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Is the cold the only reason why we heat our homes? Empirical evidence from spatial series data

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HIGHLIGHTS

- Spatial series data of natural gas consumption are analyzed.
- A two-stage interpolation including a spatially lagged dependent variable is used.
- A positive income elasticity characterizes natural gas consumption.
- Money saving from efficiency measures is partly used to increase energy use.
- Space does matter in shaping the consumption choices on domestic heating.

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ABSTRACT

Climatic conditions are commonly considered the primary determinant of consumers' choices about energy use for heating. Besides, current regulations on the matter focus on the physical characteristics of the buildings, relying on a strict relationship between efficiency and savings. Nevertheless, the literature shows that energy demand determinants are difficult to be estimated with the accuracy required for predictive purposes, while the energy savings stemming from efficiency gains are partly outweighed by the consumers' behavior. We deal with these issues by analyzing spatial series data of natural gas consumptions for space heating and hot water production in the residential sector. The regression analysis takes four fields of covariates into account: climate, building characteristics, market aspects, and technological development. The estimation process is based on the following cornerstones: a spatially lagged dependent variable to deal with the problem of spatial autocorrelation, linear and logarithmic functional forms, and a two-stage interpolation strategy that is meant to provide unbiased estimates of both the dispersion matrix and the *t*-statistics by combining Ordinary Least Squares and Weighted Least Squares. The models turn out to be well specified, and their explanatory power is high, so the results are suitable for demand forecasting. Although the spatial autoregressive term does not appear among the significant regressors, we show that space does matter in shaping the natural gas consumption in different regions. Our analysis proves that heating gas demand is characterized by a positive elasticity to income. We use these results to provide estimates of the rebound effect. Nevertheless, the additional consumption directly attributable to an income effect is of moderate magnitude when the gas price does not vary.

1. Introduction

1.1. The commitment to energy efficiency in buildings

Energy efficiency is a topic of primary interest for the building industry and the housing sector. During the last four decades, several political and economic issues have attracted the attention to the energy use. For instance, the oil shocks occurred during the seventies – namely, oil embargoes and inescapable rise of the energy prices – led to the adoption of the first regulations about energy efficiency, with remarkable implications for the building industry [1–3]. Moreover, during the nineties and the 2000s, the commitment to the reduction of greenhouse gas emissions [4–6] and the long-term goal of a low-carbon economy [7] brought the efficiency issue back to the fore.

Under the framework above, buildings are crucial because they substantially contribute to energy consumptions and carbon emissions. According to Eurostat [8], residential and tertiary constructions are deemed responsible for 36% of consumptions and 40%

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Nomenclature

Roman letters

AGE	weighted average age of the buildings [y]
ALT	altitude above the mean sea level [m]
AWk	average daily temperature during winter [K]
B60	share of buildings built during the sixties [%]
B90	share of buildings built starting from the nineties [%]
CO	per capita emissions of carbon monoxide [mg]
CO2	per capita emissions of carbon dioxide [mg]
CON	diffusion index of high-speed internet connections
CPIb	consumer price index: cost of bread [€/kg]
CPIc	consumer price index: cost of an espresso coffee [€]
CPIg	consumer price index: cost of gasoline [€/l]
CPIp	consumer price index: cost of pasta [€/kg]
D30k	temperature deviation relative to the 30 years average [K]
DH	per capita energy supply by district heating [m^3]
HDD	heating degree days [°C]
HiT	incidence index of high-technology companies
I	identity matrix
IHS	share of independent heating systems [%]
IHW	share of independent domestic hot water systems [%]
IP	number of industrial patents [no.]
LAT	latitude [degrees]
MWk	average minimum temperature during the winter [K]
m, n	number of independent variables and observations
NGC	per capita natural gas consumption in the residential sector [m^3]
NGPR	natural gas penetration rate [%]
NOx	per capita emissions of nitrogen oxides [mg]
NPI	natural persons' income [€]
P	composite pollution index
PM10	particulate < 10 μm [mg]
PM2.5	particulate < 2.5 μm [mg]
RAD	average solar radiation during a five-year period [MJ/m^2]
SO2	per capita emissions of sulfur dioxide [mg]
SQMB	average square meters per occupied building [m^2]
SQMR	average square meters per resident [m^2]
TECH	composite high-tech index
UB	share of unoccupied buildings [%]
v	weights in the weighted least squares
W	contiguity matrix
WDD	winter degree days [°C]
WRR	waste recycling rate [%]
X, x	matrix of the independent variables and generic independent variable
y	dependent variable
z	instrumental variable

Greek letters

α	intercept of the regression equations
β, γ	coefficients of the regression equations
ε	residuals of the regression
η	elasticity of natural gas consumption
σ	standard deviation of the residuals

Subscripts

i	index of observations
j	index of independent variables
s	spatial indicator
s − 1	indicator of spatially lagged variables

of emissions. The EU is implementing enhanced regulations on the matter, such as the Directives 2010/31 "on the energy performance of buildings". The subsequent Directive 2012/27 "on energy efficiency" relies on the supposed strong link between energy savings and efficient technologies (see, for instance, s. 7 et seq). Nonetheless, the results achieved so far are unsatisfactory. The EU institutions complain about the lack of progress toward the nearly Zero-Energy Building standard [9], and several reports raise doubts about actual improvements on performance and emission levels [10–12]. From a broader perspective, the literature argues that relying only on energy efficiency does not represent an effective way to reduce consumptions; nor it allows to achieve the desired environmental targets [13]. The underlying reason may be found in the seminal work of the economist William Stanley Jevons [14], who gave rise to the namesake paradox. Concisely, the fuel efficiency driven by the technological progress enables to benefit from lower fuel prices, at least in relative terms, which in turn triggers a higher demand for the same resource [15]. The expression "rebound effect" well summarizes this phenomenon [16].

Although the occurrence and magnitude of the rebound effect are debated [17,18], some recent remarks show that this is a topical issue. Specifically, the Odex index has been developed within the Odyssee-Mure project [19], aiming to represent the energy efficiency improvements in several sectors, mainly manufacturing industry, transport and building. The technical document providing the index definition [20, p. 8] states that "In some countries, there is a slow down or even a deterioration of energy efficiency progress for heating since the mid-nineties ... Such changes should not be interpreted as a reduction of energy efficiency, as technical savings have not actually stopped ... This situation rather reflects negative behavioral savings, due to higher indoor temperature." The above quote calls into question our knowledge about how the users' attitudes and other factors affect the energy consumption in buildings. The researchers are aware that modeling the energy use is an unavoidable task to improve the related policies [21], but several difficulties arise [22], and the results often lack the required statistical significance. Particularly, recent studies show we are barely able to explain 50% of the energy consumptions and savings [23,24], so our predictive ability is limited.

1.2. Aim of this study

According to the framework discussed in the previous paragraph, this study deals with two major issues. Firstly, is it possible to achieve highly reliable estimates of the factors driving energy consumptions, so to use the results for predictive purposes? Secondly, do these results provide evidence that the rebound effect occurs?

As far as the first issue is concerned, we focus on the natural gas consumption for space heating and hot water production, because it is a large part of the energy used in buildings [15] and it is recognized as an important source of environmental impacts [25]. Many studies analyze cross-sectional or time-series data, and others make use of panel data. We adopt a rather different perspective, by analyzing *spatial series* data. It means that a spatial order characterizes the observations, although they are not placed on a regular grid. This spatial order, in turn, entails the need to delve into the proximity relationships and the data autocorrelation. Like many other ecological and social phenomena, also the energy use in a given area may be affected by the consumption behavior in the surrounding areas, due to causes such as diffusion of habits, emulation of neighbors, and so forth. To the best of our knowledge,