.

Table 4 – Results of the estimation of the first-stage regression

	Model 1	Model 2	Model 3	Model 4
	Instrumental variables			
IV(1): Housing retrofit subsidy (<i>RETRO</i>)	-0.021 (-12.374)*** ^a	-0.019 (-8.368)***	-0.056 (-9.030)***	-0.0437 (-15.000)***
IV(2): Energy prices (<i>P</i>)	3.010 (2.786)***	2.382 (2.149)**	2.763 (3.305)***	1.973 (5.972)***
Control variables	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Adj R^2	0.231	0.197	0.184	0.326
Fisher's statistic ^b	18.412***	18.106***	19.923***	20.054***

a. *** denotes significance at 1%, ** 5%, and * 10%.

b. Weak instruments.

676

677 4 Conclusion and policy recommendations

678 In this article, I studied the causal relationship between fuel poverty and self-assessed health
 679 status by using a large scale nationally representative dataset and an instrumental fixed-effects
 680 model. I considered objective as well as subjective indicators of fuel poverty. The results show
 681 that there is a significant causal relationship between fuel poverty and self-assessed health status
 682 regardless of the fuel-poverty indicator and that this causal effect shows a lag in time. The results
 683 also show that the magnitude of causality is greater for subjective measures of fuel poverty.

684 Throughout this study, I aimed to shed light on the need to take overall health into account
 685 when defining policy measures devoted to fighting fuel poverty in the residential sector. Negative
 686 impacts on health may represent an additional potential argument to enhance efforts to combat
 687 fuel poverty by investing in curative and preventive energy efficiency schemes. For example, in
 688 January 2018, an Energy Voucher was created as a curative measure in France to replace social
 689 tariffs of electricity and gas. Likewise, preventive measures that focus on improving dwelling energy
 690 efficiency have also recently been developed in France, *i.e.* diagnosis of energy use, financial sup-
 691 port for retrofit measures. Furthermore, the negative impacts of residential fuel poverty on health
 692 may lend support to the idea that fighting this problem may constitute a key lever for reducing
 693 public expenditures on health care on the medium and long term. A recent study, based on the
 694 HHSRS Ezratty et al. (2017), assessed the cost of inefficient dwellings for the French health sector
 695 as well as the cost benefits of housing improvements and thermal upgrades in France. It shows
 696 that the reduction in the annual health cost due to upgrading energy-inefficient dwellings occupied
 697 by low-income households is equal to €614.7 M. The authors argue that it is important to assess
 698 the benefits of improving housing conditions for the health sector and call for the development of
 699 methodologies to carry out this type of assessment. This argument provides the rationale for pro-
 700 moting expenditures on home-improvement schemes, because they represent savings in health-care
 701 costs.

702 Nevertheless, although, both studies based on experimental designs and observational data ar-

Table 5 – Causality analysis: results of the instrumental fixed-effects model

	Model 1	Model 2	Model 3	Model 4
Fuel poverty indicators				
$\bar{F}\bar{P}\bar{O}\bar{V}$	-0.109 (-1.970)**	—	—	-0.083 (-3.238)***
TEM	—	0.112 (1.711)*	—	0.143 (2.647)***
$DIFFH$	—	—	-0.130 (-2.098)***	-0.132 (-1.983)**
Control variables: household characteristics				
$\bar{S}\bar{E}\bar{X}$	0.023 (3.112)***	0.034 (3.209)***	0.021 (4.298)***	0.045 (1.983)**
MAR	0.233 (0.023)	0.782 (0.411)	0.521 (0.240)	(-0.313) (1.349)
$HSIZE$	-0.002 (-2.121)**	-0.001 (-1.873)*	-0.002 (-1.994)**	-0.004 (-2.103)**
INC	0.078 (4.134)***	0.0283 (3.292)***	0.0231 (3.604)***	0.098 (6.239)***
Control variables: dwelling characteristics				
$DWTY$	0.031 (1.973)**	0.021 (2.041)**	0.028 (1.991)**	0.012 (2.310)***
$LEAKS$	-0.001 (-2.230)***	-0.002 (-5.293)***	-0.003 (-3.030)***	0.003 (-1.983)**
$DARK$	-0.631 (-0.081)	-0.223 (-0.009)	-0.323 (-0.000)	-0.231 (0.023)
$SURF$	-0.002 (-2.012)**	-0.003 (-1.991)**	-0.003 (-2.090)***	-0.023 (-3.289)***
$DWAGE$	0.021 (1.895)**	0.187 (2.022)**	0.112 (2.117)**	0.231 (3.128)***
$RURAL$	0.003 (0.700)	-0.002 (-0.001)	-0.001 (-0.003)	0.002 (0.000)
Control variables: climate characteristics				
$CLIMFR1$	-0.003 (-10.320)***	-0.003 (-9.973)***	-0.004 (-6.101)***	-0.001 (-8.809)***
$CLIMFR2$	-0.001 (-2.212)**	-0.003 (-4.163)***	-0.002 (-5.102)***	-0.004 (-8.999)***
$CLIMFR3$	-0.060 (1.790)**	0.4352 (0.030)	0.203 (1.231)	-0.037 (-2.427)***
$CLIMFR4$	-0.302 (-0.000)	-0.676 (-0.000)	-0.231 (-0.002)	-0.351 (-0.004)
Year fixed effects	Yes	Yes	Yes	Yes
KP LM Underid	35.231***	34.239***	31.340***	29.239***
KP Wald F-test	20.233***	19.349***	18.390***	21.382***
Sargan p	0.064	0.056	0.060	0.074

703 gue for causality between residential fuel poverty and health outcomes, there is still a need more
704 detailed analyses of causality identification. At the same time, results of such analyses should
705 be considered in addition to other ones dealing with the definition, the measurement, and the
706 socio-economic consequences of fuel poverty. The later represents in fact a multidimensional phe-
707 nomenon that must be fought as part of an integrated approach taking into account its multiple
708 facets. Therefore, (claims for the) identification of causality in this article is not intended to pro-
709 vide an optimal solution to the problem of fuel poverty but rather to highlight the existence of a
710 lever of action which is still until now unconsidered in terms of public policies despite the growing
711 recognition and political sensitivity to the adverse welfare impacts of fuel poverty, *i.e.* impacts on
712 physical and mental health and on educational attainments.

713 I conclude this article by giving some avenues for future research that can improve on this
714 study. First, some populations, namely infants and the elderly, are more vulnerable than others

Table 6 – Lagged causality analysis: results of the instrumental fixed-effects model

	Model 1	Model 2	Model 3	Model 4
Fuel poverty indicators				
$\bar{F}\bar{P}\bar{O}\bar{V}$	-0.201 (-0.970)	—	—	-0.192 (-0.203)
$lag1FPOV$	-0.141 (-12.070)***	—	—	-0.173 (-15.933)***
TEM	—	0.111 (0.211)	—	0.321 (0.722)
$lag1TEM$	—	0.211 (12.001)**	—	0.287 (4.383)***
$IDIFFH$	—	—	0.183 (1.672)*	-0.291 (-1.123)
$lag1DIFFH$	—	—	-0.124 (-11.033)***	-0.231 (-15.343)***
Control variables: household characteristics				
$\bar{S}\bar{E}\bar{X}$	0.003 (8.649)***	0.023 (4.942)***	0.034 (4.122)***	0.004 (9.342)***
$H SIZE$	-0.023 (-11.404)***	-0.098 (-9.211)***	-0.076 (-6.622)***	-0.021 (-8.323)***
INC	0.073 (5.182)***	0.089 (5.928)***	0.093 (3.091)***	0.065 (7.939)***
Control variables: dwelling characteristics				
$\bar{D}\bar{W}\bar{T}\bar{Y}$	0.015 (3.933)***	0.021 (4.261)**	0.017 (5.221)***	0.0348 (3.130)***
$LEAKS$	-0.003 (-2.984)***	-0.004 (-3.483)***	-0.004 (-1.983)***	0.006 (-3.243)***
$SURF$	-0.087 (-2.233)***	-0.034 (-4.741)***	-0.044 (-3.134)***	-0.078 (-5.923)***
$DWAGE$	0.013 (23.985)***	0.015 (18.834)***	0.019 (14.000)***	0.034 (9.632)***
Control variables: climate characteristics				
$CLIMFR1$	-0.010 (-2.540)**	-0.045 (-4.323)***	-0.035 (-8.124)***	-0.039 (-6.039)***
$CLIMFR2$	-0.021 (-3.534)***	-0.002 (-2.003)**	-0.002 (-3.093)**	-0.054 (-4.403)**
$CLIMFR3$	-0.004 (2.730)**	0.001 (0.030)	0.001 (1.671)*	-0.032 (-2.290)**
$CLIMFR4$	-0.041 (-3.124)***	-0.0376 (-0.020)	0.231 (0.112)	-0.021 (-0.012)
Year fixed effects	Yes	Yes	Yes	Yes
KP LM Underid	30.121***	26.200***	28.910***	28.999***
KP Wald F-test	20.123***	22.002***	20.123***	18.122***
Sargan p	0.055	0.053	0.059	0.069

715 to poor housing conditions and the health impacts may be more harmful for them. Therefore,
716 a separate analysis on different populations, with a distinction between infants and the elderly,
717 may provide more relevant conclusions. Second, a growing body of literature shows the increasing
718 interest in the determinants of mental health and social well-being. Incipiently, a focus on the con-
719 sequences of housing conditions and residential fuel poverty on mental health and social well-being
720 would expand this analysis to these determinants of overall health. Considering these two areas of
721 research within the framework of a dynamic monitoring goal of fuel poverty represents a fruitful
722 and challenging area of research. In fact, because of the dynamic character of fuel poverty, there
723 is a need for reliable estimation of scarring effects to obtain a reliable assess its health impacts.

724 To explore these avenues of research, improvements are sorely needed in data collection to
725 enhance the quality and quantity of data on residential fuel poverty and health. When I started
726 working on the question of the relationship between residential fuel poverty and health, the chal-

727 lenge was to find empirical data. Although the EU-SILC database has valuable longitudinal data,
728 it still suffers from a dearth of data on health and housing conditions and is generally not designed
729 to explore the relationship between fuel poverty and health. The medium- and long-term effects
730 need to be analyzed in a more relevant way by using realistic data to monitor the fuel poverty
731 and health conditions of households over several years and to study different populations according
732 to age. Ideally, this database should be interdisciplinary and combine economic, epidemiological,
733 medical, geographical setting and location data on households' fuel poverty and health situation.
734 The development of this type of database is needed not only on a national, but also a European
735 level and should be developed using general harmonized rules that can be adapted to national
736 specificities to allow for international comparisons and feedback.

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A Summary statistics of central variables - Self-assessed health status and fuel poverty

Table A.1 – Summary statistics for the self-assessed health status variable

	Frequency	Percentage
Very bad	1.49	1.22
Bad	10.11	8.27
Fairly good	31.7	25.92
Good	55.22	45.15
Very good	23.78	19.44

Table A.2 – Intra-individual variation in the self-assessed health status

	Very bad	Bad	Fairly good	Good	Very good
Very bad	34.09	48.18	12.58	4.78	0.38
Bad	6.87	49.5	34.65	8.36	0.61
Fairly good	0.64	11.01	56.23	29.51	2.61
Good	0.15	1.92	18.94	66.06	12.93
Very good	0.07	0.55	4.99	36.51	57.88

Table A.3 – Summary statistics for fuel poverty as approximated by the two subjective indicators of fuel poverty

	Percentage
Dwelling not difficult to heat	74.76
Dwelling difficult to heat	25.24
Financial ability to maintain adequate temp.	69.21
No financial ability to maintain adequate temp.	30.79

Table A.4 – Intra-individual variation in fuel poverty as approximated by the variable “dwelling difficult to heat”

	Not difficult to heat	Difficult to heat
Not difficult to heat	86.13	13.87
Difficult to heat	42.93	57.07

Table A.5 – Summary statistics for fuel poverty as approximated by the two subjective indicators of fuel poverty

	Financial ability to maintain adequate temp.	Financial inability to maintain adequate temp.
Financial ability to maintain adequate temp.	87.33	12.67
No financial ability to maintain adequate temp.	35.91	64.09

Table A.6 – Intra-individual variation in fuel poverty as approximated by the variable “dwelling difficult to heat”

	Fuel-poor	Not fuel-poor
Fuel-poor	80.29	19.71
Not fuel-poor	12.43	87.57

744 B Methodology used to calculate individual-specific energy 745 prices

746 The EU-SILC database does not provide data on individual-specific energy prices. We need to
747 calculate these prices by merging data from three databases namely EU-SILC, PHEBUS³³, and
748 PEGASE³⁴. To do so, we considered two crucial points.

749 First, the energy tariff in France depends on the power needed for space and water heating,
750 appliances, lighting and cooking, etc. This power itself depends on the structure of the energy
751 mix in the dwelling (share of gas and electricity) and the size of the dwelling (surface area). For
752 instance, the electricity tariff is not the same for a dwelling using gas for heating and a dwelling
753 using electricity for a given surface area. Such information on tariffs is available in PHEBUS
754 database.

755 Second, we needed to associate the energy tariff (divided by the price of the base fee and the
756 unit cost of kWh) with each dwelling (household), which depends on its surface area and its energy
757 mix. For each household, we must determine an electricity tariff and a gas tariff.

758 From a practical point of view, to include energy prices in the EU-SILC database, we used the
759 three following steps:

- 760 — First, we split the EU-SILC database into categories according to the surface of the dwelling
761 (10 classes), the share of electricity expenditures (10 classes from 0% to 100%) and the share
762 of gas expenditures (10 classes from 0% to 100%).
- 763 — Second, we split the PHEBUS database into the same categories. Because for each category
764 of household, the tariff for electricity and gas is given in PHEBUS database, we incorporated
765 this information (tariffs) into the EU-SILC database. This step let us attribute an electricity
766 and gas tariff for each housing unit in the EU-SILC database.
- 767 — Finally, we used information provided in the PEGASE database to assign to each energy
768 tariff in the EU-SILC database an energy price covering base fees and consumption.

769 More details about the merging process can be found in Charlier and Kahouli (2019).

33. The “PHEBUS” database (“*Performance de l’Habitat, Equipements, Besoins et Usages de l’énergie*”) is especially devoted to the in-depth analysis of the fuel poverty issue in France. This database was compiled from April to October 2013 by the Ministry of Ecology, Sustainable Development and Energy (“*Ministère de l’Ecologie, du Développement durable et de l’Energie*”; MEDDE), the General Commission for Sustainable Development (“*Commissariat Général au Développement Durable*” (CGDD)), and the Department of Observation and Statistics (“*Service de l’observation et des statistiques*”; SOeS). It has two parts: (1) a face-to-face interview with the occupants of the home about their energy consumption, expenditures and attitudes and (2) an energy-efficiency diagnosis of the dwelling. In particular, “PHEBUS” contains information describing the household, *i.e.* the amount of energy expenditures, attitudes toward energy consumption, disposable income, age, etc., and dwelling characteristics, *i.e.* surface, type of heating system, level of energy efficiency, etc. Therefore, it can study households’ energy consumption in detail and the associated question of fuel poverty. The “PHEBUS” database covers the year 2013.

34. The PEGASE database (“*Petrole, Electricite, Gaz et Autres Statistiques de l’Energie*”) stores and distributes French energy statistics collected by the Department of Observation and Statistics (“*Service de l’Observation et des Statistiques*”; SOeS)). The new methodology of dissemination of detailed statistics is based on a Beyond 20/20 format which is also used by the International Energy Agency (IEA) and the French National Institute of Statistics and Economic Studies (INSEE; “*Institut National des Statistiques et des Etudes Economiques*”). It mainly provides long-term data series. The annual energy statistics summarize the consumption of different types of energies. This database presents the annual series in units (per kWh for gas or electricity). All statistics can be downloaded free of charge and reused with any license or payment of royalties, provided the acknowledgement of the source. More details on the PEGASE database are available on <http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/r/pegase.html>

C Overview of studies on the relationship between residential fuel poverty and health

770

Table C.1 – Overview of studies on the relationship between residential fuel poverty and health

References	Topic	Country	Methodology		Health dimension		Results
					Physical	Mental Social	
Platt et al. (1989)	Relationship between damp and mould and symptomatic ill health	Glasgow, Edinburgh, London	Cross-sectional study of random sample of households containing children. ³⁵	Separate and independent assessments of housing conditions and health	x		— Damp and mouldy living conditions have an adverse effect on symptomatic health, in particular of children
Packer et al. (1994)	Relationship between damp housing and adult health	Worcester (England)	Analysis of responses gathered in a cross sectional, postal questionnaire survey of a randomly selected sample of 5347 residents of Worcester		x	x	— People who live in damp housing are more likely to report long-standing illness, disability or infirmity — The prevalence of ill health increases as the severity of dampness increases
Hopton and Hunt (1996)	Impacts of different aspects of poor housing on mental health	Glasgow (Scotland)	A post-hoc analysis of data from a household interview survey			x	— Negative impacts of damp on mental health
Eurowinter (1997)	European differences in mortality rate per 1°C of temperature decrease	Linear multiple modelling	Finland, Germany, the Netherlands, London, Italy, Athens, Palermo			x	— Drop in temperature increases mortality in regions with warm winters, in populations with cooler homes, and among people who wear fewer clothes and are less active indoors
Energy Action Scotland (1999)	Relationship between poor housing, fuel poverty and health	Glasgow	Survey and detailed questionnaire			x	— Evidence of causality between children's poor health and dampness — Investment in housing renewal may be cost effective, given additional costs of poor housing for the National Health Service (NHS)
Collins (2000)	Impact of outdoor and indoor cold to seasonal respiratory and cardiovascular disease and mortality	—	Literature review			x	— Outdoor and indoor cold temperatures potentially promote respiratory illnesses in the presence of respiratory pathogens — It is methodologically difficult to disentangle the different roles of mould and dust mites in causing asthma, and thus to show a definitive link between home temperatures and specific health outcomes — Direct associations between a reduction in mortality indices and increased protective measures against cold temperatures

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35. 1169 children in 597 households.

Table C.1 – Continued from the previous page

References	Topic	City	Methodology	Health dimension		Focus and/or results
				Physical	Mental Social	
Goodwin (2000)	Review of the relationship between cold stress and health in the elderly (focus on circulatory disease)	—	Literature review	x		— Hypothermia represents a minor cause of excess winter mortality
						— Respiratory disease accounts for half of excess cold-related deaths and ischemic heart disease, and cerebrovascular disease for the other half
						— Elderly people experience increased blood pressure and heart rate in winter relative to summer at precisely the times of day that correspond to the times of greatest risk of the acute onset of thrombosis
Somerville et al. (2000)	Assessment of the use of NHS money to improve health by installing a central heating system in homes of asthmatic children	Cornwall	Pilot intervention study	x		— Improvement in the energy efficiency of the house seems to have a positive impact on children's health, particularly on their respiratory problems
Khanom (2000)	Assessment of the health impact of energy-efficiency improvement in fuel-poor houses	London (Tower hamlets)	Structured questionnaires and two in-depth interviews	x	x	— Significant relationship between poor housing and certain health outcomes, particularly depression and vomiting in the case of children — Depression is related to worries over fuel bills and inability to improve housing conditions
Green et al. (2000)	Relationship between improved energy efficiency and health	Sheffield	Cross-sectional survey of 135 residents of improved blocks and matched sample of 140 residents of unimproved blocks	x	x	— Residents of improved blocks had higher mean scores of SF-36 ³⁶ , indicating better health than residents of unimproved blocks — Housing investment can be a relevant tool to combat low incomes, poor housing and poor health
Howieson et al. (2001)	Assessment of strategies for reducing indoor water vapour pressure, allergen reservoirs and dust mite activity and measurement of effects on the respiratory health of asthmatics	Three phases intervention study	Lanarkshire	x		— Allergen avoidance measures associated with mechanical heat recovery ventilation (MHRV) can reduce allergen reservoirs which, as a consequence, may have a significant effect on lung function in asthmatics

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36. The 36-Item Short Form Survey is a health survey that represents a measure of perceived health.

Table C.1 – Continued from the previous page

References	Topic	City	Methodology	Health dimension		Focus and/or results
				Physical	Mental Social	
Howden-Chapman et al. (2005)	Consequences of insulation measures ³⁷ on health and well-being of the occupants, as well as on their utilisation of health care	Single-blinded, clustered and randomised housing and health trial	New Zealand	x		— Large trials of complex environmental interventions can be conducted in a robust manner with high participation rates. Crucial success factors are effective community involvement and intervention that is valued by the participants
Shenassa et al. (2007)	Assessment of a previously reported association between home damp and mould and the risk of depression. Exploration whether depression was mediated by perception of control over one's home or mould-related physical illness	Analysis of survey data from eight European cities ³⁸	Eight European countries ³⁹		x	— Dampness and mould were associated with depression, independent of individual and housing characteristics. — This association was independently mediated by the perception of control over one's home and by physical health
Ezratty et al. (2009)	Relationship between dwelling energy inefficiency and health ⁴⁰	EU	Epidemiological study based on logistic regressions	x		— Significant relationship between thermal discomfort and risk of respiratory and cardiovascular diseases — Significant relationship between the presence of mould and moisture and respiratory diseases — Potential link between hypertension and temperature changes — Presence of links between certain indicators of energy efficiency and the presence of digestive diseases ⁴¹
Ezratty (2010)	Impacts of fuel poverty on health	—	Discursive	x	x	— Direct impacts of fuel poverty on physical health, <i>i.e.</i> respiratory and cardiovascular diseases, allergy and asthma, — Indirect impacts of fuel poverty on physical health, <i>i.e.</i> risk of carbon monoxide poisoning

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37. Insulation measures affect indoor temperature, humidity, energy consumption and mould growth.

38. In particular, creation of a dampness and mould score from resident- and inspector-reported data and use of validated index of depressive symptoms to assess depression.

39. Angers (France), Bonn (Germany), Bratislava (Slovakia), Budapest (Hungary), Ferreira do Alentejo (Portugal), Forli (Italy), Geneva (Switzerland), Vilnius (Lithuania).

40. In Ezratty et al. (2009), dwelling energy inefficiency is defined in terms of characteristics of dwelling construction, indoor air quality, heating and cooking systems, ventilation, thermal comfort and weather-tightness of windows and roof.

41. Diarrhoea and ulcers of the stomach or duodenum.

Table C.1 – Continued from the previous page

References	Topic	City	Methodology	Health dimension		Focus and/or results
				Physical	Mental Social	
Harris et al. (2010)	Relationship between housing conditions and physical and mental health	England	Survey analysis ⁴²	x	x x	— Negative impact of fuel poverty, <i>i.e.</i> cold and damp home, on physical and mental health — It is possible to identify different household clusters depending on their financial and housing characteristics
Liddell and Morris (2010)	Impacts of fuel poverty on health	5 cities ⁴³	Discursive (literature review)	x	x	— Physical health effects of fuel poverty are modest in adults, but significant in children (respiratory health) and infants (weight gain and susceptibility to illness). — Mental health effects of fuel poverty is significant in adults and adolescents
Marmot Review (2011)	Effects of cold homes and fuel poverty on health	Discursive evidence reviews	UK	x	x x	— Direct health impact — Countries that have more energy-efficient housing have fewer excess winter deaths (EWDs) — Children living in cold homes are more than twice as likely to suffer from a variety of respiratory problems — Mental health is negatively affected by fuel poverty and cold housing for any age group — Indirect health impacts — Cold housing negatively affects children's educational attainment, emotional well-being and resilience — Cold housing negatively affects dexterity and increases the risk of accidents and injuries in the home — Investing in the energy efficiency of housing can help stimulate the labour market and economy and the creation of skilled workforce
Ormandy and Ezratty (2012)	Relationship between thermal discomfort and health	Europe	Discursive	x	x x	— Negative impacts of thermal discomfort on health — Some groups may be more susceptible to high or low indoor temperatures than others
Howden-Chapman et al. (2012)	A review of policies, research, and health impacts	New Zealand	Discursive	x	x x	— Negative impacts of thermal discomfort on health — Some groups may be more susceptible to high or low indoor temperatures than others

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42. This study employed the Adult Psychiatric Morbidity Survey (APMS) 2007. APMS 2007 includes a structured clinical assessment of mental health that allowed for the reliable diagnosis of common mental disorders such as anxiety and depression. The survey also covered aspects of housing conditions and financial strain related to domestic fuel use, including presence of mould, cutting back on fuel usage, lack of central heating and double-glazing, being cold at home and fuel-related debt or utility disconnection problems.

43. England and Wales, Scotland, New Zealand, England, and USA.

Table C.1 – Continued from the previous page

References	Topic	City	Methodology		Health dimension		Focus and/or results
			Physical	Mental	Social	Social	
Host et al. (2014)	Relationship between fuel poverty and health	Ile-de-France	x	x	x	x	— Negative direct impacts of fuel poverty on physical health ⁴⁴ and mental health (depression) — Negative indirect impacts of fuel poverty on physical health related to risky behaviour, <i>i.e.</i> intoxication (due to the use of alternative heating) and domestic accidents — Negative impact of fuel poverty on social well-being, <i>i.e.</i> social isolation
Liddell and Guiney (2015)	Relationship between fuel poverty and mental health	—	Discursive (Literature review of 9 studies) ⁴⁵	x			— Living in cold and damp housing contributes to a variety of different mental health stressors, such as persistent worry about debt and affordability, thermal discomfort and worry about the consequences of cold and damp for health — Improvements in energy efficiency are often associated with significant improvements in mental well-being
Lacroix and Chaton (2015)	Relationship between fuel poverty and self-reported health status ⁴⁶	France	Econometric analysis based on a binary probit model	x	x ⁴⁷	x ⁴⁷	— A person in fuel poverty is 2.36 percentage points more likely to report poor or fair health status than a person who is not in fuel poverty
Liddell et al. (2016)	Review of historical data, going from 1980 to 2013, on cold-related deaths	30 European countries ⁴⁸	Use of classic winter deaths methodology to estimate cold-related mortality and proposal of an alternative estimation method based on heating degree days	x			— The classical winter deaths methodology yields limited relevant results, <i>i.e.</i> accurate estimates of the actual public health impacts of cold temperatures in only 2 of 30 European countries — The alternative heating degree days methodology may yield more accurate estimations

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44. Cardiovascular problems, hypertension, asthma attacks, allergies, headaches, colds and sore throats.

45. Liddell and Guiney (2015) focus on intervention studies in which heating and insulation improvements were carried out and impacts on well-being assessed.

46. Lacroix and Chaton (2015) use a subjective measure of fuel poverty, *i.e.* self-reported feeling cold. For health status, they use self-reported health status as a proxy. In addition to the impact of fuel poverty, the authors also assessed the impact of other particular individual and environmental features on self-reported health status.

47. Mental health (and social well-being dimensions) are taken into account by introducing three variables describing mental health status, namely “Feeling sad”, “Feeling happy”, and “Feeling discouraged” in the estimation. For each of these variables, five answers were possible: “Always”, “Most of the time”, “From time to time”, “Rarely”, “Never”.

48. Cyprus, Malta, Greece, Portugal, Bulgaria, Italy, Hungary, Romania, Spain, Slovenia, Slovakia, France, Austria, Poland, Czech, Germany, Lithuania, Belgium, the Netherlands, Latvia, Luxembourg, Switzerland, Estonia, Denmark, Finland, Sweden, UK, Ireland, Norway, Iceland.

Table C.1 – Continued from the previous page

References	Topic	City	Methodology	Health dimension		Focus and/or results
				Physical	Social	
Thomson et al. (2017)	Relationship between fuel poverty, health and well-being	32 European countries ⁴⁹	Statistical approach based on the Mann-Whitney U tests, prevalence rates and logistic regressions	x	x	— Unequal concentration of energy poverty, poor health and poor well-being across Europe, with Eastern and Central Europe affected the worst — A higher incidence of poor physical and mental health amongst the energy-poor populations of most countries, compared with non-energy poor households — The largest disparities in health and well-being levels between energy-poor and non-energy-poor households occur within relatively equal societies
Robić and Antčić (2018)	Health impacts of living in energy poverty	Sisak-Moslavina - Croatia	Data analysis based several fuel-poverty indicators ⁵⁰	x	x	— Households who are affected by fuel poverty live in inadequate conditions and face adverse impacts on their health
Llorca et al. (2018)	Relationship between fuel poverty and self-assessed health.	Spain	Latent class-ordered probit model	x		— Poor housing conditions, fuel poverty and material deprivation have a negative impact on health — Individuals who rate themselves as fuel-poor tend to report poorer health status — The effect of objective fuel poverty on health is stronger when unobserved heterogeneity of individuals is controlled for

49. Sweden, Finland, Austria, Denmark, Luxembourg, the Netherlands, Slovenia, Czech Republic, Germany, Belgium, Montenegro, France, Ireland, Croatia, Italy, Slovakia, UK, Macedonia, Hungary, Serbia, Spain, Romania, Latvia, Bulgaria, Lithuania, Poland, Estonia, Malta, Greece, Portugal, Cyprus, Turkey.

50. In particular, Robić and Antčić (2018) use the following fuel-poverty indicators: (1) subjective qualitative assessments by the affected persons, (2) subjective qualitative assessments by others, (3) objective non-expenditure-based indicators and (4) expenditure-based indicators. To construct their database, a total of 394 households were visited in Sisak-Moslavina County, and complete data were collected and analysed for 375 households.

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