UNIVERSITÀ DEGLI STUDI FIRENZE
DISEI
DIPARTIMENTO DI SCIENZE PER L'ECONOMIA E L'IMPRESA

Working Papers - Economics

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Working Paper N. 20/2019

DISEI, Università degli Studi di Firenze
Via delle Pandette 9, 50127 Firenze (Italia) www.disei.unifi.it

WHEN I WAS YOUR AGE... POPULATION DYNAMICS AND HOUSEHOLD ENERGY CONSUMPTION

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Abstract

Generational values inspire behaviour in numerous areas such as politics, labour markets, social cohesion, consumption and energy use. Stephenson et al. (2015) highlight the role of so-called *energy culture* in shaping the behaviour of different population cohorts regarding energy consumption and environmental protection, and empirical studies have confirmed the relevance of cohort effects in residential and transport-related energy use (Bardazzi and Pazienza, 2017; Chancel, 2014). This paper aims to assess how ageing and evolving generational energy cultures in Italy affect the future path of energy consumption, considering the expected changes in the Italian population size, composition and location. We use a pseudo-panel of Italian households to estimate cohort and age effects by macro-area and then we combine these effects with official demographic projections to forecast the potential consequences for energy consumption up to 2050. Our findings show that age and generation are key determinants of household behaviour regarding residential energy consumption and these effects interplay with future population dynamics, which are also area-specific due to internal migration.

Keywords: Household energy demand, Pseudo-panel, Population age structure, Cohort effects

JEL: D12, Q4, J11, Q56

1. Introduction

The speed at which population ageing has been progressing in the vast majority of developed countries is bound to have a strong impact on social and economic scenarios, especially if its interaction with overlapping generation effects is considered. Generational values influence various domains as diverse as politics, labour markets and social cohesion. Recently, attention has been devoted to the influence of so-called *energy culture* in shaping the behaviour of different population cohorts regarding energy consumption and environmental protection (Stephenson et al., 2015). Individuals react to the pressure of several factors that define the concept of energy culture, among which are socio-demographic and economic transformations, changes in lifestyle and in pro-environmental attitudes. When only considering age effects on consumption, we assume that people may show a different pattern of energy use as they age. However, if a cohort effect exists, for instance, the members of younger generations may start from a higher base level of consumption and continue to demand relatively more at every stage in their life. Recent empirical studies have confirmed the relevance of cohort effects in energy use (Bardazzi and Pazienza, 2017; Chancel, 2014) and therefore it can be argued that the future patterns of energy consumption and emissions will be affected by the fact that younger generations will substitute older cohorts in the population.

This paper provides an analysis of the effect of ageing and generational behaviour on the residential energy demand of Italian households using synthetic cohort techniques. The case of Italy is particularly interesting because of its notable cohort effects, very fast population ageing and significant internal migration. Our contributions to the literature are manifold. First, we build a pseudo-panel of Italian households covering the period 1997-2016 to capture long-term energy demand behaviour considering demographic characteristics, price and demand elasticities and general weather conditions. The sample is disaggregated by geographical area to determine whether differences in behaviour are related to differences in local energy cultures and contexts. These data offer long-term longitudinal information which combines the advantages of time-series analysis while partially preserving the heterogeneity of microeconomic survey data. Then, cohort and age effects are estimated at the regional level, also taking into account the role of different income levels. The results of our analysis of age and generational profiles are then used to forecast regional energy consumption on the basis of demographic projections, as we are interested in assessing the extent to which projected demographic trends have the potential to affect future energy consumption. A sensitivity analysis is undertaken to assess the robustness of our results to different assumptions about demographic scenarios and the stability of age and cohort coefficients. Finally, we discuss the implications of the energy culture framework to identify policy interventions: we argue that since new generations show more energy-intensive consumption behaviour, environmental policies such as energy efficiency regulation and carbon pricing can play key roles in the Italian energy transition pattern.

2. Literature review

Among the biggest challenges facing western countries, ageing populations and energy transition towards cleaner and more efficient technologies seem to be incompatible. Moreover, internal and international migrations in a framework of rising inequality – a concentration of income, innovation and good living conditions among a small portion of players and territories – will make these long-term transformations even trickier. To accommodate energy transition, both new investment and behavioural changes are crucial.[1] Energy demand encompasses two separate decisions: on the selection of a particular type of equipment and on the level of utilization of the equipment. Indeed, focusing on residential energy use, the characteristics of dwellings and of electrical and heating equipment – key drivers of energy use in combination with average weather conditions – can be improved by energy saving investment and more accurate purchase decisions. The level of utilization – energy demand – is jointly determined by income, ownership, wealth, education, demographic characteristics (age, gender and household size), location and environmental concerns.[2] All these factors have been extensively analysed in the economics literature and grouped according to different classification criteria.[3] Ageing populations interact in specific ways with each factor. The combination of an ageing population and these consumption determinants has generally been evaluated as leading to higher energy use (Yamasaki and Tominaga, 1997; Hamza and Gilroy, 2011; Menz and Welsh, 2012). Among the main explanations are lower economies of scale in energy use – due to smaller household sizes[4] – more time spent at home and the need for heating comfort. However, older households generally have lower income levels and this constitutes a factor mitigating both energy demand and energy-saving investment.

The economics literature has analysed the long-term evolution of energy demand mainly by means of IPAT models. These models originate from an accounting formula proposed in the early 1970s and are linked to the work of Ehrlich and Holdren (1971). The simplest version stresses the role of an increasing population (P) in effects on the environment (I, impact), consumption levels and habits, synthetized by the 'affluence' term (A), whereas the positive role of innovation in resource needs is represented by the technology level (T),[5] so I=P*A*T. The IPAT-based literature evaluating the effect of the population on energy consumption and CO_2 emissions has generally relied on simple measures of age composition and technology and shows mixed evidence. Cole and Neumayer (2004), among several others, study the link between ageing and demographic characteristics in a cross-country setting, finding effects of population age composition, household size and urbanization patterns on CO_2 emissions. Using a modified and generalised version of the IPAT[6] identity, Zagheni (2011) considers several demographic characteristics (age structure, fertility and birth rates) to estimate the age-specific consumption profiles for key CO_2-intensive goods. By combining these results with US population forecasts, he finds a small decrease in total CO_2 production in the US in 2050 for a bundle of main consumption goods and an increase in consumption and CO_2 levels of energy products. This last result for energy products is based on a hypothesis of static technology with a fixed CO_2 content of electricity and natural gas.

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1 See Day (2015) on how to enhance older people's participation in low carbon domestic transitions.

2 The economics literature stresses that elderly people are generally less concerned about climate change and are less likely to support climate-friendly policies. See Andor et al. (2018) for a recent empirical assessment for Germany.

3 See, for instance, human/non-human factors in Bardazzi and Pazienza (2016) or individual/situational predictors in Frederiks et al. (2015).

4 On the long-term evolution of household size, see Bradbury et al. (2014) and Schröder et al. (2015). In particular, Schröder et al. (2015) estimate that a 5% decline in average household size during the period 2005-10 in Japan resulted in a 3.5% increase in household-sector energy demand.

5 This sort of Malthusian idea was originally sketched in the book 'Population Bomb' written by P. Ehlrich in the late sixties. In a context of fast increasing global population, Elrich and Holdren doubted that innovation would be able to significantly reduce per capita resource use and so supported population control.

6 The modified version needed to properly assess the impact of population change on the environment is known as STIRPAT (STochastic Impacts by Regression on Population, Affluence and Technology). Zagheni also uses an input-output multisectoral model to properly consider technologies.

Although there is a large consensus on the fact that an ageing population is a factor increasing energy demand (see Zagheni and Estiri, 2018 for a recent analysis), a recent strand of literature has stressed that age is a multi-dimensional phenomenon. Beyond biological physical status and levels of education and wealth, generational culture and biographical considerations can be very important in understanding energy use and investment in new technologies. Energy consumption patterns vary greatly between apparently similar types of household. This heterogeneity goes beyond bias and errors in evaluating costs and price signals and can be better described by looking at the characteristics of energy culture[7]. According to Stephenson et al. (2010), energy choices can be understood by looking at the interactions between "cognitive norms, (e.g. beliefs, understandings), material culture (e.g. technologies, building form) and energy practices (e.g. activities, processes)."[8] As stressed in our previous work, we think that this concept can be very useful to interpret different behaviours among generations and when considering traditional instruments – such as carbon pricing, which relies on monetary incentives – to understand how climate and energy security policies should take into account specific energy cultures prevailing in households. As Greene (2018) stresses, although how to push behavioural change to support public policy is the key question, how and why people develop, maintain or change particular energy lifestyles remains an open field of research. In addition to the three pillars defining energy cultures, Greene (2018) highlights the role of contextual factors in shaping the evolution of individuals' environmentally-significant behaviour over the course of their lives. Energy culture standards are not immutable. On the contrary, new standards of energy practises can be rapidly adopted and they can be shaped by prevailing social norms as well as by the availability of technology, personal experiences and public policies.[9] In particular, cohort effects can be interpreted as results of evolving generational consumption attitudes or of individuals' lifetime exposure to energy scarcity, negative income shocks or political contexts. As the life cycle literature shows, these shocks can have long lasting impacts on consumers' habits and consumption choices and therefore on energy saving attitudes.[10]

Among recent empirical evidence in this line of research, Chancel (2014) uses individual datasets – for France and the US – to unravel a generational effect on the emission patterns of French and US households, looking at residential and transport energy use. He finds two opposite results: a clear cohort effect for France (with the 1930-1955 cohort consuming more than other cohorts) and a homogenous consumption pattern across US generations. He presents three drivers as possible factors explaining the generational effect in France: an income factor (the 1930-1955 generation experienced better life chances and therefore gains in income differentials), a technological factor (important in residential energy use) and a behavioural factor (the younger generation may have higher environmental concern and the baby boom generation may have difficulties in modifying their consumption patterns). Bardazzi and Pazienza (2017, 2018) find evidence of age and cohort effects in household energy demand. Indeed, very differentiated generational patterns of energy culture can be traced for residential energy demand

[7] Yamasaki and Tominaga (1997) do not explicitly consider generational cultures but focus on average income growth to describe generational changes in energy use. "The next ageing generation can seek more affluent living than is currently available for the elderly. In this case, their presence leads to growing energy consumption." p.909.

[8] Stephenson et al. (2010), p. 6124. Carlsson-Kanyama et al. (2005) also conclude that generations matter when residential energy consumption is considered.

[9] See Stephenson (2018).

[10] See Malmendier and Sheng Shen (2018).

(where the older generation is more saving-oriented) and for transport demand (where the fuel demand of the baby boom generation is oriented by car preference).

3. The Italian case: selected stylized facts

3.1. Population trends

In 2017 the Italian population represented almost 12 per cent of the inhabitants of the European Union (511 million), coming fourth in the demographic ranking of countries after Germany, France and the United Kingdom.[11] As for the ageing index – the number of old people (65 and over) for every 100 young people (under 15) – Italy ranked first before Germany (165 and 159 per cent respectively) and is among the countries with the highest dependency ratio[12] (55.8 per cent compared to the EU28 average of 53.9 per cent). Both indicators have been steadily increasing in the last decade while the average annual total population growth rate has been less than 0.4 per cent. Moreover, Italy is among the European countries with the highest level of life expectancy at birth and the lowest fertility rate.

Beside these general features, Italy is characterised by a noticeable heterogeneity at the territorial level. Almost half of the total population lives in the northern regions (46 per cent in 2017), more than a third in the *mezzogiorno* (34 per cent in the southern regions and islands) and the rest in the centre (20 per cent). The natural population balance (the number of live births minus the number of deaths each year) shows negative values in all these areas. The change in migration flows – both in and out – is positive in the central and northern regions but negative in the south and islands due to internal migration. As for the ageing index, in the northern and central regions it is the highest (on average respectively 177 and 178 per cent) and in the southern area including the islands it is the lowest (153 per cent). Data show that people live longer in the north, with a life expectancy at birth close to 81 years for men and 85 for women. In the centre, the values are slightly above the national average while in the south and islands area they remain below it.

Present and past demographic trends are important to determine the future of the Italian population both at the national and regional levels. ISTAT[13] computes demographic projections for Italy using the cohort components model (Istat, 2017). The key exogenous variables concern fertility rates, life expectancy and net internal and international migration. The most recent projections (Istat, 2017) use the population in 2016 as base and forecast up to 2065 (long run), with 2025 as short-term and 2045 as medium-term projections. Three alternative projections are proposed depending on the assumptions about the exogenous variables. The median demographic projection is considered the most likely forecast scenario and therefore it is the one used in this paper.

According to the median scenario, the Italian population is expected to decrease from 60.7 million in 2016 to 58 in 2050 and 53.7 in 2065. In the southern regions, this progressive decline should cover the whole projection period while in central and northern Italy the population should increase. Therefore, the demographic territorial

[11] These population data are from the Eurostat database (demo_pjan).

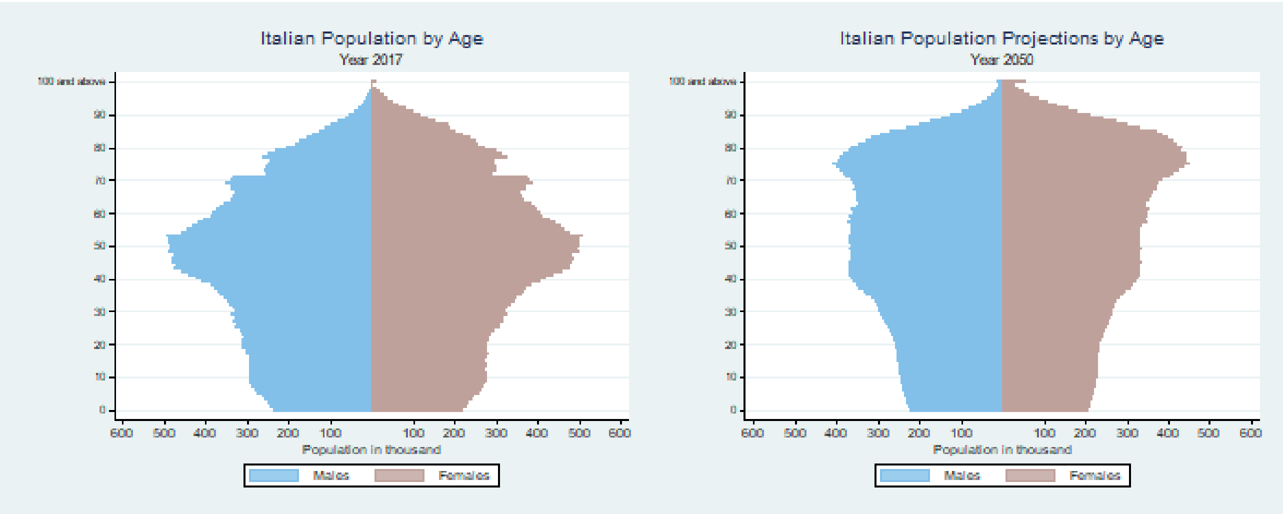
[12] The dependency ratio is obtained by dividing the resident inactive population (aged 0-14 and over 65) by the working population (aged 15 to 64).

[13] ISTAT is the Italian National Institute of Statistics.

distribution should shift from the south (34 per cent of the total population in 2016, 29 per cent in 2065) to the centre-north (66 per cent in 2016, 71 per cent in 2065).

This reduction in population size is accompanied by an increase in the average age from 44.7 to more than 50 in 2065. The population ageing will be certain and severe. The age structure of the population is already unbalanced in the base year as is shown in the 2017 population pyramid (Figure 1, left-hand panel), where the share of individuals over 65 is 22 per cent, but it will increase even further giving rise to an inverted pyramid by 2050, as is shown in the right-hand panel.

Figure 1 – Italian population pyramid (2017) (left-hand panel) and population projection (2050) (right-hand panel)

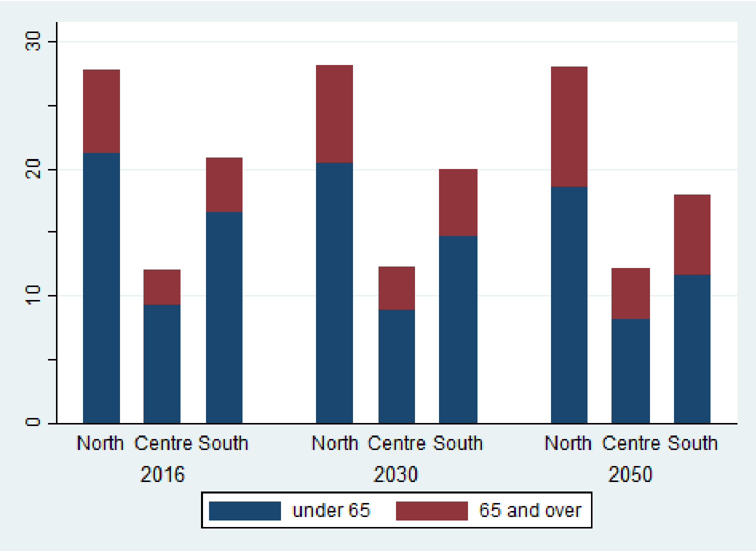


Source: Authors' elaboration on ISTAT data

The future projection is partly explained by the transition of baby boomers from the 40-64 cohort to the older cohort (over 65). The ageing peak should hit Italy around the years 2045-2050, when individuals over 65 will represent more than a third of the total population.

The transformation in the age structure of the population will change the intergenerational balances across the country heterogeneously. The regions in northern and central Italy should experience a similar convergence path from an average age of 45 in 2016 to 50 in 2050. On the other hand, in the south and islands the average age should change from 43-44 (less than in the rest of the country) to 51 in 2050. Therefore, southern Italy should become the area with the highest ageing process and will also have a shirking population, as is shown in Figure 2.

Figure 2 – Italian population projections by area (millions)



Source: Authors' elaboration of ISTAT data

3.2 Residential Energy use

Italy has traditionally one of the lowest levels of energy intensity, both at the GDP and household consumption levels: this characteristic is strictly linked to its high energy dependency (which together with high energy taxation leads to high energy prices) and to its mild climate.[14]

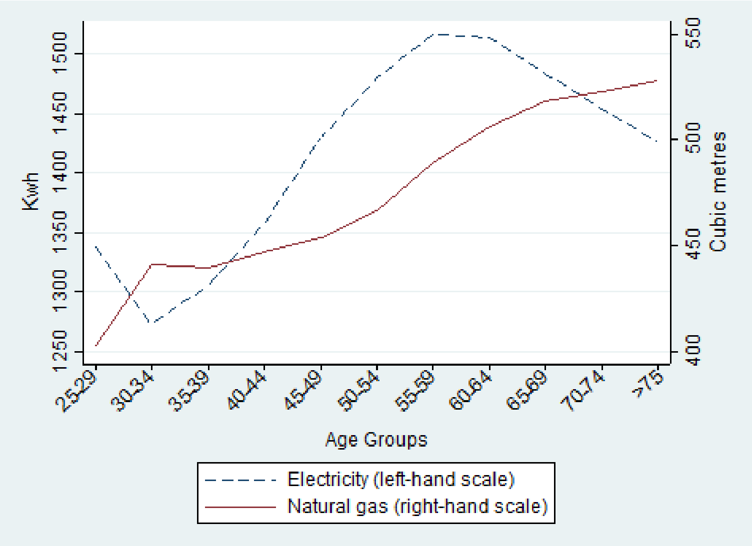
To investigate the link between household demographics and energy use, Figure 3 shows the average residential electricity and natural gas demand for all households with household heads of the same age against the head's age.[15] Looking at the hump-shaped electricity curve, we observe that consumption rises from the age of 25 up to 55-59 years and declines thereafter. Therefore, Italian data confirm a standard finding in the empirical literature analysing the link between age and energy consumption (see Estiri and Zagheni, 2018 for the US and Meier and Rehdanz, 2010 for the British case): a peak when the household head is about 50 years old and the family has reached its largest size and about its maximum income level. However, when considering natural gas consumption – which is linked to heating needs – the inverted U shape vanishes and we observe a constant rise as householder age increases. Here again, our data confirm higher thermal comfort needs and more time spent at home by the elderly. However, this descriptive evidence could result from additional factors besides ageing: similarities in experiences and social influences across a particular generation affect its members' choices and define a set of cultural values that determine its consumption behaviour. To investigate the existence of a generational energy culture, it is necessary to distinguish between a pure age effect and a cohort effect on energy use. The previously shown energy consumption behaviour includes an age effect, which is the characteristic life-cycle component of the variable, and potentially a cohort effect that leads to differences in the position of age profiles for different cohorts. If these differences exist, it is not correct to extrapolate information about the life-cycle consumption of

[14] Italy finances the deployment of renewables by means of a surcharge on electricity bills. For a snapshot on energy prices and energy taxation, see Bardazzi and Pazienza (2016).

[15] We use data on household expenditure collected through the Italian Household Budget Survey (IHBS) published by the Italian Statistical Office (ISTAT). Altogether, some 22,000 households are sampled throughout the year to represent the Italian population at the regional level for the period 1997-2016. Householders below 25 years old are excluded. The data in the figure are the average equivalent quantities over the whole sample period.

an individual household from cross-sectional data and it is necessary to use a model that estimates separate age and cohort effects.

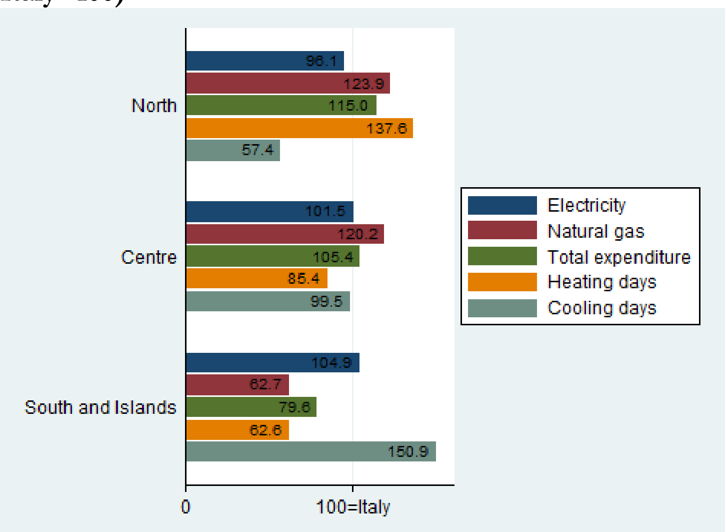
Figure 3 - Electricity and natural gas consumption by householder age (kWh and Cubic Metres)



Source: Authors' elaboration of ISTAT data

Other important determinants of energy use are climatic conditions and economic variables, such as household income and energy prices. Figure 4 shows the average residential energy demand and climatic conditions for different geographical macro-areas. Given the remarkable difference in average weather conditions, with the temperature rising from the north to the south of the peninsula, we observe decreasing natural gas use from north to south – following the index of heating days – and an increasing electricity demand, because of cooling and refrigerating needs being greater in the south than in the north. Because of large income differences between the areas, the graph also includes the index of total equivalent expenditure (as a proxy for income).

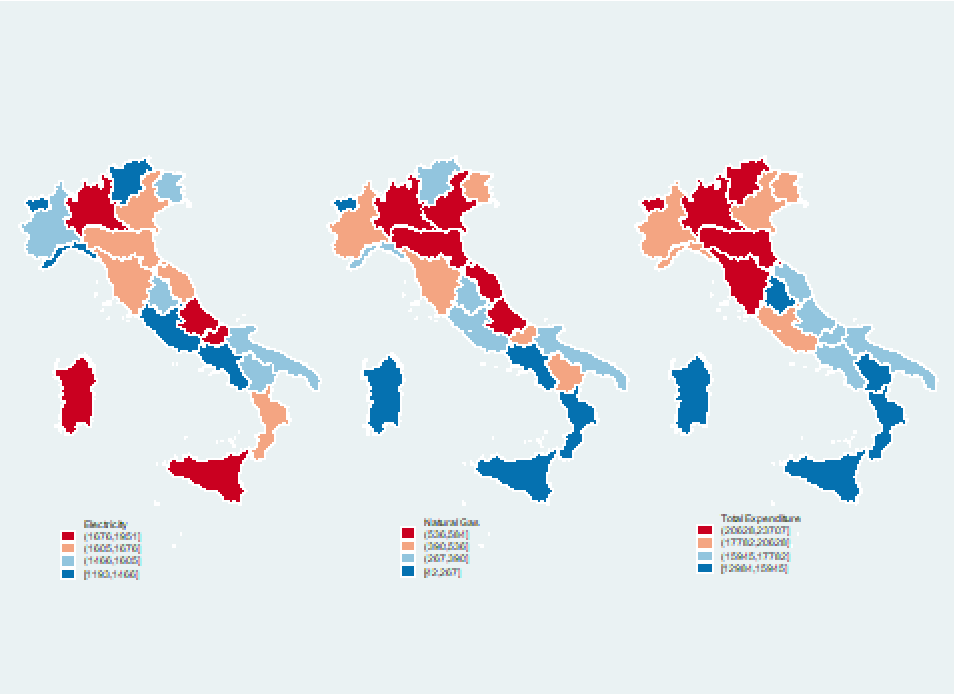
Figure 4 - Energy use, total expenditure and climatic conditions by geographical area (indexes, Italy=100)



Source: Authors' elaboration of ISTAT data

Notwithstanding the average weather conditions, energy demand is heterogeneous within the macro-areas. Figure 5 shows the regional distribution of per adult equivalent total expenditure (as a proxy for income) and energy demand (per adult equivalent quantities). In the right-hand panel, the cleavage between the north and south is very evident regarding total expenditure: all the regions in the centre and northern parts of the country are richer (so coloured red and orange) than the southern regions (coloured light and dark blue). As for electricity (left-hand panel) and, partially, for natural gas (middle panel) the situation is much more mixed: red and blue are present in both the northern and southern regions. This means that average climate conditions and income levels cannot fully explain energy demand.

Figure 5 - Energy use by Italian Region in 2016 (average per adult equivalent energy unit and euros)



Source: Authors' elaboration of ISTAT data

To summarize, significant geographical heterogeneity, a structural demographic shift in terms of both the age and size of the Italian population, and a potential interaction of different generations with different energy cultures are deemed to influence the future pattern of energy use and should be specifically considered in modelling household residential energy consumption.

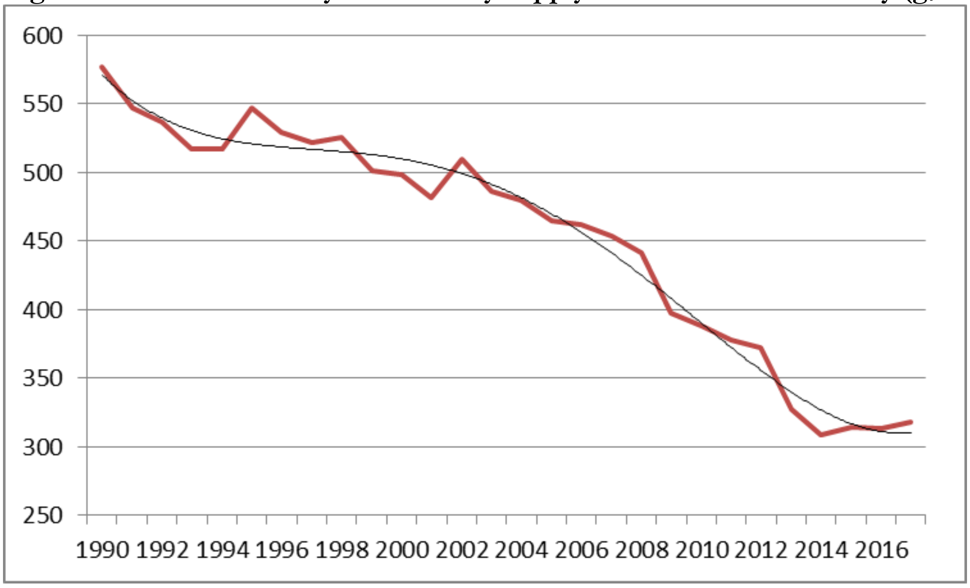
3.3 Emissions and carbon intensity in residential energy use

Italy's overall carbon intensity, i.e. the quantity of carbon emission per unit of output, is in line with the EU average and has been stable since 2006.[16] Italy's strategy for climate-related emission mitigation has relied heavily on market-based instruments and specifically on promoting renewables by means of economic incentives, which in

[16] See Bardazzi and Pazienza (2016).

turn contributes to energy independence. Indeed, Italy experienced a rapid increase in installed renewable capacity in a few years thanks to a generous system subsidising photovoltaic and wind technologies which led to a rapid reduction in carbon intensity in the power sector. A year-by-year analysis of emission factors conducted by ISPRA (2017) shows that an increasing share of renewable sources is the main driver of the decrease in CO_2 emissions from electricity generation in recent years. Figure 6 shows the carbon intensity path of electricity for residential use.

Figure 6 - Carbon intensity of electricity supply for domestic use in Italy (g/kwh)



Source: ISPRA – Inventory of national emissions (2017)

From the chart above it is possible to identify a steepening of the slope for electricity carbon intensity from the second half of last decade, which mirrors the very generous feed-in tariff system introduced in Italy between 2005 and 2013. Indeed, carbon intensity almost halved between 1990 and 2017 and the average reduction rate was -2.1% for the whole period and -3.4% between 2008 and 2017. On the contrary, carbon intensity for natural gas has been almost stable and no remarkable change is expected in future decades.[17]

4. Data and model

4.1 The data: a pseudo-panel of residential energy use

We use data collected through the Household Budget Survey (IHBS) released by ISTAT. The survey is based on the harmonized international classification of expenditure items (Classification of Individual COnsumption by Purpose – Coicop) to ensure international comparability. The main focus of the IHBS is on all the expenditure incurred in resident households to purchase goods and services exclusively devoted to household consumption. Altogether, some 22,000 households are sampled throughout the year to represent the Italian population at the

[17] See Koffi *et al.* (2017).

regional level.[18] Our analysis uses annual observations of these independent cross sections for the period 1997-2016 concerning demographic characteristics and household expenditure by categories, including fuel. [19]

We consider expenditure on electricity and natural gas used in the main residence and we compute energy quantities by considering the energy prices. As the marginal price for the utilities faced by each household are not available, we obtain the physical fuel use by dividing total fuel expenditure at the household level by the annual average block prices (including taxes and other cost components) of electricity and natural gas provided by Eurostat. Additional demographic and economic control variables are included in the survey data. Nominal expenditure (except on electricity and natural gas) are converted to real values using commodity-specific price indexes (base year 2010). Moreover, to consider different demographic compositions, we use the square root of household size as an equivalence scale (as suggested by OECD). Finally, regional weather variables are taken from a Eurostat database.

Cohorts are formed on the basis of the age of the household head. To construct the pseudo-panel for our analysis, we only keep households in which the head is 25-85 years old. This truncation eliminates those below 25, because there are very few household heads so young, and those above 85 to avoid a selectivity problem. The cohorts are defined in five-year brackets, except for the youngest cohort born between 1985 and 1995 and the oldest born between 1920 and 1924. This gives a total of 1220 cells, and it is a reasonable compromise between accuracy (given the homogeneity in unobservable characteristics affecting energy demand linked to the birth year) and statistical significance (Verbeek, 2008). We build different pseudo-panels at the national and at the three macro-area levels (north, centre and south) as territorial differences are significant both in residential energy use and population projections.

4.2 Methodology

Our aim is to investigate how the interplay between demographic long-term trends, age and generational effects can shape future energy demand. Age effects mean ageing-related changes in behaviour and are common to many issues, including consumption choices. Cohort effects reflect a tendency for durable energy consumption attitudes to form early in life, perhaps influenced by the circumstances prevailing when the cohort entered adult life. Individuals – despite their intrinsic differences – from the same birth cohort are marked by cultural or contextual elements that have a specific effect, which can remain features of the cohort throughout its trajectory.

When only considering age effects on consumption, we assume that people from different generations may demand less electricity and more natural gas as they age (Bardazzi and Pazienza, 2017). However, if a cohort effect exists, then, for instance, the members of the millennial generation may start from a higher base level of electricity consumption, because of the use of social media and new music and gaming devices, and continue to demand relatively more electricity at every stage of their lives. In addition to these effects, all households may be affected by macro-shocks that synchronously but temporarily move all generations away from their profiles (period effects). These different effects can be estimated using an age-cohort-period model to distinguish between a pure age effect

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[18] The design of the survey was revised in 2014 when a new HBS replaced the old HBS which was carried out between 1997 and 2013. The data used in this paper are linked between the two types of survey by means of a correspondence analysis of each variable of interest performed by the authors.

[19] From this dataset, extreme and unreliable values of the variables of interest are cleaned through a trimming procedure that excludes observations falling outside the first and last percentiles.

and a cohort effect on energy uses. The empirical findings in Bardazzi and Pazienza (2017) confirm that both the electricity and heating expenditure of Italian families rise with the age of the householder and from the older to younger generations. The results were obtained by modelling energy expenditure as a function of dummy variables for age, cohort and period effects. To solve the well-known problem of multicollinearity between age, period and birth cohort, year effects were constrained to be orthogonal to a time trend and to sum to zero (Deaton and Paxson, 1994). In the present work, we overcome this restriction and pursue a different strategy by introducing further information in our model. Therefore, we use a set of variables as indicators to capture the environment at historical time t, such as energy prices, real income, climatic conditions and some demographic characteristics. Let w_t be the variables that capture the time fixed effects, a the age of the householder and c the birth cohort. The panel model is specified as:

$$y_{i,t} = \alpha + \beta a_i + \delta c_i + \varphi w_{i,t} + \varepsilon_{i,t} \qquad i = 1, \ldots . N \qquad t = 1, \ldots \ldots . T\ , \qquad (1)$$

where $y_{i,t}$ is the fuel consumption of household i at time t. For this model a large panel dataset is needed. As our data consist of repeated cross-sections of household surveys, we build a pseudo-panel that consists of averages of the variable of interest over individual households belonging to each cell defined according to the birth year of the household head at 5-year intervals. Therefore, a cohort is a group of individuals with the same year of birth and their behaviour is followed over time.

Since we apply the model to a pseudo-panel, all the variables must be averaged by cohort c at time t, and the model can be parsimoniously written in matrix form as:

$$y = \alpha + D_a\beta + D_c\delta + W\varphi + \varepsilon\ , \qquad (2)$$

where y is the stacked vector of cohort mean observations, D_a and D_c are the matrices of dummy variables for the age and birth cohort[20] and W is a matrix of time-varying covariates, including fuel prices, household total expenditure in real terms (as a proxy for income), some control characteristics like the householder's educational level and household size, and the climatic conditions of the residential area (numbers of heating and cooling days). When we control for variables that change over time, we want to see the extent to which the life cycle and generational behaviour of variable y is explained by these variables. The β and δ parameters will then capture the age and cohort effects that are not captured by movements in the w variables.

Equation (2) (with various sets of control variables) constitutes the basis for our analysis. In this paper the left-hand side variable is either the logarithm of average consumption of electricity in kilowatt-hours (kWh) or the logarithm of natural gas in cubic metres. As we are interested in exploring the variability of effects on future energy demand at the regional level, we estimate the model at the national level and on three different subsamples of the data for the macro-areas of the northern, central and southern regions of the country. To estimate the model and avoid singularity between age and cohort dummy matrices, we omit the first age group (25 years), and the second

[20] In our case, all the matrices have m rows, which is the number of cohort-year pairs for each commodity. The number of columns is 61 (the number of ages) for matrix D_a and 14 (the number of cohorts) for D_c.

cohort (born 1980-1984). Additional variables include the adult equivalent total expenditure in real terms and fuel prices (all in logs). There is a debate in the literature over the choice of variable to be used for energy price, as is discussed by Alberini and Filippini (2011). The question is whether it is the marginal or the average price to which households respond to when deciding on their energy demand. As our data are cohort averages, we consider that the potential for the average price to be endogenous – as the average price depends on the quantity consumed in the presence of block pricing schemes – is mitigated by the aggregation of many different individual and local pricing levels (Shin, 1985). This assumption is also supported by some empirical findings (Ito, 2014). Moreover, we are more interested in estimating age and cohort coefficients to assess the extent to which they interact with projected demographic changes than in estimating income and price elasticities. Therefore, we do not apply instrumental variable estimation to investigate the endogeneity of prices as in Miller and Alberini (2016). Finally, to consider the effect of climatic conditions on energy demand, we use the log of the numbers of heating and cooling degree days (HDD and CDD) that are available at the regional level.

Table 1 shows the descriptive statistics of the variables used in the estimation at the national level. When the variables are available at the regional level, the statistics for the macro-areas are presented below the national values. As is shown in Figures 4 and 5, the average consumption of electricity increases going from the north to the south while the opposite is observed for natural gas. This is partially explained by the heating and cooling days (at the bottom of Table 1) and by the geographical heterogeneity in real income (proxied by total expenditure), which is on average almost 20 per cent lower in southern Italy than at the national level. Regarding some socio-demographic characteristics considered in our model, the south is also characterized by larger household sizes and a lower educational level of householders.

In sum, we estimate two log-log demand models – for electricity and natural gas consumption – using the national and the regional pseudo-panels. Then, the estimated age and cohort coefficients for the macro-areas are used to project the future consumption of electricity and natural gas in conjunction with population projections by age and region.

Table 1 – Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Electricity average adult equivalent consumption (kWh)	1422.004	214.751	859.871	1813.953
North	*1358.951*	*209.223*	*558.332*	*1952.428*
Centre	*1440.353*	*243.791*	*722.494*	*2041.141*
South	*1480.200*	*253.690*	*340.611*	*2117.634*
Natural gas adult equivalent consumption (cubic metres)	546.464	95.281	295.104	764.998
North	*579.029*	*120.726*	*77.956*	*1860.621*
Centre	*562.475*	*138.231*	*0*	*1464.935*
South	*284.487*	*79.496*	*0*	*788.811*
Average adult equivalent total expenditure (2010 euros)	16437.523	1.132	11289.801	20555.833
North	*19025.719*	*1.148*	*10170.615*	*65336.100*
Centre	*17678.544*	*1.155*	*8291.391*	*38934.265*

South	*13187.847*	*1.146*	*6675.471*	*45652.790*
Average household size	2.455	0.567	1	3.701
North	*2.262*	*0.523*	*1*	*3.487*
Centre	*2.333*	*0.544*	*1*	*3.735*
South	*2.558*	*0.696*	*1*	*4.010*
Average educational level (0=no education; 5=PhD)	0.152	0.170	0	0.841
North	*0.145*	*0.160*	*0*	*0.811*
Centre	*0.151*	*0.157*	*0*	*0.828*
South	*0.139*	*0.179*	*0*	*0.876*
Average price of natural gas per cubic meter (euros)	0.732	0.150	0.555	1.000
Average price of electricity per kWh (euros)	0.213	0.016	0.193	0.244
Heating degree days (HDD)	2007	121	1735	2262
North	*2901*	*152*	*2561*	*3212*
Centre	*1800*	*133*	*1523*	*2067*
South	*1318*	*101*	*1098*	*1531*
Cooling degree days (CDD)	191	64	103	378
North	*107*	*45*	*45*	*248*
Centre	*186*	*80*	*70*	*418*
South	*282*	*71*	*178*	*467*

4.3 Estimation results

The estimation results of our model are shown in Tables 2 and 3 and in Figure 6.[21] The parameters of the variables *W* in model [2] are shown in the tables with each column referring to a specific geographical aggregation. All the coefficients have the expected sign and are statistically significant with few exceptions. The price elasticity is negative but below 1 in absolute value both for electricity and natural gas demand and it presents different values at the regional level. In general, households living in central and southern Italy react more than northern families to changes in energy prices. For electricity, compared to the value for the north (-0.525) the demand in the centre is almost 60 per cent more elastic and in the south the difference is more than 2/3. This heterogeneity in price elasticity is also estimated for the natural gas model. In this case the central area shows the highest parameter (-0.8) while northern households decrease their demand by half a percentage point for a 1 per cent increase in the natural gas price. Our price elasticities are larger than those estimated for residential electricity demand in Italy by Haas and Schipper (1998) for the period 1985-1993 (-0.06) and, more recently, by Dicembrino and Trovato (2013) on monthly data for the period 2000-2012 (-0.013). This result could be explained by the general evidence in the literature about differences in estimated elasticities based on aggregate time-series data, on cross-sections and on panel data, where the first two of these tend to be biased downwards (Labandeira et al., 2017). However, our estimates are within the range of values estimated by Espey and Espey (2004) in their meta-analysis of studies on residential electricity demand and higher than the average values for electricity and natural gas estimated by Labandeira et al. (2017).

[21] The complete results for Italy are shown in the Appendix.

The income elasticities for both fuels are positive but lower than 1. The residential natural gas demand is twice more elastic than the electricity demand and both show high geographical heterogeneity: income elasticities in the southern region are half the national average. The per-capita equivalent energy consumption is characterized by economies of scale and decreases as the household size increases. A high educational level of the householder is associated with a lower level of energy consumption, especially for heating, as has already been estimated by Bardazzi and Pazienza (2017) for Italian households with a probit model. Finally, cooling degree days are significant in increasing electricity consumption but they are not included in the model for natural gas because its use is for heating and cooking, which are not influenced by hot weather conditions. On the other hand, electricity is used for both air conditioning and, especially in the south, for heating. Therefore, its consumption is sensitive to both extreme climatic conditions.

Table 2 – Estimation results: Electricity (Control variables)

	Italy	North	Centre	South
Total expenditure (log)	0.274***	0.456***	0.389***	0.151***
	(0.052)	*(0.049)*	*(0.043)*	*(0.037)*
Electricity price (log)	-0.705***	-0.525***	-0.819***	-0.882***
	(0.037)	*(0.040)*	*(0.042)*	*(0.047)*
Household size	-0.133***	-0.097***	-0.063***	-0.185***
	(0.031)	*(0.030)*	*(0.023)*	*(0.022)*
Educational level	-0.133***	-0.121***	-0.070***	-0.203***
	(0.020)	*(0.020)*	*(0.023)*	*(0.025)*
Cooling Degree Days	0.069***	0.056***	0.059***	0.085***
	(0.007)	*(0.006)*	*(0.007)*	*(0.013)*
Heating Degree Days	0.114**	0.031	0.003	0.246***
	(0.045)	*(0.054)*	*(0.040)*	*(0.048)*
Constant	2.467***	1.512**	1.973***	2.628***
	(0.562)	*(0.600)*	*(0.469)*	*(0.495)*
R^2	0.82	0.80	0.78	0.74
N	1,220	1,220	1,220	1,220

* *p*<0.1; ** *p*<0.05; *** *p*<0.01

Table 3 – Estimation results: Natural Gas (Control variables)

	Italy	North	Centre	South
Total expenditure (log)	0.537***	0.657***	0.747***	0.250***
	(0.081)	*(0.089)*	*(0.078)*	*(0.065)*
Natural gas price (log)	-0.621***	-0.538***	-0.800***	-0.758***
	(0.042)	*(0.051)*	*(0.056)*	*(0.058)*
Household size	-0.072*	-0.122**	0.003	-0.097***
	(0.041)	*(0.051)*	*(0.040)*	*(0.037)*
Educational level	-0.338***	-0.414***	-0.500***	-0.215***
	(0.026)	*(0.034)*	*(0.038)*	*(0.036)*
Heating Degree Days	0.816***	0.995***	0.614***	0.871***
	(0.060)	*(0.089)*	*(0.067)*	*(0.076)*
Constant	-5.325***	-8.145***	-6.040***	-2.587***
	(0.920)	*(1.134)*	*(0.859)*	*(0.880)*
R^2	0.67	0.56	0.59	0.50
N	1,220	1,220	1,220	1,220

* *p*<0.1; ** *p*<0.05; *** *p*<0.01

The most important result for our further empirical analysis is from the estimation of age and cohort effects. For both fuels the age and cohort effects show similar patterns but the geographical variation is much larger for natural gas (Figure 8) than for electricity (Figure 7). For the latter, the age effects show an increasing pattern which for the national sample ranges between zero at the age of 25 and 1.51 at the age of 85, so that the consumption of electricity increases, on average, by about 2.5 per cent per year of age. Conversely, the cohort effects are lower for the younger generations compared to householders born in the 1920s, who show the maximum absolute value (-1.65). The average rate of change is about 12 per cent for each five-year cohort. As the model is log linear, the coefficients must be transformed to be interpreted with respect to the reference age class (25) and cohort (born in 1985-1995). For example, in the case of electricity, a householder aged 80 consumes almost three times more than a 30-year-old but, at the same time, younger householders – such as those born in the late 1980s consume 80 per cent more than individuals born in the early 1920s.

Figure 7 – Electricity: estimated age and cohort effects

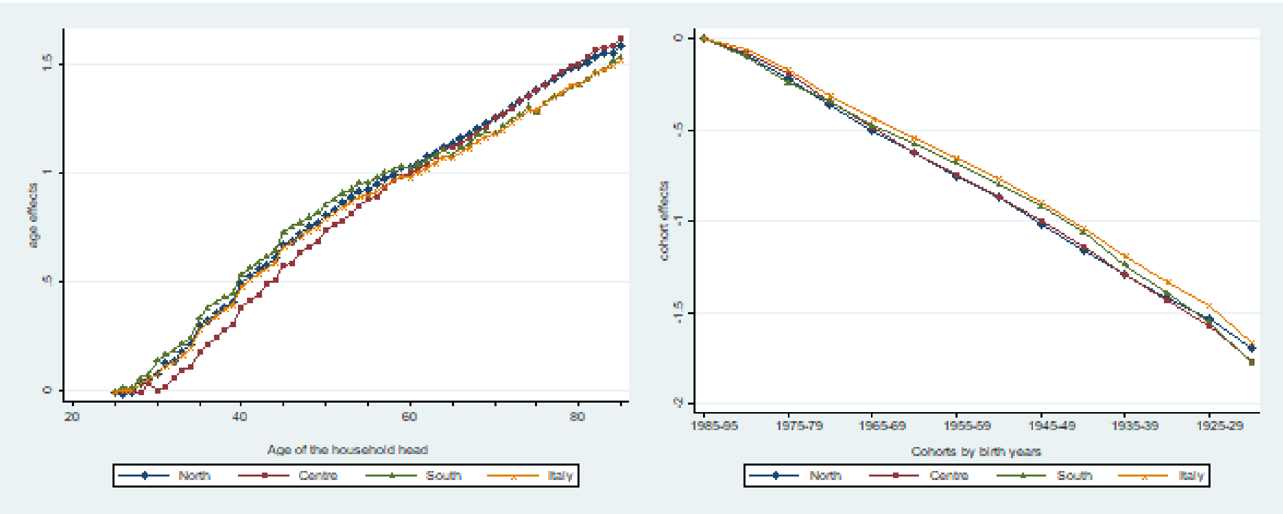
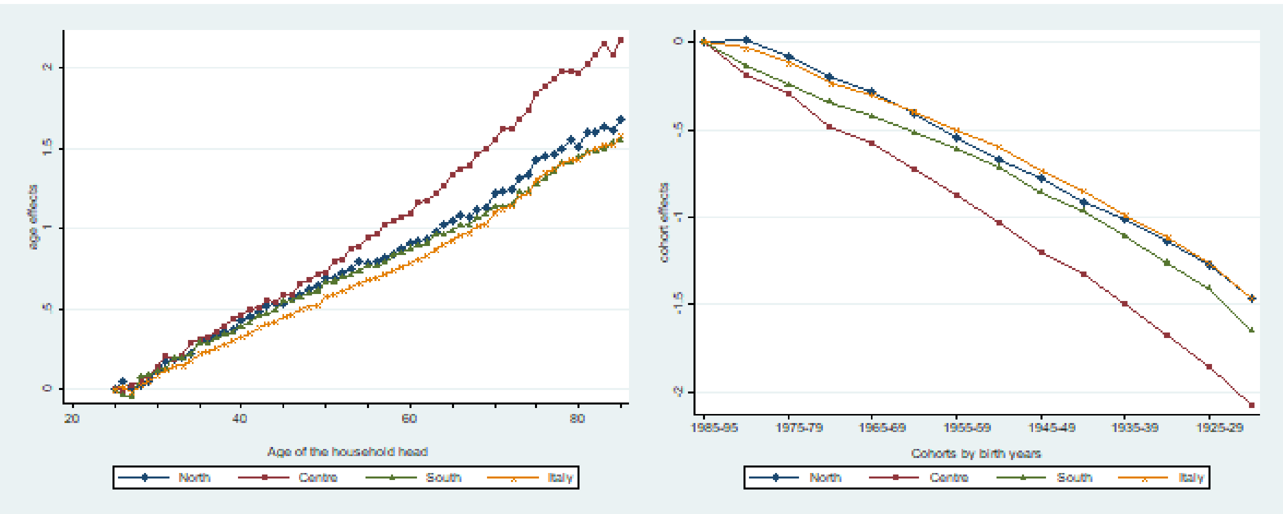


Figure 8 – Natural gas: estimated age and cohort effects



Our results on age and cohort effects by geographical area confirm the empirical findings in Bardazzi and Pazienza (2017). Notwithstanding the use of energy quantities instead of expenditure and the more sophisticated specification of model (2) that includes several additional determinants to explain household consumption behaviour, for all the Italian macro-regions both the electricity and heating use of Italian families rise with the age of the householder and from older to younger generations. Therefore, these age and generational profiles will interplay with projected demographic changes to affect future energy consumption.

5. Projecting residential energy use and CO_2 emissions

We take advantage of the estimated age and cohort coefficients to investigate how ageing and generational cultures interact with demographic trends to shape future emissions resulting from residential energy use. As Bussolo et al. (2017) stress, these kinds of projections should be considered mere accounting projections as no further behavioural adjustment – besides population and CO_2 intensity trends – is considered. The analysis uses official ISTAT population projections up to 2050 as discussed in section 3. The ISTAT projections only forecast population by age and do not provide any data or hypothesis on household numbers or average household composition. Therefore, as a first step we compute the incidence of householders among adults for each age in 2016 as the vector α_{j,a,t°:

$$\alpha_{j,a,t^\circ} = \left(\frac{HH_{j,a,t^\circ}}{Pop_{j,a,t^\circ}}\right) \qquad j = 1, \dots 3 \quad \text{a} = \cdots \quad , \qquad (3)$$

where j stands for the three Italian macro-areas, a is age and t° is the last year in the dataset (2016).

We then use these ratios to compute the HH matrix of projected households by age classes and area, starting with the projected population, as shown in the following equation:

$$HH_{j,a,t^\circ+i} = \alpha_{j,a,t^\circ} * Pop_{j,a,t^\circ+i} \qquad i = 1, \dots 34, \;\; j = 1, \dots, 3 \;\; , \qquad (4)$$

where the matrices HHj contain the number of householders (families) by age class for each of the 34 years of the projected period. It is evident that this is a very strong simplifying assumption because marital and divorce propensities by age are frozen at 2016, the last year of our dataset.

Our calculation of projected residential energy use considers both expected population variations and changes in the average energy use of the pseudo-panel observation units. Starting with the energy use observed in 2016 by age and area, we project the average quantity for each household unit by considering how the age and cohort effects will affect the last observed data on energy use, $q_{j,\,a^\circ+i,t^\circ}$, year by year.[22]

In the case of cohorts with householders at least 25 years old in 2016, that is householders born before 1992, the projected average quantity q in area j can be sketched as:

$$q_{j,C^\circ-x,t^\circ+i} = q_{j,a^\circ+j,t^\circ} * (1 + \gamma_{j,C^\circ-x,t^\circ+i}) \qquad for \;\; 0 \le x \le 59 \, , \qquad (5)$$

where C°-x represents the cohort (birth year) and x is an index of all the birth years ranging between 1931 and 1991 ($0 \le x \le 59$).[23] γ is a vector of coefficients representing the age effect, which modifies the average energy used

[22] a° stands for an age of 25 years and C°, used in the following equation, represents the birth year 1991, the youngest householder in 2016.

[23] In this case, that is for householders at least 25 years old in 2016, $0 \le x \le 59$. Therefore C°-0=1991 and C°-59=1931.

each year by householders living in area j in the projected timespan (t°+i, i.e. 2017-2050, $1 \leq i \leq 34$).[24] Indeed, the age effect γ shows the effect on the energy used in t°+i by an average household whose householder was born in year C°-x. As an example, in the projected timespan i=4, so that 2016+4= 2020, a householder born in year x=41, thus 1991-41=1950, should be 70 years old in 2020, and then we consider the difference between the average energy use of a 66-year-old (1950 cohort in 2016) and the average quantity used by a 70-year-old householder (1950 cohort in 2020). The vector γ is built from the estimated age coefficients shown in the Appendix[25].
For the projected householders – those born after 1991 - we can also add a cohort effect (δ) as follows:

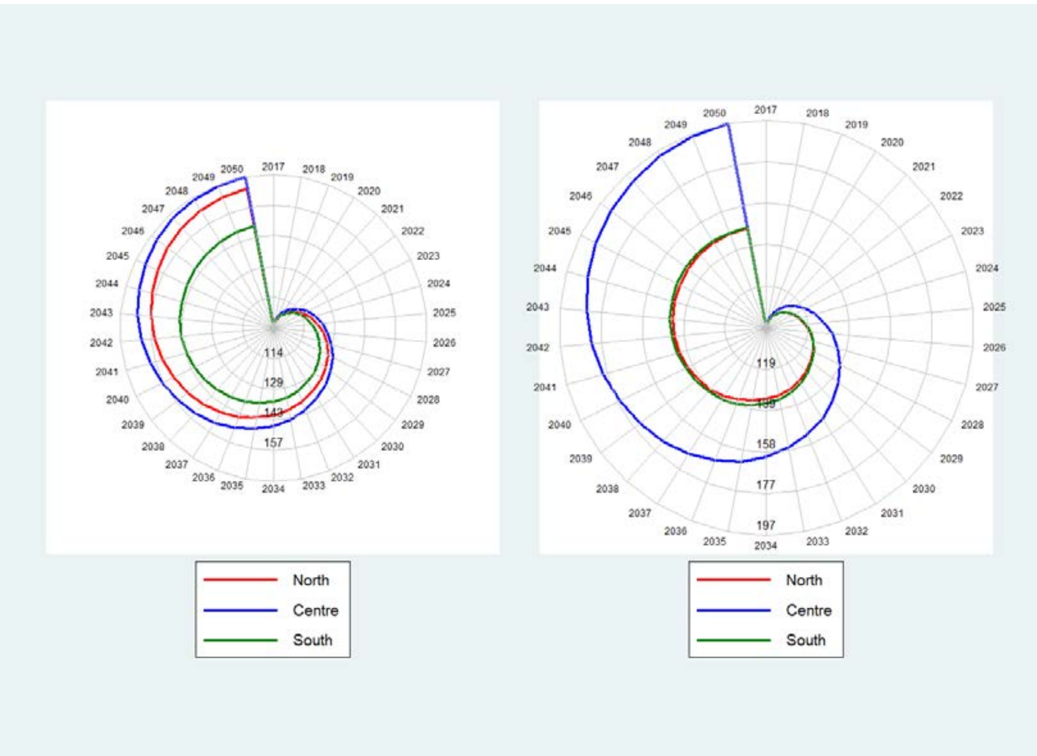
$$q_{j,C^\circ-x,t^\circ+i} = \left[q_{j,a^\circ+i,t^\circ} * (1+\delta_j)\right] * \left(1+\gamma_{j,C^\circ-x,t^\circ+i}\right) \qquad for -34 \leq x < 0\,, \tag{6}$$

where δ_j are the coefficients of the cohort effects in equation (2) for the last generation. In this case, x=-2 means birth year C°-x equals 1993 and x=-34 corresponds to birth year 2025 for a householder 25 years old in the last year of our time span (2050).
Overall energy use is therefore obtained by considering the estimated household average energy use by age in each year (or, equivalently, by cohort in each year) and the householder distribution by age HHj in the projected timespan:

$$q^{tot}_{j,C^\circ-x,t^\circ+i} = q_{j,C^\circ-x,t^\circ+i} * HH_{j,a,t^\circ+i}\,. \tag{7}$$

Figure 9 shows the resulting residential energy demand for electricity (left-hand panel) and natural gas (right-hand panel).

Figure 9 - Residential electricity and natural gas demand projections by area (index 2017=100).



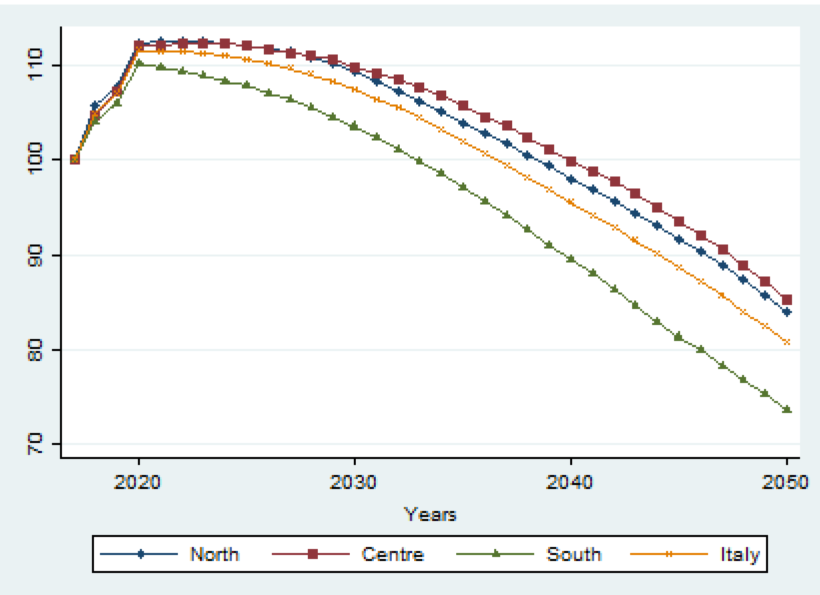
[24] It is worth stressing that when considering both cohort (C°-x) and years (t°+i) the householder's age is univocally identified.
[25] The appendix shows estimated coefficients for Italy. Coefficients estimated at the macro-area level used in the paper are available from the authors upon request.

The two graphs show how the projected demographic changes interact with energy demand in the next decades. As discussed in section 3, the Italian population size is projected to significantly drop by 2050 (by 2 million inhabitants) and both the age composition and the geographical distribution will considerably shift. The two graphs show that the estimated increasing age effects and decreasing cohort effects (meaning that newer generations tend to adapt their demand more to thermal comfort standards and to new electric appliances) overtake the population decrease effect and therefore energy demand is projected to increase by 2050. However, marked differences in regional patterns are evident: in the southern areas both electricity and natural gas demand increase moderately, whereas in the other areas population size and population ageing push the residential energy demand up, confirming the key role of internal migration. More specifically, in the northern regions the total population increases and the newer generations are relatively more present, whereas in the central regions the population is stable but the ageing effect dominates, therefore pushing up heating demand. It is very important to stress that Figure 9 gives evidence on the interaction between pure population effects and the age and cohort components in residential energy demand and does not consider other variables such as income levels, income distribution by age and cohort, temperature and climate variations or energy efficiency trends.

In order to have some hint on the potential role of other variables, we also consider the $C0_2$ impact of residential energy demand. It is evident that converting household energy demand into emissions has a very different meaning for the two energy products due to the diverging trends in and expectations of carbon intensity for electricity and natural gas discussed in section 3.3.

Figure 10 shows that on average CO_2 emissions resulting from residential electricity use are projected to be above the level of the starting year until 2033 and then decrease thereafter. Indeed, in the next few years the total population is relatively stable and the cohort effect, combined with age structure, leads to an increase in both energy use and $C0_2$ emissions. Then, the cumulative reduction in carbon intensity[26] dominates and leads to a decrease in total emissions resulting from electricity used for residential purposes.

Figure 10 – Projection of CO_2 emissions from residential electricity use. Scenario with age/cohort effects and 2.4% yearly carbon intensity reduction hypothesis



[26] As a central hypothesis, we consider the average rate of carbon intensity reduction between 2000 and 2017.

This result also mirrors the effect of internal migration from the southern regions to the northern area of the country as the carbon intensity reduction hypothesis is homogenous across all areas. Although the average household electricity use in the southern regions is currently higher than in the north, at the end of the period electricity demand and therefore CO_2 emissions will be much lower in the centre and the south. This is due to the combination of integral migration and the fertility differential, which leads to a differentiated geographical age structure of the population.

CO_2 emissions from residential natural gas (not shown in the paper) almost completely reflect the projected trend in energy use, as only a negligible decrease in carbon intensity for natural gas can be found in recent years. In this case, we observe a 50% increase in total emissions at the end of the period, mostly due to the ageing population in the central area, which pushes natural gas use up. Indeed, the estimated coefficients for natural gas age effects are stronger than in the electricity case, so the impact of the ageing population overtakes the effect of new generations moving towards the northern regions.

6. Sensitivity analysis

Our simulations are based on several simplifying assumptions concerning the stability of age and cohort effects, the population projections and the future state of technology. Here we test the sensitivity of the estimated age and cohort effects and the influence of the implicit assumptions embedded in the official population projections. In the period covered by our analysis, household income in Italy has experienced a deterioration in real terms but different population subgroups have been unevenly affected by this trend. In particular, the recent economic crisis has contributed to modifying the relative position of different cohorts of households, with younger generations performing worse than older ones. This increasing impoverishment of the young is due to the joint occurrence of various factors besides the poor performance of the economy, such as the institutions in the labour market, pension reforms and the tax benefit system (Brandolini et al., 2018). Therefore, one could question whether the cohort and age effects estimated in our analysis also capture a change in income distribution across different generations in recent decades. In order to test whether our results are robust we build several pseudo-panels according to the quartile of total equivalent expenditure (as a proxy for income). Then we estimate model (2) by income quartile and compare the estimated coefficients. We focus our attention on the age and cohort effects that have been used to project the electricity and natural gas demands (Figures 11 and 12). Overall, both sets of coefficients show a lower dispersion by income quartile in the case of electricity use than in natural gas use, and the age and cohort profiles are steeper for households in the first half of the income distribution. These descriptive insights are quantified in Table 4. On average, the consumption of electricity increases by about 2 per cent per year of age and by 11 per cent per five-year cohort for the first two quartiles, while the rates of change slow down for the richer householders characterised by higher average energy expenditure. The same evidence characterizes the use of natural gas. However, in the case of electricity there is almost no difference between quartiles for young householders up to the age of 50 and for generations born between 1975 and 1995. For natural gas, the age and cohort effects by quartile are not statistically different from the reference category for householders younger than 40 and for cohorts born later than 1960. These findings confirm that our general results are robust with respect to the relative position of households in the income distribution. In particular, although younger generations have suffered the most from the poor performance of the economy, they are affected by experiences and possess cultural values that determine similar energy consumption behaviour across all quartiles.

Figure 11 – Age and cohort effects by income quartile – Electricity

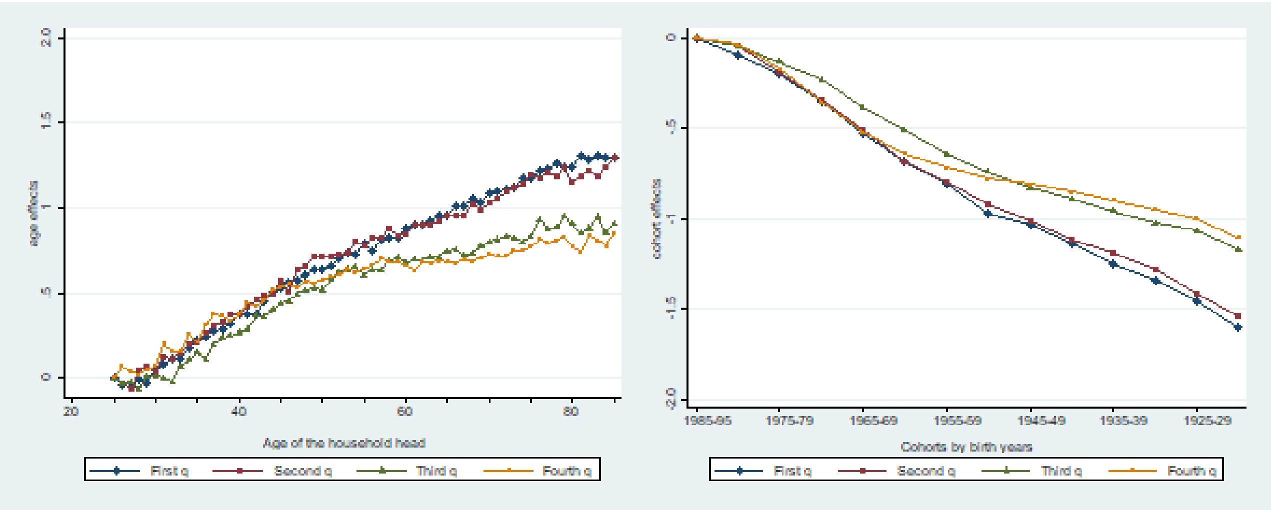


Figure 12 – Age and cohort effects by income quartile – Natural gas

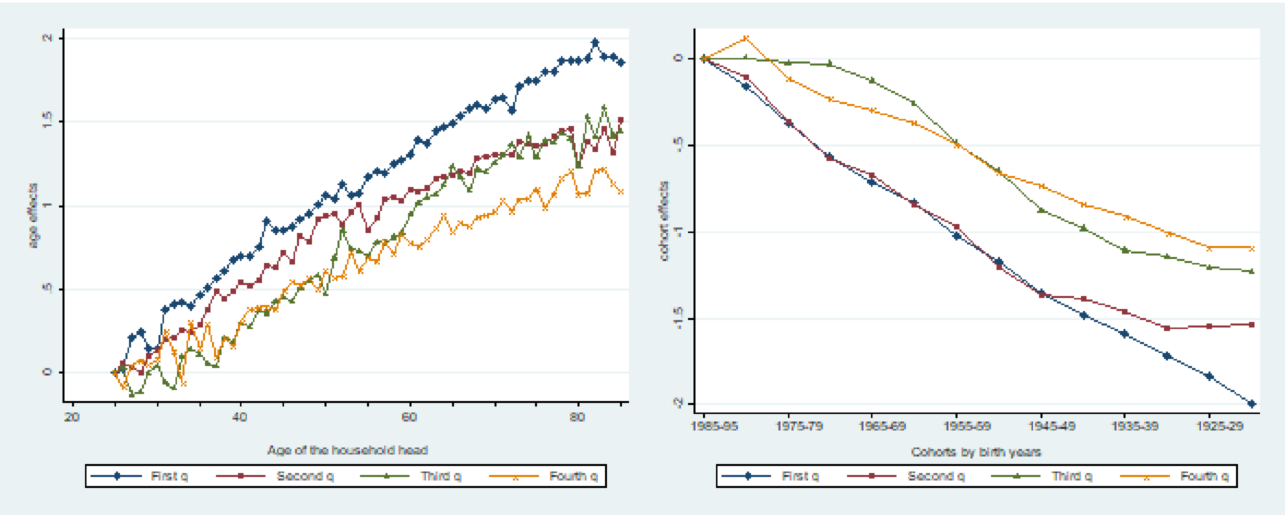
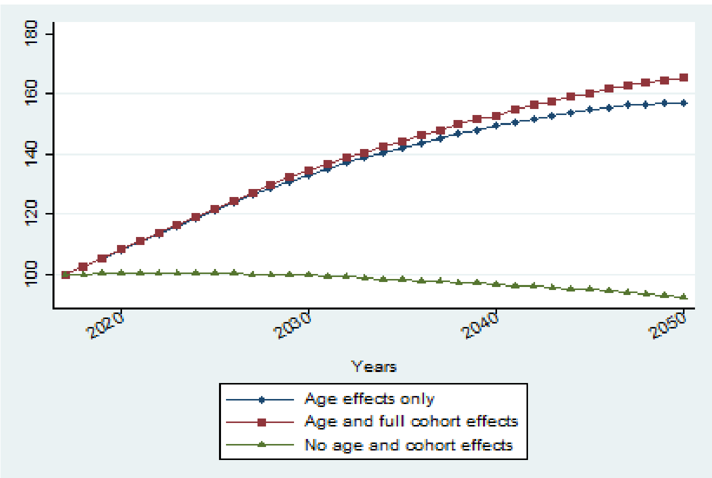


Table 4 - Estimated demographic effects and average expenditure by quartile

Income quartile	Age effects: Annual average change	Cohort effects Annual average change per cohort	Annual average equivalent expenditure (euros)
		Electricity	
Q1	2.1%	-11.4%	278
Q2	2.1%	-11.0%	301
Q3	1.5%	-8.4%	322
Q4	1.4%	-7.9%	359
		Natural Gas	
Q1	3.0%	-14.3%	227
Q2	2.4%	-11.0%	347
Q3	2.3%	-8.8%	423
Q4	1.7%	-7.8%	498

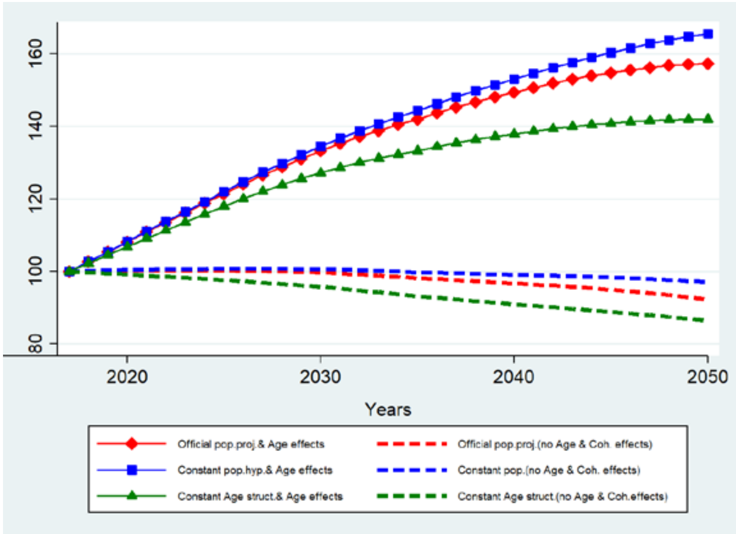
The projections of residential energy demand discussed in the previous paragraph are based on the estimated cohort and age effects and the population dynamics embedded in the official ISTAT forecast. Figure 13 shows – for electricity demand – the role of the estimated coefficients: the bottom green line shows projected electricity demand without any age or cohort effects: due to the projected decrease in the Italian population size, energy demand would decrease by 7% if no age and cohort effect were taken into account. The blue line considers the age effect and shows a remarkable increase (slightly more than 55%) in electricity demand by 2050, whereas the red line shows the case in which the full age and cohort effects are considered.

Figure 13– The role of age and cohort effects in the projected residential electricity demand



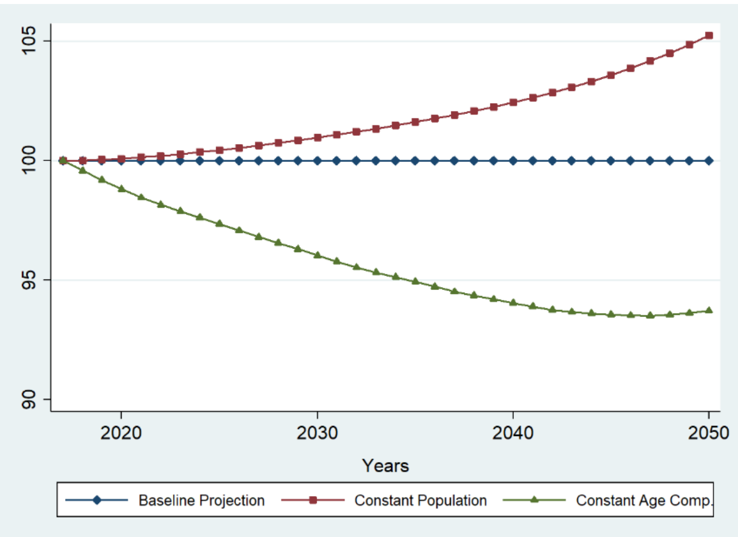
As underlined, the ISTAT median scenario considers a decrease in the Italian population size and a remarkable ageing component. To appraise their respective roles, Figure 14 disentangles the size effect and the ageing effect in our electricity projection. The two blue lines show electricity demand based on the official population projection: the bottom line excludes the age effect whereas the upper line includes it. The pairs of red and green lines consider the population size effect and the age structure effects. In detail, the red lines consider how the electricity projection would change if the population size were not decreasing: with a constant population size, even considering the ageing effect both red lines lie above the blue lines, meaning that the size effect prevails over the age structure one. On the contrary, the pair of green lines show the effect on the electricity demand projection considering an age structure frozen at 2017: the smaller share of elderly people at the end of the period combined with the decreasing population size would cause a much smaller increase in electricity demand (solid green line) or a noticeable decrease if age effects are excluded from the analysis (bottom green line).

Figure 14 – Residential electricity demand projections according to different hypotheses



To stress the point, Figure 15 highlights the role of two separate factors in the ISTAT official projection: a shrinking population size and an increasing share of elderly people (ongoing ageing). Considering the official ISTAT projection as baseline, the red line shows that keeping the population size constant (that is, freezing the population at 60 million) would result in 5% additional electricity demand in 2050. Conversely, freezing the population ageing (that is, keeping the share of the elderly constant at the 2016 level and letting the population size decrease) would result in a 6.7% decrease in electricity demand by 2050 (green line in Figure 15).

Figure 15 – Residential electricity demand projections according to different hypotheses



Concluding remarks

Energy transition and the ageing population will be among the most pressing challenges in future decades and the public policies implemented to tackle these issues seem, so far, unable to change current trends. These issues are particularly problematic for Italy, which is still characterized by high energy dependency, a slow electrification transition and a rapidly ageing and declining population. This paper has considered the interplay between the change in the population (both the size and age structures are relevant) and energy use, trying to disentangle the separate impacts of ageing and generational effects (so-called *energy cultures)* in shaping energy consumption behaviour. Indeed, empirical studies have confirmed the relevance of both age and cohort-related effects in energy use (Bardazzi and Pazienza, 2017; Chancel, 2014) and therefore it can be argued that the future pattern of energy consumption and emissions will be affected by the change in the population structure and overlapping energy cultures. Using a pseudo-panel built on the Italian Household Budget Surveys, we first estimated household residential energy demand at the regional level and then used our results to forecast total energy consumption based on demographic projections. In the estimation results, we found that demographic characteristics (age and cohort effects), price and income elasticities and general weather conditions are all significant and markedly area-specific. By combining the estimated age and cohort effects with official population projections – which include ageing, a decreasing population size and external and internal migrations – our results show that ageing and generational effects dominate the population reduction effect so that, assuming constant energy intensity technology, both electricity and natural gas demand will increase in the next decades. Considering the recent trends in carbon intensity, we estimated a decrease in total CO_2 emissions derived from residential electricity use and constant emissions from natural gas use. It is important to stress that our results come from a *ceteris paribus* projection. Like Bussolo et al. (2017), we are interested in focusing on and assessing the extent to which projected demographic changes have the potential to affect future energy consumption. To gain more hints we also performed a sensitivity analysis to consider both the role of income distribution and of population-related hypotheses. Our analysis showed that the sign and the magnitude of age and cohort effects are robust with respect to the relative position of households in the income distribution, but these effects are flatter for the last two quartiles. The estimated age and cohort effects play a significant role in the energy demand projection: a sensitivity analysis showed that without these demographic components the dimensional effect would dominate and the total projected demand would decrease at the end of the period.

Summing up, our findings show that population dynamics and energy consumption habits across different generations should be considered important determinants of future energy demand and taken into account when energy saving policies are designed. The projected increase in energy demand calls for public policies to intervene in the desired direction: carbon policies, in particular, can alter energy prices and activate price elasticities, whereas technology can modify energy intensity and carbon intensity. However, policy design should also take into account different generational approaches and nudge increasing awareness and energy-saving attitudes.

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Appendix

Estimation results for Italy

	Electricity	Natural gas
Total expenditure (log)	0.274***	0.537***
	(0.052)	*(0.081)*
Electricity price (log)	-0.705***	-0.621***
	(0.037)	*(0.042)*
Household size	-0.133***	-0.072*
	(0.031)	*(0.041)*
Educational level	-0.133***	-0.338***
	(0.020)	*(0.026)*
Cooling Degree Days	0.069***	
	(0.007)	
Heating Degree Days	0.114**	0.816***
	(0.045)	*(0.060)*
age== 26	0.002	0.019
	(0.023)	*(0.031)*
age== 27	0.003	-0.019
	(0.023)	*(0.031)*
age== 28	0.040*	0.029
	(0.023)	*(0.031)*
age== 29	0.056**	0.053*
	(0.023)	*(0.031)*
age== 30	0.085***	0.087**
	(0.026)	*(0.035)*
age== 31	0.120***	0.118***
	(0.026)	*(0.036)*
age== 32	0.134***	0.140***
	(0.027)	*(0.037)*
age== 33	0.168***	0.147***
	(0.027)	*(0.037)*
age== 34	0.198***	0.173***
	(0.027)	*(0.038)*
age== 35	0.283***	0.224***
	(0.033)	*(0.046)*
age== 36	0.317***	0.238***
	(0.034)	*(0.046)*
age== 37	0.347***	0.257***
	(0.034)	*(0.047)*
age== 38	0.374***	0.284***
	(0.034)	*(0.047)*
age== 39	0.398***	0.301***
	(0.034)	*(0.047)*
age== 40	0.479***	0.327***
	(0.038)	*(0.053)*
age== 41	0.510***	0.354***
	(0.038)	*(0.053)*
age== 42	0.543***	0.385***
	(0.038)	*(0.053)*
age== 43	0.565***	0.407***
	(0.038)	*(0.053)*
age== 44	0.594***	0.416***
	(0.038)	*(0.053)*
age== 45	0.663***	0.454***
	(0.038)	*(0.054)*
age== 46	0.680***	0.465***
	(0.038)	*(0.054)*
age== 47	0.711***	0.495***
	(0.038)	*(0.054)*
age== 48	0.736***	0.514***

		(0.037)	*(0.053)*
age==	49	0.755***	0.526***
		(0.037)	*(0.053)*
age==	50	0.794***	0.576***
		(0.035)	*(0.052)*
age==	51	0.821***	0.590***
		(0.035)	*(0.052)*
age==	52	0.847***	0.614***
		(0.035)	*(0.052)*
age==	53	0.869***	0.633***
		(0.035)	*(0.052)*
age==	54	0.897***	0.658***
		(0.035)	*(0.052)*
age==	55	0.904***	0.678***
		(0.032)	*(0.049)*
age==	56	0.924***	0.692***
		(0.032)	*(0.049)*
age==	57	0.949***	0.720***
		(0.032)	*(0.050)*
age==	58	0.970***	0.740***
		(0.033)	*(0.050)*
age==	59	0.992***	0.766***
		(0.033)	*(0.051)*
age==	60	0.986***	0.786***
		(0.034)	*(0.051)*
age==	61	1.006***	0.808***
		(0.035)	*(0.053)*
age==	62	1.029***	0.829***
		(0.035)	*(0.054)*
age==	63	1.054***	0.872***
		(0.036)	*(0.055)*
age==	64	1.080***	0.903***
		(0.037)	*(0.056)*
age==	65	1.073***	0.928***
		(0.040)	*(0.059)*
age==	66	1.101***	0.959***
		(0.041)	*(0.060)*
age==	67	1.122***	0.977***
		(0.041)	*(0.061)*
age==	68	1.150***	1.012***
		(0.042)	*(0.062)*
age==	69	1.173***	1.031***
		(0.042)	*(0.063)*
age==	70	1.184***	1.102***
		(0.047)	*(0.067)*
age==	71	1.205***	1.124***
		(0.047)	*(0.068)*
age==	72	1.236***	1.146***
		(0.048)	*(0.069)*
age==	73	1.263***	1.197***
		(0.048)	*(0.070)*
age==	74	1.294***	1.226***
		(0.049)	*(0.071)*
age==	75	1.295***	1.306***
		(0.055)	*(0.077)*
age==	76	1.330***	1.346***
		(0.055)	*(0.077)*
age==	77	1.354***	1.376***
		(0.055)	*(0.078)*
age==	78	1.376***	1.403***
		(0.056)	*(0.079)*
age==	79	1.408***	1.427***
		(0.056)	*(0.079)*

age== 80	1.414***	1.430***
	(0.056)	*(0.080)*
age== 81	1.438***	1.476***
	(0.057)	*(0.081)*
age== 82	1.469***	1.495***
	(0.057)	*(0.081)*
age== 83	1.483***	1.524***
	(0.057)	*(0.082)*
age== 84	1.495***	1.522***
	(0.058)	*(0.082)*
age== 85	1.524***	1.575***
	(0.058)	*(0.083)*
cohort 1980-84	-0.068***	-0.034
	(0.018)	*(0.025)*
cohort 1975-79	-0.178***	-0.118***
	(0.020)	*(0.027)*
cohort 1970-74	-0.318***	-0.234***
	(0.022)	*(0.030)*
cohort 1965-69	-0.444***	-0.306***
	(0.025)	*(0.035)*
cohort 1960-64	-0.554***	-0.402***
	(0.029)	*(0.041)*
cohort 1955-59	-0.663***	-0.500***
	(0.034)	*(0.048)*
cohort 1950-54	-0.775***	-0.602***
	(0.039)	*(0.055)*
cohort 1945-49	-0.908***	-0.734***
	(0.043)	*(0.060)*
cohort 1940-44	-1.050***	-0.853***
	(0.045)	*(0.065)*
cohort 1935-39	-1.200***	-0.987***
	(0.046)	*(0.068)*
cohort 1930-34	-1.338***	-1.118***
	(0.047)	*(0.072)*
cohort 1925-29	-1.474***	-1.259***
	(0.048)	*(0.077)*
cohort 1920-24	-1.672***	-1.466***
	(0.049)	*(0.082)*
Constant	2.467***	-5.325***
	(0.562)	*(0.920)*
R^2	0.82	0.67
N	1,220	1,220