"Heating externalities in multi-family housing: Significance, regulation and incidence"

Abstract :

Basic physics has it that heat can move across multi-family dwellings. This creates externalities – occupants in one dwelling turning their thermostat down as they benefit from heat transfers from adjacent dwellings, the occupant of which in turn turns her thermostat up – and thus excessive energy use in equilibrium. Using data from the 2013 French housing survey, we quantify these little-discussed externalities. Specifically, we study how energy use varies across floor designations and energy billing contracts and compare these patterns with water use, which arguably is immune from externalities. We address endogeneity problems between floor choice and energy use by using elevator as an instrument. We find that dwellings located on intermediate floors use significantly less energy than those located on either ground or top floors, while water consumption is not significantly different. Over-consumption in ground and top floors (most subject to heat losses) is however economically lower than that due to utility-included contracts (as opposed to individual billing). This has important implications for mandatory substitution of individual billing for utility-included contracts, an increasingly widespread policy that removes contractual incentives to over-use energy while creating heating externalities. Our results suggest that the intervention retains most of its benefits in terms of aggregate energy use reduction but raises equity concerns, as those dwellings suffering most from externalities tend to be occupied by poorer households.

Key-words : Energy efficiency; heating; externalities; Moral hazard; Endogeneity.

JEL CODES : D86; H23, Q41, C26

1/ Introduction

Individual preferences aside, energy use in multi-family dwellings results from a complex interplay between physics, technology, and contractual incentives. Basic physics has it that heat can move across adjacent dwellings. Heat transfers chiefly occur along a vertical gradient and, to a lesser extent, along a horizontal one, especially if control systems allow heating intensities to differ across dwellings. From an economic perspective, these physical and technological features create heating externalities – occupants in one dwelling turning down their thermostat as they benefit from heat transfers from adjacent dwellings, the occupant of which in turn turns

her thermostat up. In equilibrium, this leads to excessive energy use in the building, as compared to a benchmark where heat is optimally dispatched across dwellings in a way that ensures the same level of comfort to all.
Such a benchmark is typically relevant when all households share the building energy expenditure under a utility-included rental contract. By bringing down the marginal cost of a household's energy usage (possibly to zero), such billing schemes create incentives to over-use (Levinson and Niemann, 2004; Maruejols and Young, 2011; Gillingham et al., 2012; see Giraudet, 2018, for a review). Interventions substituting individual energy billing for utility-included contracts have proved to remove these distortions and thus effectively reduce energy use (Elinder et al., 2017). Yet it is seldom noted that, by restoring price signals, these interventions also create heating externalities if the physical structure of the building permits significant heat transfers.

To our knowledge, the economic significance of heating externalities, and how it compares to that of distortions inherent in utility-included contracts, have never been assessed. These problems are however important, from both an economic and policy perspective. In France, multi-family dwellings represent 43,5% of the housing stock in 2018, 14% of which is covered by utility-included contracts (Source: INSEE, 2018). In the United States, 60% of housing rental contracts include at least one energy or water utility (Choi and Kim, 2012). Substitutions of individual billing for utility-included contracts is increasingly becoming mandatory across Europe, as is the case in France since 2017 for multi-family buildings using more than 80 kWh/m² annually on heating (ADEME, 2019). As of 2017, 1.8 million dwellings occupied by 6 million individuals were subject to this obligation.

In this paper, we ask: How big are heating externalities? Are they so important as to fully offset the aggregate cost reductions permitted by switching to individual energy billing? Do they affect the distribution of benefits of such an intervention across dwellings?

We examine these questions in the French context, using data from the French housing survey of 2013. Our sample of interest contains detailed information about the socio-economic (income, rents, utility and home investment expenditure, loan repayments, etc.) and material (location, size, solar input, energy efficiency equipment of the dwelling) characteristics of 12,561 households living in multi-family dwellings. We quantify how energy use varies across floor designations (which are subject to varying heat losses) and energy billing contracts, and compare variations in energy expenditure under different billing contracts to variations in water expenditure, which is plausibly not subject to uncontrolled physical transfers across dwellings. In this task, we face a number of empirical challenges, in particular the problem of endogeneity of floor choice and energy use. We address it using the presence of an elevator as an instrument. We thereby disentangle the motivation of a household for living on upper floors and their energy usage patterns.

We find that energy expenditure is highest for those households living on the ground floor, followed by those from the top floor and those from the middle floor. Living on the middle floor decreases energy expenditure by 41% compared to living on the ground floor. In contrast, additional regressions indicate that the floor designation has no influence on water expenditure. This benchmark confirms the significance of heat transfers across dwellings from different floors. Over-heating seems necessary to maintain a desirable temperature in dwellings located on the ground floor, from which heat easily flows up. The same phenomenon applies to the top floor, though to a lesser extent, as top-floor dwellings plausibly benefit from heat input from lower floors. The most important marginal effects in explaining energy expenditure, however, are the impact of utility-included contracts, the presence of a heating control system, and the interaction between the two. Households that cannot control heating and enjoy utility-included contracts have a 73% higher energy expenditure and a 42% higher water expenditure. The moral hazard problem induced by not facing the marginal cost of water and energy therefore is substantial. The magnitude of the effect is little affected in regressions ran by floor designation or on a smaller sample (water sample). Our estimates of other parameters are consistent with those found in the literature, with positive but low income elasticities and a positive relationship between the age of construction (until 1949) and energy expenditure.

Our results suggest that, as the distortions induced by utility-included contracts induce more energy over-use than do the heating externalities typically arising when switching to individual billing, the mandatory ban of utility-included contracts retains most of its benefits in terms of energy (and thus cost) savings. As energy use can be seen as a sufficient statistic of welfare effects in this context, we can conclude that banning utility-included contracts is welfare improving (in the Hicks-Kaldor sense). It is, however, probably not Pareto improving, as descriptive statistics indicate that poorer households tend to occupy ground floors and top-floor with no elevator, both of which are particularly subject to negative heating externalities. A policy solution to jointly address the two distortions is to promote two-part utility contracts in which a fixed part is designed to address externalities. In France, this fixed part is set to 30%. Whether this fraction is optimal is an interesting question for future research.

2/ Theoretical background

Prediction 1: consumers use more energy under utility-included contracts…
Prediction 2: consumers in intermediate dwellings…
Prediction 3: consumers with control…

	Individual billing	Utility-included contract
Control	Over-use	Over-use
No control		Possibly optimal if the manager sets the thermostat diligently

Energy (arguably transfers across dwellings)

	Individual billing	Utility-included contract
Control	Over-use	Over-use
No control		Possibly optimal if the manager sets the thermostat diligently

Water (arguably no physical transfers across dwellings)

3/ Model

Econometric analysis of household energy use has heavily relied on conditional demand analysis and the two-step discrete-continuous model first developed by Dubin and McFadden (1984). This framework genuinely links continuous energy use (or expenditure) to discrete investment choices (appliances, heating and cooling systems, insulation). As such, it allows one to address the endogeneity problem of household characteristics determining energy use directly through usage and indirectly through equipment choice (Vaage, 2000; Nesbakken, 2001; Risch and Salmon, 2017; Bakaloglou and Charlier, 2019). It also addresses selectivity biases in data sets with endogenously partitioned observational units (Frondel*, et al.*, 2016).

We build on this framework and extend it to account for the fact that household characteristics determine energy expenditure not only through their effect on energy efficiency investment, but also through the floor the household chooses to live on. We effectively assume that household expenditure is endogenous to the choice of a heating system and the floor. To test this assumption, we use an extended regression model that interacts household characteristics with their dwelling's energy efficiency. Based on Bakaloglou and Charlier (2019), we specify a utility model such that household fuel demand based R* is determined by a stochastic indirect utility function, which we assume to be unobserved. Indirect utility V depends on income Y, household characteristics (including preferences) Z and building characteristics W. It is defined conditionally on the choice of a heating system and the floor designation:

$$R_{ij}^{*} = V_{ijf}[Y_i, Z_i, W_i] + v_{ijf} \quad (1)$$

where, for each individual i={1,…N}, j=0,1 is the type of heating system (collective versus individual???), f=0,..;,F is the floor the household lives on, and v_{ij} is the error term.

When simplified, the energy demand of household i, conditional on a heating system j and a floor f reads:

$$q_{ij} = \gamma_{ijf} z_{ijf} + \nu_{ijf} w_{ijf} + \beta_{ijf} Floor_i + \beta_{ijf} Heating_i + \eta_{ij} \quad (2)$$

where q_{ij} is the quantity of energy consumed by household i using a heating system j in floor f, z_{ij} is a vector of household characteristics, $Floor_i$ is the floor designation, $Heating_i$ is the type of heating system, w_{ij} is a vector of building characteristics, γ_{ij} and ν_{ij} are vectors of the related parameters, and η_{ij} the error term considering the influence of unobservable parameters.

We face two endogeneity problems in the choice of the dwelling's thermal performance, one linked to the floor designation and the other to the heating system. Following Risch and Salmon (2017), we instrument the latter problem using connection to the gas distribution network and urban size. In contrast, the former problem has, at least to our knowledge, not been studied in the literature. We address it using the presence of an elevator and the number of dwellings in the building as an instrument. Specifically, we assume that the probability of living on an intermediate floor is higher in a building with more dwellings, and that this does not affect energy expenditure. To address the difficulty of testing the quality of instrument when the endogenous variable is discrete, we use a two-step methodology. First, we conduct a significavity test and a wald test to ensure the quality of instruments. Second, we consider that endogenous variables are not discrete but continuous and conduct the validity tests of instruments (identification and exogeneity using the Wooldridge's (1995) robust score test). We performs test that determine whether endogenous regressors in the model are in fact exogenous: 2SLS estimation with an adjusted VCE, Wooldridge's (1995) robust score test and a robust regression-based test. In all cases, if the test statistic is significant, then the variables being tested must be treated as endogenous. We also perform tests of overidentifying restrictions.

Our tests being unsignificant, we conclude that our instruments are valid. Proofs are provided in appendix A.

We also compare two types of estimates, one with a dummy variable for top floor and one with an order variable, the level of floor (top floor, intermediate floor, ground floor). It would be also possible to conduct some robustness check with the level of floor in a continuous form.

Thus, for the discrete choice of the model, we use an ordered probit because floor designations arise sequentially (Cameron and Trivadi, 2010) and a binary probit model for the heating system. For individual i, we specify:

$$floor_i^* = \gamma'_{ijf} z_{ijf} + \nu'_{ijf} w_{ijf} + u_i \quad (3)$$

with $floor^*$a latent variable which is an unobserved measure of the floor; z_{ijf} and w_{ijf} the regressors. For an m-alternative ordered model (here $m = 3$ because of the 3 levels), we define:

$$Floor_i = f \quad if \;\; \alpha_{j-1} < y_i^* \leq \alpha_j, \qquad f = 1, \ldots., m$$

$$\Pr(y_i = f) = \Pr\,(\alpha_{f-1} < floor_i^* \leq \alpha_f)$$

The regression parameters β and the m-1 threshold parameters $\alpha_1, \ldots, \alpha_{m-1}$ are obtained by maximizing the log likelihood with $p_{if} = \Pr(floor_i = f)$.

Then, we also have:

$$heating_i^* = \gamma''_{ijf} z_{ijf} + \nu''_{ijf} w_{ijf} + u_i \quad (4)$$

With *heating* a binary variable measuring the type of heating system; z_{ijf} and w_{ijf} the regressors.

Conditional on both discrete choices, a household makes decisions regarding the quantity of energy to use. Therefore, the total energy expenditure (the logarithm of the energy expenditure in euros) is estimated, conditional on the dwelling's heating system and the floor and a set of explanatory variables (income, individual characteristics, housing characteristics, etc).

Finally, we have a system composed of a three-simultaneous-equations model (2) (3) and (4). Using the extended regression models, we can estimate simultaneously our two endogenous discrete-choices and our linear regression expenditure using the maximum likelihood.

4/ Data, variables and descriptive statistics

4.1 Data

We use data from the 2013 French housing survey (INSEE, 2013). Carried out every 7 years or so, this survey provides detailed information about the physical characteristics of the housing stock (size, comfort variables, heating equipment), housing conditions (location, solar input, noise exposure, characteristics of the neighborhoud), expenditure (rents, energy and water utilities, mortgage and other loan repayments, retrofit expenditure) and various sources of household income. The sample of multi-family dwellings we are interested in contains 12,561 observations. In literature, it is commonly adopted that energy expenditures of a dwelling is explained by three main determinants: technical building and appliances characteristics including the local environment and household characteristics (socioeconomic characteristics, individual preferences, income, etc.). The number of occupants has a positive impact on energy consumption (Leahy and Lyons 2010; Vaage 2000), and there is a cyclical effect based on the age of the reference person: energy consumption is comparatively higher for dwellings whose occupants are between 45 and 65 than for other age classes (Brounen and Kok 2011; Brounen et al. 2013). Regarding income elasticity, the effect is positive in most studies, which is consistent with the "normal good status" of energy consumption: income elasticity often lies between 0.01 and 0.15. Positive elasticity may mainly involve the purchase of more energy-efficient appliances, which will induce lower energy consumption (Cayla et al. 2011; Labandeira et al. 2006; Nesbakken 2001; Santamouris et al. 2007). Morever, housing characteristics and localization (climate mostly) can account for more than half of the energy consumption variability in the residential sector (Estiri 2015). Newer buildings tend to consume less energy, and housing type is an important variable (Nesbakken 2001; Santin 2011; Vaage 2000). Dwelling insulation (attic or cavity walls or global insulation) reduces energy consumption from -10% to -17% (Brounen, Kok, et Quigley 2012). Finally, local climate also has an impact: in western countries, the longer the heating period is, the more energy a dwelling consumes (Kaza, 2010).

4.2 Descriptive statistics

Main descriptive statistics are provided in Table 1 below.

Table 1: Descriptive statistics

	Obs	Mean	Std. Dev.	Min	Max
Energy expenditures	10,304	954.658	575.939	14	4630
Water expenditures	10,304	90.95	179.784	0	1954
Income	10,304	33078.18	28555.59	3.667	389767
Man	10,304	0.524	0.499	0	1
Couple	10,304	0.429	0.495	0	1
Age	10,304	50.626	17.276	19	101
Nb children	10,304	0.616	1.05	0	8
Bac+2	10,304	0.107	0.309	0	1
Sup. Bac+2	10,304	0.207	0.405	0	1
Climate zone 4	10,304	0.097	0.297	0	1
Climate zone 3	10,304	0.084	0.277	0	1
Climate zone 2	10,304	0.592	0.491	0	1
Climate zone 1 (coldest)	10,304	0.227	0.419	0	1
Surface area	10,304	66.126	23.047	1	260
Double glazing	10,304	0.829	0.377	0	1
Constructed before 1949	10,304	0.177	0.382	0	1
Constructed 1949-1974	10,304	0.483	0.5	0	1
Constructed 1975-1981	10,304	0.135	0.341	0	1
Constructed 1982-1989	10,304	0.058	0.234	0	1
Constructed 1990-1998	10,304	0.073	0.259	0	1
After 1999	10,304	0.076	0.264	0	1
Heating Controller	10,304	0.101	0.302	0	1
Heating expenditures included	10,304	0.138	0.345	0	1
Included water expenditures	10,304	0.232	0.422	0	1
Collective heating system – urban or gaz	10,304	0.425	0.494	0	1
To be connected to the gas	10,304	0.698	0.459	0	1
Living zone: Paris	10,304	0.404	0.491	0	1
First floor	10,304	0.148	0.355	0	1
Intermediary floor	10,304	0.634	0.482	0	1
Last floor	10,304	0.218	0.413	0	1
Floor number	10,304	5.14	3.675	1	95

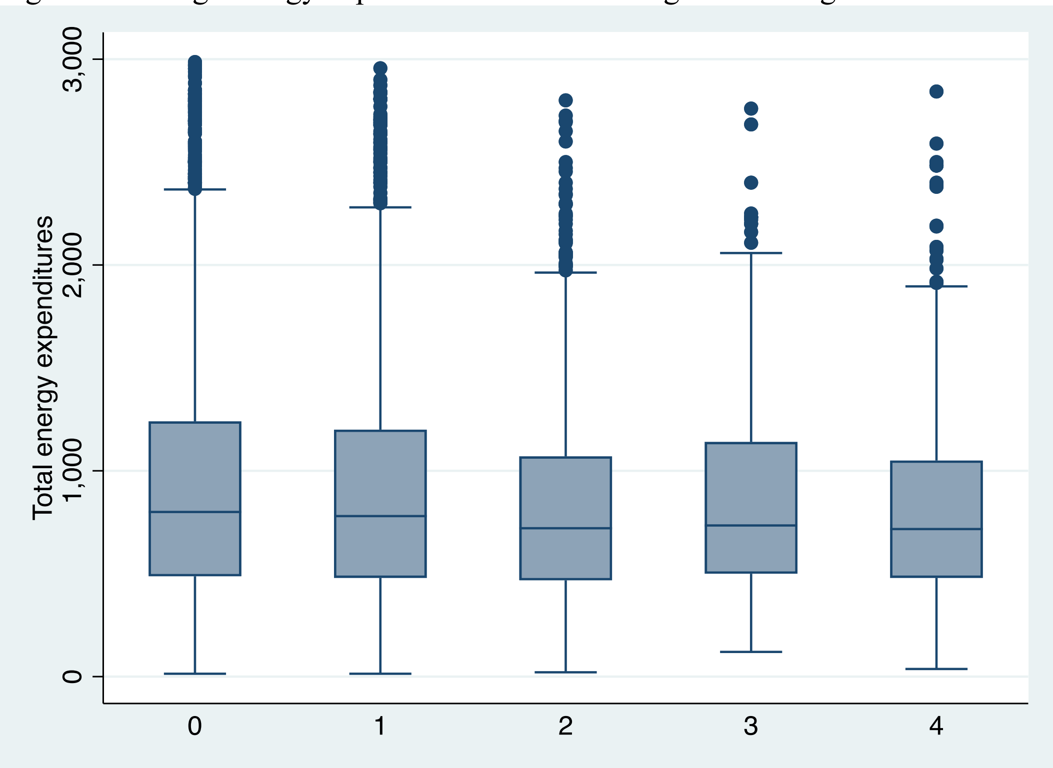
On average, energy expenditure represents 955 euros against 91 euros for water expenditure[1]. Only 7,6% of dwellings where constructed before 1999, when building codes, including that of 2005, have become tight. This regulation set minimum performance standards for the building

[1] There are a large number of zeros, so the regressions will be conducted on the 3106 households that report non-zero spending.

envelope. A maximum energy use was permitted from 130kwh/m2 of primary energy to 80kwh/m2 according to climate zone. It was replaced in 2013 by new, tighter building code.

Comparing total energy expenditure across building code vintages (very close to the construction period, except for building constructed after 1999), however, does not reveal important variations, probably because of a concomitant increase in energy prices over the period.

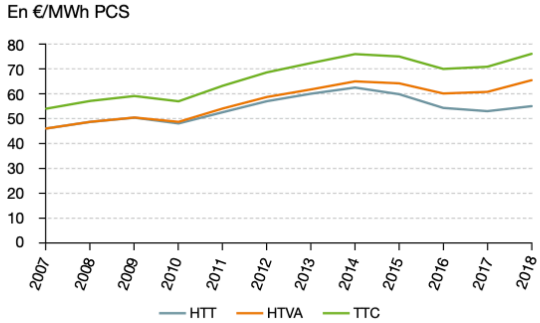
Figure 1: average energy expenditure across building code vintages.



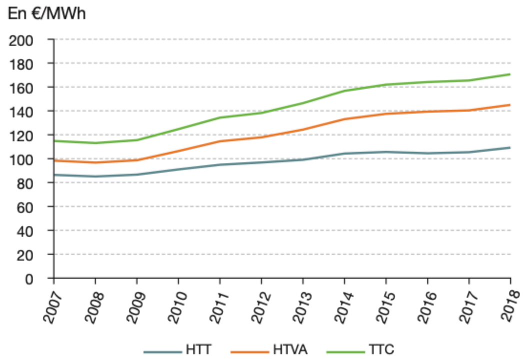
Note : 0 "No thermal regulation" 1 "Thermal regulation 1974" 2 "thermal reg ulation 1988" 3 "thermal regulation 2000" 4 "thermal regulation 2005 and 2012"

Figure 2: evolution of energy prices (gas and electricity) in France

Gas Electricity



Source : *SDES, enquête transparence des prix du gaz et de l'électricité*



Source : *SDES, enquête transparence des prix du gaz et de l'électricité*

By cross-referencing information on housing costs, household income, and the type of floor they live on (Table 2), we find that the most expensive dwellings are in the middle floors, which tend to be occupied by the wealthiest households. This descriptive result suggests that the distribution of households may not random but endogenous to their profile. 30,1% of households living in multi-family dwellings are homeowners, against 58% on average for the total building stock.

Table 2: Descriptive statistics by floor

Floor	Heating expenditures		Water expenditures		Dwelling price		Rent		Income	
	mean	Std. dev	mean	Std. dev	mean	Std. dev	mean	Std. dev	mean	Std. dev
First floor	996.85	585.64	127.83	195.47	185663	79256.	415.40	188.63	29781	22897
Intermediate floor	971.15	563.67	139.88	211.49	193773	117910	438.10	266.52	32532	27689
Last floor	939.16	577.27	110.09	209.83	243160	176989	452.67	279.02	34033	29943
obs	10,304		8,055		636		8,055		10,304	

At a glance, there is no significant difference in energy expenditure across floor designations. Nevertheless, households living on top floors are more likely to report overheating problems (see figure 3). Dependency tests reveal a dependency between (i) the floor and reporting cold or overheating issues (Pearson chi2(2) 5,21, with a p critical value equal to 0,072) and (ii) having a regulator and energy expenditure (Pearson chi2(2) =101,87, with a p critical value equal to zero) .

Figure 3: Households reporting overheating problem across floor designations

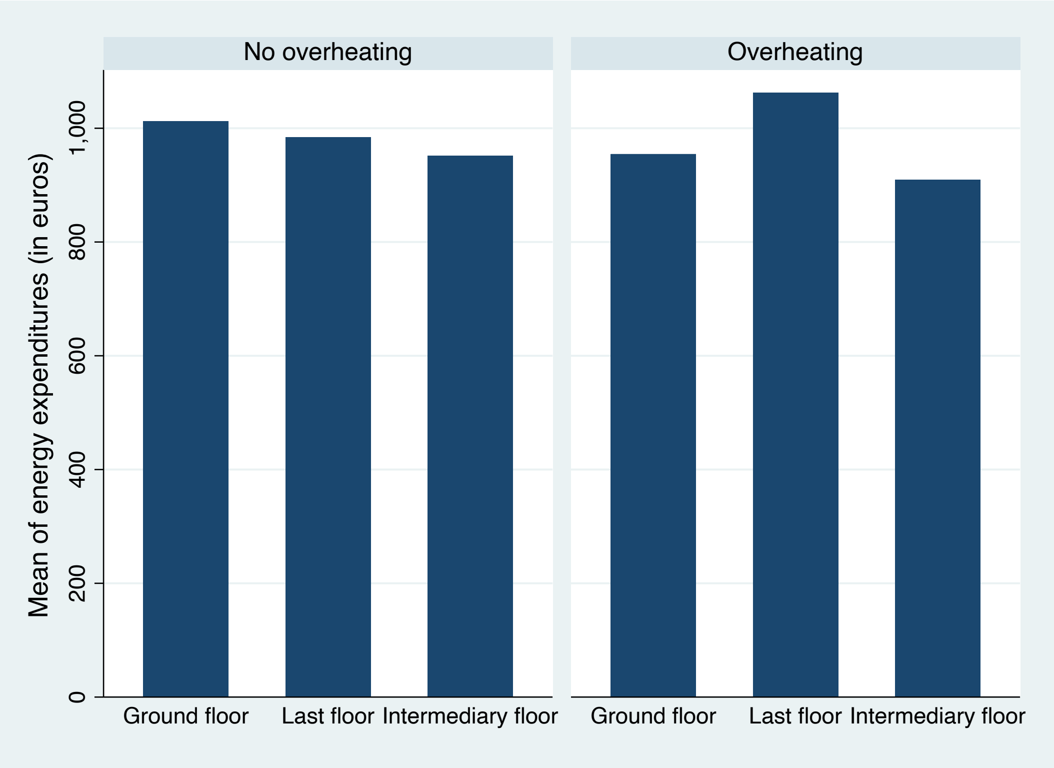
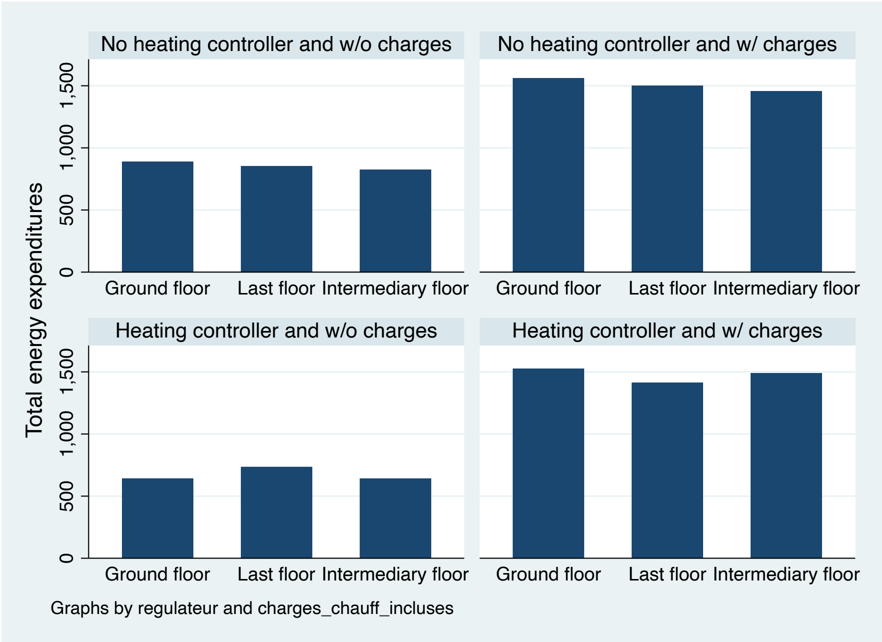


Table 3 : water and energy expenditure included in co-ownership fees

	Included water expenditures		
Included heating expenditures	No	Yes	
No	7,819	1,065	8,884
Yes	91	1,329	1,420
	7,910	2,394	10,304
Chi2 test of dependance	Pearson chi2(1) = 4,6+03	critical pvalue 0.0000	

There is also a strong dependency between inclusion of water and heating in utility bills. Only 11.2% of the sample have only one utility (water or heating) included. Overall,households have either all or no utility included. This result also means that 11% of households do not face the full marginal cost of utilities. In multi-family dwellings with collective heating systems, some households have no control over heating. Over-consumption can therefore be expected. Looking at Figure 4, it is clear that households whose energy expenditure is included in condominium bills spend significantly more, whether or not they are regulated. It is also noticeable that households that are able to regulate their consumption spend less.

Figure 4: Having heating controller, charges and floor



5/ Results and discussion

Table 4: empirical results

VARIABLES	(1)	(2)	(3)	(4)	(5)
Heating controller	-0.0572**	-0.0559**	-0.0538**	-0.0519**	0.0153
	(0.0159)	(0.0158)	(0.0157)	(0.0157)	
Included heating expenditures	0.728***	0.733***	0.734***	0.737***	
	(0.0159)	(0.0158)	(0.0157)	(0.0157)	
Included heating expenditures#Heating controller	0.0741**	0.0721**	0.0763**	0.0751**	
	(0.0368)	(0.0366)	(0.0363)	(0.0361)	
Heating system	-0.437***	-0.429***	-0.0949***	-0.0849***	0.116
	(0.0132)	(0.0133)	(0.0282)	(0.0280)	(0.0957)
Ground floor				REF	REF
Last floor	0.0129	0.290***	0.285***	-0.200***	-0.00726
	(0.0126)	(0.0294)	(0.0296)	(0.0219)	(0.0676)
Intermediary floor				-0.410***	-0.0873
				(0.0401)	(0.133)
Included water expenditures					0.420***
					(0.0863)
Control variables	Yes	Yes	Yes	Yes	Yes
Observations	10,304	10,304	10,304	10,304	3,106
R-squared	0.352				
Cut 1				-0.7525	-0.6666
				0.0209	0.0321
Cut 2				-0.0080	0 .1501
				0.0203	0.0311
Correlation error terms					
Floor and energy expenditures (or water expenditures)		-0.3055***	-0.2736***	0.2475***	0.0311
Heating sytem and energy expenditures			-0.3801***	-0.3748***	0 .099
Heating system and floor			-0.0519***	0.0777***	0.0871***

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; (1) OLS, (2) control for one endogeneity source on last floor,, (3) control for two endogeneities sources: on last floor and on type of heating system, (4) control for two endogeneities sources: floors and on type of heating system, floors are an ordered equation and (5) ontrol for two endogeneities sources: floors and on type of heating system, floors are an ordered equation – control regression for water expenditures

A preliminary look at error correlation terms reveals significant correlation. This result justifies the correction of the endogeneity of the heating system and the choice of the stage. By comparing our results with a simple OLS model, neglecting this endogeneity problem amounts to (i) considering that the floor has no influence on expenses, which is far from being the case after correction, (ii) overestimating the impact of the heating system on final expenses.

Secondly, looking at the impact of the choice of floor on energy expenses, it is clear that living on the top floor explains the increase in expenses (28.5% compared to an household who do not live in the last floor). However, the households that spend the most are those living on the ground floor, followed by those from the top floor and those from the middle floor. Living on the middle floor decreases energy expenditure by 41% compared to living on the ground floor.

In contrast, additional regressions indicate that the floor designation has no influence on water expenditure. This benchmark confirms the significance of heat transfers across dwellings from different floors. Over-heating seems necessary to maintain a desirable temperature in dwellings located on the ground floor. The same phenomenon plausibly applies to the top floor, which is particularly subject to heat losses. As descriptive statistics indicate that poor households tend to live on the ground floor, a policy promoting individual billing could have negative distributional impacts.

The most important marginal effect in explaining energy expenditure is the impact of utility-included contracts, the presence of a heating control system, and the interaction between the two. Households that cannot control heating and enjoy utility-included contracts have a 73% higher energy expenditure and a 42% higher water expenditure. The moral hazard problem induced by not facing the marginal cost of water and energy therefore is substantial. The magnitude of the effect is little affected in regressions ran by floor designation or on a smaller sample (66% in the water sample). The moral hazard problem therefore seems to occur irrespective of the floor households live on. The effect is amplified when occupants have control over heating. Having control over heating reduces energy expenditure by 5% under individual billing but only 0.96% under utility-included contracts. Moreover, regressions by floor designation (see appendix A) indicate that the effect of a control system is more pronounced for those people living on ground and intermediate floors; under utility-included contracts, in contrast, expenditure increases by 1.7%.

Finally, our estimates of other parameters are consistent with those found in the literature. Income elasticicities are positive and low (0,035) which is consistent with the normal good status Cayla et al. 2011; Labandeira et al. 2006; Nesbakken 2001; Santamouris et al. 2007).

The number of children has a positive impact on energy expenditures around 0,07 (Leahy and Lyons 2010; Vaage 2000), but there is not a cyclical effect based on the age of the reference person contrary to Brounen and Kok (2011) and Brounen et al. (2013). Living with a partner and having children are positively associated with energy expenditure.

Morever, housing characteristics and localization (climate mostly) can explain the variability of energy expenditures in collective dwellings: newer building and building located in warmest zone tend to consume less (Estiri 2015, Nesbakken 2001; Santin 2011; Vaage 2000).
The more recent the dwellings are compared to dwellings built in 1949, the lower the expenditure, which illustrates the impact of building codes.

6/ Conclusion

Our paper proposes an original instrumental-variable approach to quantify a little discussed problem: heating externalities in multi-family dwellings. We find a significant variation in energy use across floor designations, with intermediate floor using relatively little energy, arguably because they benefit from heat transfers from adjacent dwellings. Albeit significant, the effect is not so large as to offset the energy savings induced by substituting individual energy billing for utility-included contracts. It does however imply that some households – particularly those living on ground floors, who tend to be poorer – may be hurt by such an intervention.

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Appendix A

A.1 Instrumental regressions

Results for 2sls estimation

	(1)		(2)		(3)		(4)		(5)	
VARIABLES	2nd stage	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage	1st stage
Last floor	1.359***								2.286***	
	(0.125)								(0..353)	
Floor[a]			-0.293***							
			(0.0325)							
Floor (number)					-0.0479***					
					(0.00507)					
Elevator		-0.106***		0.346***		0.00523				0.138***
		(0.00872)		(0.0155)		(0.00746)				(0.0093)
Number of dwellings		-0.000248***		0.000602***		-4.85e-05				
		(5.73e-05)		(0.000105)		(4.66e-05)				(0.00012)
Collective heating system – urban or gaz	-0.0239**	-0.398***	0.0628***	-0.393***	-0.00502	0.551***		0.800***		
	(0.00945)	(0.0147)	(0.0169)	(0.0142)	(0.00812)	(0.0940)		(0.215)		
Be connected to the gas network								0.152***		
								(0.00946)		(0.00931
Living zone: Paris								0.0909***		
								(0.0116)		(0.0115)
Other controls variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,304	10,304	10,304	10,304	10,304	10,304	10,304	10,304	10,304	10,304
Tests of endogeneity Ho: variables are exogenous										
Robust score chi2(1)	211.508 (p = 0.0000)		67.1703 (p = 0.0000)		44.8822 (p = 0.0000)		175.03 (p = 0.0000)		191.486 (p = 0.0000)	
	F(1,10281) = 205.559 (p = 0.0000)		F(1,10280) = 67.447 (p = 0.0000)		F(1,10280) = 44.0227 (p = 0.0000)		F(1,10281)= 182.521 (p = 0.0000)		F(2,10279) = 101.01 (p = 0.0000)	

Test of overidentifying restrictions: Ho: variables are overidentified					
Score chi2(1)	0.026745 (p = 0.8701)	0.007903 (p = 0.9292)	0.594744 (p = 0.4406)		3.88047 (p = 0.1437)

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

(1) control for one endogeneity source on last floor, (2) control for one endogeneity source on level of floors (ground, intermediary, last), (3) control for one endogeneity source on the number of floor, (4) control for one endogeneity source on heating system, (5) control for two endogeneities sources: on last floor and on type of heating system

-a: 0 ground floor, 1 last floor, 2 intermediary floor

-control variables: Income (log), Man,Couple,Age,Nb children,Bac+2,Sup. Bac+2,Climate zone 4,Climate zone 3,Climate zone 2,,Surface area,Double glazing,constructed 1949-1974,Constructed 1975-1981, Constructed 1982-1989, Constructed 1990-1998,After 1999, Heating Controller,Heating expenditures included, Included heating expenditures#Heating controller

A. 2

Detailed results

VARIABLES	(1)	(2)	(3)	(4)	(5)
Income (log)	0.0366***	0.0377***	0.0343***	0.0359***	0.0506***
	(0.00837)	(0.00840)	(0.00836)	(0.00840)	(0.0176)
Man	-0.00958	-0.00934	-0.00700	-0.00714	-0.0231
	(0.0118)	(0.0118)	(0.0117)	(0.0117)	(0.0235)
Couple	0.150***	0.150***	0.147***	0.146***	0.287***
	(0.0136)	(0.0136)	(0.0135)	(0.0135)	(0.0267)
Age	-4.08e-05	9.32e-05	-9.26e-05	-3.64e-05	-0.00160**
	(0.000365)	(0.000366)	(0.000366)	(0.000364)	(0.000699)
Nb children	0.0701***	0.0699***	0.0682***	0.0680***	0.155***
	(0.00562)	(0.00561)	(0.00558)	(0.00556)	(0.0118)
Bac+2	-0.0123	-0.0121	-0.00967	-0.00698	-0.0242
	(0.0169)	(0.0168)	(0.0167)	(0.0166)	(0.0366)
Sup. Bac+2	-0.0440***	-0.0395***	-0.0356**	-0.0291**	-0.104***
	(0.0142)	(0.0141)	(0.0141)	(0.0141)	(0.0376)
Climate zone 4	0.00175	0.00302	0.00472	0.00771	0.103***
	(0.0196)	(0.0195)	(0.0195)	(0.0194)	(0.0339)
Climate zone 3	-0.0285**	-0.0235*	-0.0502***	-0.0440***	0.0222
	(0.0138)	(0.0137)	(0.0140)	(0.0139)	(0.0263)
Climate zone 2	-0.0935***	-0.0941***	-0.0976***	-0.0981***	-0.105***
	(0.0208)	(0.0208)	(0.0208)	(0.0207)	(0.0329)
Surface area	0.00698***	0.00700***	0.00683***	0.00693***	0.00447***
	(0.000288)	(0.000288)	(0.000288)	(0.000288)	(0.000596)
Double glazing	0.00838	0.00577	0.00390	0.00159	-0.00620
	(0.0147)	(0.0147)	(0.0146)	(0.0146)	(0.0332)
Construction period 2	-0.119***	-0.112***	-0.120***	-0.114***	0.0616**
	(0.0162)	(0.0161)	(0.0162)	(0.0162)	(0.0309)
Construction period 3	-0.156***	-0.144***	-0.135***	-0.126***	0.0495
	(0.0201)	(0.0201)	(0.0200)	(0.0200)	(0.0435)
Construction period 4	-0.0856***	-0.0757***	-0.0545**	-0.0497**	0.00806
	(0.0253)	(0.0253)	(0.0253)	(0.0251)	(0.0539)
Conbstruction period 5	-0.0836***	-0.0714***	-0.0484**	-0.0425*	0.0178
	(0.0223)	(0.0223)	(0.0223)	(0.0223)	(0.0502)
Construction period 6	-0.114***	-0.100***	-0.0718***	-0.0703***	0.0447
	(0.0209)	(0.0209)	(0.0210)	(0.0213)	(0.0421)
Heating controller	-0.0572**	-0.0559**	-0.0538**	-0.0519**	0.0153
	(0.0237)	(0.0237)	(0.0234)	(0.0234)	(0.0443)
Included heating expenditures	0.728***	0.733***	0.734***	0.737***	
	(0.0159)	(0.0158)	(0.0157)	(0.0157)	
Included heating expenditures#Heating controller	0.0741**	0.0721**	0.0763**	0.0751**	
	(0.0368)	(0.0366)	(0.0363)	(0.0361)	
Heating system	-0.437***	-0.429***	-0.0949***	-0.0849***	0.116
	(0.0132)	(0.0133)	(0.0282)	(0.0280)	(0.0957)
Ground floor	0.0129	0.290***	0.285***	REF	
	(0.0126)	(0.0294)	(0.0296)		
Last floor	0.0129	0.290***	0.285***	-0.200***	-0.00726
	(0.0126)	(0.0294)	(0.0296)	(0.0219)	(0.0676)
Intermediary floor				-0.410***	-0.0873

VARIABLES	(1)	(2)	(3)	(4)	(5)
				(0.0401)	(0.133)
Included water expenditures					0.420***
					(0.0863)
Constant	5.951***	5.858***	5.787***	6.114***	4.558***
	(0.0801)	(0.0812)	(0.0813)	(0.0832)	(0.181)
Observations	10,304	10,304	10,304	10,304	3,106
R-squared	0.352				
Cut 1				-0.7525	-0.6666
				0.0209	0.0321
Cut 2				-0.0080	0 .1501
				0.0203	0.0311
Correlation error terms					
Floor and energy expenditures (or water expenditures)		-0.3055***	-0.2736***	0.2475***	0.0311
Heating sytem and energy expenditures			-0.3801***	-0.3748***	0 .099
Heating system and floor			-0.0519***	0.0777***	0.0871***

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; (1) OLS, (2) control for one endogeneity source on last floor,, (3) control for two endogeneities sources: on last floor and on type of heating system, (4) control for two endogeneities sources: floors and on type of heating system, floors are an ordered equation and (5) ontrol for two endogeneities sources: floors and on type of heating system, floors are an ordered equation – control regression for water expenditures

A. 3 Results for instrumental equations

		Energy			Water	
1		2		3		4
Last Floor	Last floor	Heating system	Floor	Heating system	Floor	Heating system
-0.419***	-0.405***		0.559***		0.609***	
(0.0345)	(0.0338)		(0.0295)		(0.0505)	
-0.00261***	-0.00249***		0.00308***		0.00462***	
(0.000861)	(0.000844)		(0.000739)		(0.00103)	
		0.840***		0.833***		0.855***
		(0.0280)		(0.0281)		(0.0609)
		0.320***		0.319***		0.213**
		(0.0254)		(0.0254)		(0.0950)

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; (1) control for one endogeneity source on last floor,, (2) control for two endogeneities sources: on last floor and on type of heating system, (3) control for two endogeneities sources: floors and on type of heating system, floors are an ordered equation and (4) Control for two endogeneities sources: floors and on type of heating system, floors are an ordered equation – control regression for water expenditures

A.4 Robustness check – water sample (2,534 observations)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Expenditures (log)			Energy		Water
Income (log)	0.0994***	0.0994***	0.0988***	0.0893***	0.0522*
	(0.0182)	(0.0191)	(0.0185)	(0.0193)	(0.0270)
Man	-0.00501	-0.0129	-0.0125	0.0134	-0.0132
	(0.0239)	(0.0250)	(0.0249)	(0.0276)	(0.0289)
Couple	0.147***	0.158***	0.158***	0.122***	0.300***
	(0.0289)	(0.0304)	(0.0303)	(0.0331)	(0.0327)
Age	0.000775	0.00174**	0.00174**	-0.000979	-0.00309***
	(0.000735)	(0.000846)	(0.000848)	(0.00100)	(0.000952)
Nb children	0.0911***	0.0987***	0.0981***	0.0816***	0.159***
	(0.0115)	(0.0125)	(0.0125)	(0.0132)	(0.0150)
Bac+2	-0.00810	-0.0193	-0.0173	0.0160	-0.0171
	(0.0310)	(0.0335)	(0.0342)	(0.0373)	(0.0434)
Sup. Bac+2	-0.121***	-0.106***	-0.103***	-0.0957**	-0.104**
	(0.0336)	(0.0348)	(0.0356)	(0.0399)	(0.0430)
Climate zone 4	-0.0203	-0.0543	-0.0503	0.0612	0.118**
	(0.0339)	(0.0364)	(0.0377)	(0.0432)	(0.0497)
Climate zone 3	-0.0362	-0.0295	-0.0302	-0.0360	-0.0125
	(0.0250)	(0.0262)	(0.0262)	(0.0282)	(0.0301)
Climate zone 2	-0.122***	-0.145***	-0.144***	-0.107***	-0.141***
	(0.0332)	(0.0348)	(0.0350)	(0.0402)	(0.0420)
Climate zone 1 (coldest)			REF		
Surface area	0.00576***	0.00541***	0.00542***	0.00714***	0.00519***
	(0.000567)	(0.000609)	(0.000605)	(0.000797)	(0.000779)
Double glazing	0.0137	-0.0121	-0.0123	0.0429	-0.0370
	(0.0312)	(0.0332)	(0.0332)	(0.0365)	(0.0423)
Constructed before 1949			REF		
Constructed 1949-1974	-0.177***	-0.150***	-0.157***	-0.184***	0.0976*
	(0.0310)	(0.0326)	(0.0381)	(0.0400)	(0.0511)
Constructed 1975-1981	-0.214***	-0.167***	-0.172***	-0.259***	0.0929*
	(0.0394)	(0.0432)	(0.0449)	(0.0498)	(0.0546)
Constructed 1982-1989	-0.114**	-0.0907*	-0.0909*	-0.114**	0.101
	(0.0486)	(0.0518)	(0.0518)	(0.0556)	(0.0616)
Constructed 1990-1998	-0.163***	-0.150***	-0.150***	-0.186***	0.0370
	(0.0422)	(0.0455)	(0.0455)	(0.0527)	(0.0598)
After 1999	-0.232***	-0.205***	-0.205***	-0.292***	0.0674
	(0.0367)	(0.0401)	(0.0401)	(0.0442)	(0.0527)
Heating Controller	0.0451	0.0324	0.0228	0.0482	0.0319
	(0.0500)	(0.0493)	(0.0532)	(0.0603)	(0.0703)
Heating expenditures included	0.740***	0.715***	0.705***	0.774***	
	(0.0411)	(0.0445)	(0.0500)	(0.0514)	
Collective heating system – urban or gaz	-0.495***	-0.472***	-0.451***	-0.435***	0.0520
	(0.0282)	(0.0306)	(0.0617)	(0.0584)	(0.103)
Included heating expenditures#Heating controller	-0.0682	-0.0533	-0.0421	-0.0790	
	(0.0871)	(0.0913)	(0.0947)	(0.0989)	
Last floor	-0.0119	0.374***	0.375***	REF	
	(0.0237)	(0.106)	(0.107)		
Intermediary floor				-0.534***	-0.188*
				(0.112)	(0.112)

First floor				-0.970***	-0.318
				(0.227)	(0.220)
Included water expenditures					0.375***
					(0.0726)
Constant	5.475***	5.339***	5.343***	6.077***	4.730***
	(0.175)	(0.187)	(0.181)	(0.232)	(0.272)
Observations	2,534	2,534	2,534	2,534	2,534
R-squared	0.347				
Cut 1				-0.84746***	-1.01541**
				(0.140595)	(0.37852)
Cut 2				0.70955***	0.541594*
				(0.140098)	(0.378802)
Correlation error terms					
Floor and energy expenditures (or water expenditures)		-0.43143***	-0.43057***	-0.07861	-0.05493
Heating sytem and energy expenditures			-0.02236	0.56061***	0.20155
Heating system and floor			-0.08163***	-0.07271**	-0.04513

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; 1) control for one endogeneity source on last floor, (2) control for two endogeneities sources: on last floor and on type of heating system, (3) control for two endogeneities sources: floors and on type of heating system, floors are an ordered equation and (4) ontrol for two endogeneities sources: floors and on type of heating system, floors are an ordered equation – control regression for water expenditures

5 Robustness check – by floor

VARIABLES	Last floor	Intermediate floor	First floor
Energy expenditures (log)			
Income (log)	0.0185	0.0460***	0.0721***
	(0.0187)	(0.0111)	(0.0205)
Man	-0.0268	0.00544	-0.00859
	(0.0246)	(0.0152)	(0.0285)
Couple	0.178***	0.149***	0.0430
	(0.0291)	(0.0171)	(0.0355)
Age	0.000287	-0.000260	0.000593
	(0.000743)	(0.000472)	(0.000881)
Nb children	0.0811***	0.0597***	0.0821***
	(0.0118)	(0.00699)	(0.0171)
Bac+2	0.0457	-0.0329	0.0758*
	(0.0325)	(0.0224)	(0.0456)
Sup. Bac+2	-0.00971	-0.0153	-0.0939***
	(0.0295)	(0.0184)	(0.0358)
Climate zone 4	-0.01000	0.0681**	-0.00490
	(0.0375)	(0.0270)	(0.0483)
Climate zone 3	-0.0402	-0.0403**	-0.0654*
	(0.0293)	(0.0178)	(0.0356)
Climate zone 2	-0.0779*	-0.0672**	-0.114**
	(0.0433)	(0.0277)	(0.0468)

Climate zone 1 (coldest)		REF	
Surface area	0.00666***	0.00678***	0.00867***
	(0.000650)	(0.000341)	(0.000836)
Double glazing	0.0496	-0.00506	0.0601
	(0.0343)	(0.0179)	(0.0418)
Constructed before 1949		REF	
Constructed 1949-1974	-0.152***	-0.208***	-0.191***
	(0.0350)	(0.0255)	(0.0429)
Constructed 1975-1981	-0.188***	-0.225***	-0.236***
	(0.0451)	(0.0279)	(0.0543)
Constructed 1982-1989	-0.0695	-0.128***	-0.0732
	(0.0487)	(0.0331)	(0.0602)
Constructed 1990-1998	-0.0614	-0.0965***	-0.143**
	(0.0384)	(0.0310)	(0.0577)
After 1999	-0.160***	-0.0844***	-0.162***
	(0.0431)	(0.0284)	(0.0438)
Heating Controller	-0.0545	-0.148***	-0.279***
	(0.0563)	(0.0317)	(0.0717)
Heating expenditures included	0.669***	0.657***	0.662***
	(0.0374)	(0.0218)	(0.0532)
Collective heating system – urban or gaz	-0.295***	-0.175***	-0.309***
	(0.0506)	(0.0417)	(0.0633)
Included heating expenditures#Heating controller	0.0551	0.154***	0.296***
	(0.0865)	(0.0438)	(0.0972)
Constant	6.074***	5.816***	5.578***
	(0.181)	(0.108)	(0.192)
Observations	2,289	6,712	1,568
Correlation error terms	-0.157***	-0.273***	-0.227***
	(0.0470)	(0.0428)	(0.0548)

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1;

A. 6 Robustness test – with the number of the floor

VARIABLES	(1)	(2)	(3)	(4)
Expenditures (log)		Energy		Water
Income (log)	0.0359***	0.0369***	0.0450***	0.0535**
	(0.00833)	(0.00846)	(0.00888)	(0.0264)
Man	-0.00957	-0.0100	-0.00588	-0.0184
	(0.0117)	(0.0117)	(0.0119)	(0.0286)
Couple	0.148***	0.147***	0.141***	0.308***
	(0.0134)	(0.0135)	(0.0137)	(0.0311)
Age	3.27e-05	3.93e-05	2.42e-06	-0.00254***
	(0.000359)	(0.000362)	(0.000366)	(0.000842)
Nb children	0.0722***	0.0711***	0.0665***	0.162***
	(0.00559)	(0.00564)	(0.00572)	(0.0147)
Bac+2	-0.0151	-0.0163	-0.00380	-0.0232
	(0.0169)	(0.0170)	(0.0174)	(0.0427)
Sup. Bac+2	-0.0387***	-0.0295**	-0.0141	-0.109***
	(0.0140)	(0.0143)	(0.0146)	(0.0418)
Climate zone 4	0.0105	0.0204	0.0518***	0.0965**
	(0.0193)	(0.0195)	(0.0201)	(0.0470)
Climate zone 3	-0.0215	-0.00588	-0.0241*	-0.0111
	(0.0136)	(0.0139)	(0.0143)	(0.0300)
Climate zone 2	-0.0882***	-0.0850***	-0.0740***	-0.147***
	(0.0205)	(0.0206)	(0.0210)	(0.0406)
Climate zone 1 (coldest)				
Surface area	0.00713***	0.00726***	0.00712***	0.00480***
	(0.000285)	(0.000289)	(0.000292)	(0.000721)
Double glazing	0.0134	0.0123	0.0165	-0.0441
	(0.0146)	(0.0148)	(0.0151)	(0.0412)
Constructed before 1949				
Constructed 1949-1974	-0.106***	-0.0873***	-0.165***	0.101*
	(0.0160)	(0.0163)	(0.0184)	(0.0517)
Constructed 1975-1981	-0.151***	-0.134***	-0.194***	0.108**
	(0.0200)	(0.0203)	(0.0216)	(0.0525)
Constructed 1982-1989	-0.0872***	-0.0874***	-0.106***	0.100*
	(0.0249)	(0.0250)	(0.0251)	(0.0598)
Constructed 1990-1998	-0.0829***	-0.0840***	-0.0915***	0.0429
	(0.0218)	(0.0219)	(0.0223)	(0.0582)
After 1999	-0.124***	-0.137***	-0.135***	0.0860*
	(0.0206)	(0.0207)	(0.0208)	(0.0514)
Heating controller	-0.0619***	-0.0640***	-0.147***	0.0268
	(0.0234)	(0.0235)	(0.0255)	(0.0687)
Included heating expenditures	0.729***	0.735***	0.671***	
	(0.0158)	(0.0161)	(0.0178)	
Heating system	-0.419***	-0.391***	-0.187***	0.0443
	(0.0131)	(0.0143)	(0.0286)	(0.102)
Included heating expenditures#Heating controller	0.0785**	0.0752**	0.135***	
	(0.0364)	(0.0372)	(0.0370)	
Level of floor	-0.0300***	-0.0573***	-0.0577***	-0.0150
	(0.00425)	(0.00619)	(0.00619)	(0.0168)
Level of floor (square)	0.00118***	0.000890**	0.000978***	0.000872
	(0.000349)	(0.000351)	(0.000353)	(0.00116)
Included water expenditures				0.375***
				(0.0706)

Constant	5.986*** (0.0796)	6.012*** (0.0808)	5.919*** (0.0850)	4.558*** (0.243)
Observations	10,569	10,569	10,569	2,534
R-squared	0.355			
Correlation error terms				
Floor ratio and energy expenditures (or water expenditures)		0.155***	0.160***	0.0364
Heating sytem and energy expenditures			-0.234***	-0.0415
Heating system and floor ratio			-0.0925***	0.0897***

Note: In this step, in order to consider the size of the building, we introduce a quadratic term.
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; 1 OLS, 2) control for one endogeneity source on floor ratio, (3) control for two endogeneities sources: on floor ratio and on type of heating system, (4) control for two endogeneities sources: on floor ratio and on type of heating system, water expenditures

Results for instrumental equations

	(1)	(2)		(3)	
Equation for	Energy			water	
	last floor	last floor	heating system	Floor	heating system
Elevator	2.159***	2.161***		2.109***	
	(0.0485)	(0.0484)		(0.110)	
Dwelling exposure					
North			Ref		
South	0.132*	0.134*		0.0637	
	(0.0705)	(0.0706)		(0.125)	
South-West	0.107	0.109		0.137	
	(0.0855)	(0.0856)		(0.158)	
South-East	0.0652	0.0670		0.0682	
	(0.0871)	(0.0872)		(0.150)	
West	0.137*	0.138*		-0.0722	
	(0.0790)	(0.0790)		(0.137)	
East	0.0193	0.0194		0.0633	
	(0.0758)	(0.0759)		(0.138)	
To be connected to the gas			0.639***		0.625***
			(0.0358)		(0.0850)
Living zone: Paris			0.365***		0.236*
			(0.0400)		(0.143)
Other control variables	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1