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Responsiveness of Residential Natural Gas Demand to Elderly, Urban Population and Density: Evidence from Organization for Economic Co-operation and Development Countries

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ABSTRACT

This paper empirically examines per capita residential natural gas demand using annual data for 29 Organization for Economic Co-operation and Development (OECD) countries from 2005 to 2016. Earlier studies have focused on the effect of price and income to estimate natural gas demand elasticities, but most of them have neglected the demographic variables such as elderly population, population density and urbanization rate. The aim of this work is to include these attributes for modeling the demand function of natural gas. To address the problem of endogeneity, we use a dynamic panel system called Generalized Method of Moments estimator. Our study presents the following main results; First, the increase of the urbanization rate leads to more per capita consumption of natural gas in the residential sector. Second, the ageing of the population decreases the use of per capita residential natural gas in OECD countries. Third, as population density increases, per capita residential natural gas consumption decreases.

Keywords: Residential Gas Demand, Generalized Method of Moments, Population Characteristics and Consumption
JEL Classifications: Q31, Q41, Q43

1. INTRODUCTION

Organization for Economic Co-operation and Development (OECD) countries have faced decades of multiple challenge of rapidly ageing societies and declining fertility rates. On average, the proportion of the elderly population (people aged over 65 years) increased from less than 9% in 1960 to 17% in 2015, and is expected to continue to grow, going up to 28% in 2050 (see Health at a Glance 2017).

Furthermore, most OECD countries have been facing the challenge of predominantly urban population since 1970. Urbanization is higher in OECD countries, particularly in Australia, Korea, Chile, France and Japan, and the phenomenon is expected to grow steadily (see Trends in Urbanization and Urban Policies in OECD countries).

Because demographic changes raise important distributional questions, and are expected to have considerable economic implications, it is very important for OECD countries to take into account these characteristics.

Indeed, the versatility of natural gas, low price and the lower amount of greenhouse emissions from its combustion compared to coal and oil, have pushed natural gas demand to grow significantly, and gainned share in all sectors, especially in the residential one. In the OECD countries, residential demand for natural gas has increased steadily over time. As shown in Figure 1, the total has moved from about 8 million terajoules (TJ) in 1980 to more than 11 million TJ in 2016. Moreover, in order to understand the individual trend of per capita residential natural gas consumption considered as our dependent variable, during our period of study (2005-2016), we plotted per capita natural gas demand in a time-series graph for each country in Figure 2 and note that each country has its own specific trend.

These two figures help us to understand the evolution of the aggregate as well as per capita individual demand for natural gas in the residential sector over time which is useful for econometric purposes.

In fact, formulating natural gas policies and corporate strategies for investors in natural gas residential sector, depends on understanding the multiple determinants of residential consumption for natural gas and thus estimating appropriately the demand equation. The literature has focused on the effect of the price and income to estimate residential natural gas demand. Most of these studies have used either static or dynamic models or both to stimulate the behavior of natural gas consumption. However, the demographic factors were often neglected.

Looking at the past energy research (Al-Sahlawi, 1989; Alberini et al., 2011; Dagher, 2012; Ozturk and Al-mulali, 2015; Rafindadi and Ozturk, 2015; Burke and Yang, 2016; Shaikh et al., 2017; Gautam and Paudel, 2018; Tamba et al., 2018; Baltagi et al., 2002 and Zhang et al., 2018), little attention has been devoted to the demographic factors such as the elderly, population density and urbanization, that they influence explicitly or implicitly household natural gas consumption. Additionally, with the exception of Gautam and Paudel (2018), most of these studies are based on data before 2010, and it is highly relevant to update studies, especially in this economic sphere with rapidly changing inputs.

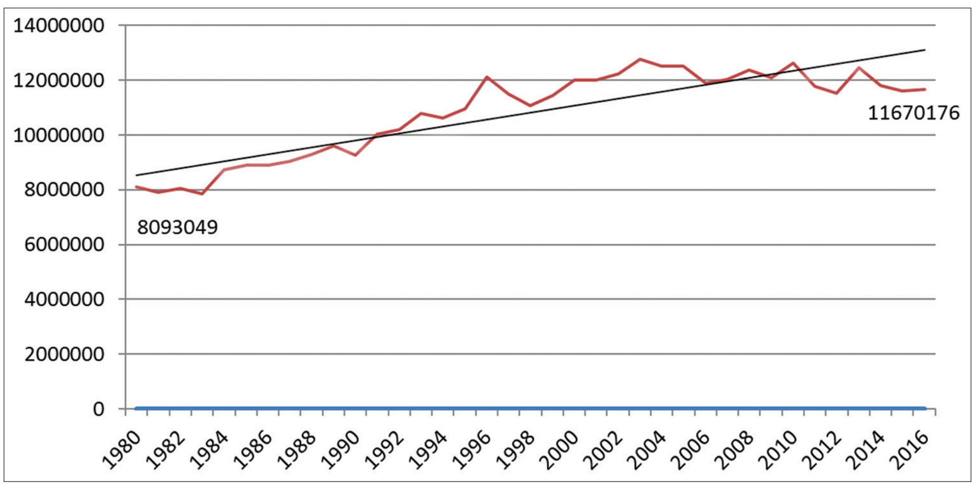
In order to make comprehensive decisions, policymakers need not only to know how natural gas demand will respond to income and price changes but how it will respond to the evolution of the elderly, the urbanization and the population density, as well. This is the key point of our work.

Our work aims at estimating the dynamic of per capita residential natural gas demand in 29 OECD countries over the period 2005-2016. The remainder of this paper is structured as follows. Section 2 provides a brief review of the literature. Section 3 describes the data and provides some descriptive statistics. The estimation results are presented in Section 4. The final section presents a brief conclusion.

2. LITERATURE REVIEW

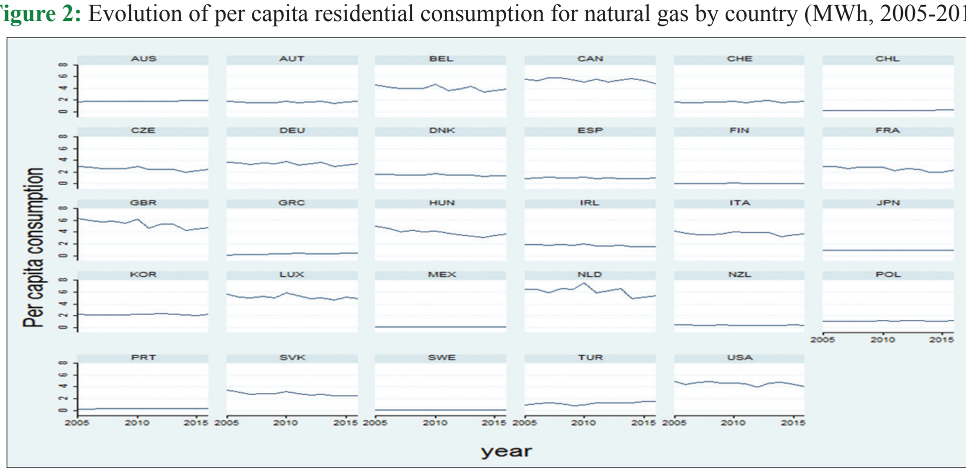
Research concerning the impact of population characteristics, especially the age, the density and the proportion of urban

Figure 1: Evolution of aggregate residential consumption for natural gas in OECD countries (terajoules, 1980-2016)



Source: Own elaboration based on IEA data

Figure 2: Evolution of per capita residential consumption for natural gas by country (MWh, 2005-2016)



Source: Own elaboration based on IEA data

Table 1: Definition of variables and descriptive statistics. N*T=464

Variable	Label	Mean	SD	Min.	Max.
Per capita residential natural gas consumption, MWh	GT	2.276022	1.835515	0.036086	7.55551
Elderly population (total)	ELD	6316611	9100802	67079	4.86e+07
Urban population (% of total population)	URB	77.1913	9.726607	53.468	97.897
Population density (inhabitants/km^2)	DEN	139.3273	128.5861	2.654778	525.7048
Population (total)	POP	4.23e+07	6.10e+07	465158	3.23e+08
Natural gas end-user price (US$ per MWh)	GP	75.96573	31.68349	15	169.6404
Electricity end-user price (US$ per MWh)	EP	201.9823	67.54572	63.73	405.56
Per capita income (current US $)	INC	38234.41	21450.6	7384.258	119225.4
Annual heating degree days[1] (baseline: 18°C)	HDD	3078.315	1573.367	128.9046	8929.906
Annual cooling degree days[2] (baseline: 18°C)	CDD	252.0716	408.8645	0	1875.273

SD: Standard deviation

population, on residential demand for natural gas are rare; this may be due to lack of data. Most research emphasized the price and the income elasticities to estimate natural gas demand. However, several studies have shed light on the population characteristics impact on residential energy consumption, as a whole, over the two decades.

Some studies have indicated a positive relationship between household age and space heating energy consumption. That is, older residents are very sensitive to temperature; thus, they tend to use more energy for space heating than younger residents since they spend more time at home. Meanwhile, in a study on Hangzhou Chinese city, Chen et al. (2013) determine that the age have a more significant influence than income, and there is a negative correlation between the age of the occupant and residential energy consumption, especially for heating and cooling. It was revealed that older householders endorse an economic behavior than younger ones.

In his study on energy use and greenhouse gas emissions in Germany, Kronenberg (2009) notes that demographic changes, characterized by the increase percentage of aging people, impact positively the energy demand especially for heating purposes.

From the 1993 Residential Energy Consumption Survey data, Huei-Chu Liao and Chang (2002) used the discrete method to model the space heating and water heating energy demands of older residents in the United-States. They claim that the older residents use more natural gas and more electricity for space heating. However, the correlation between water heating energy consumption and the aged is significantly negative.

In a recent study analyzing the demographic impacts on residential electricity and city gas demand of 47 Japanese prefectures every 5 years during the period 1990-2010, Ota et al. (2018) find that the aging of the society does not affect the city gas demand significantly. In addition, population shrinkage and the development of nuclear families increase the electricity consumption but reduce the city gas consumption.

Liu and Sweeney (2012) found that residents who live in dense areas (taking the Dublin city as example) consume lower energy for space heating than those who live in less densely regions. According to a socioeconomic and demographic study on the residential energy sector in San Antonio, Bexar County and Texas, Elnakat et al. (2016) point that, areas with higher population density consume less energy per capita compared to those with lower population density. Besides, in a study aiming to investigate consumption behavior within transport and domestic sectors in England and Wales, Arbabi and Mayfield (2016) show that, decreasing per capita gas consumption patterns are observed for growing population densities.

Further, based on data over 2001-2011 concerning China, He et al. (2015) state, as a conclusion, that the more the urban population is, the more total natural gas consumption will be.

Rather than estimating the price and income elasticities of natural gas demand, as it was done in most research, the focus of this paper is the population characteristics particularly, elderly, the population density and the urbanization rate.

3. EMPIRICAL FRAMEWORK

3.1. Data

We use annual data for OECD countries over the period 2005-2016. Our dataset relies on two principal sources: The International Energy Agency (IEA) dataset to obtain residential natural gas consumption, the price of natural gas and electricity in the residential sector, and the World Bank dataset to obtain per capita income, the overall population, population density, urban population percentage, aged population, the heating and the cooling degree day.

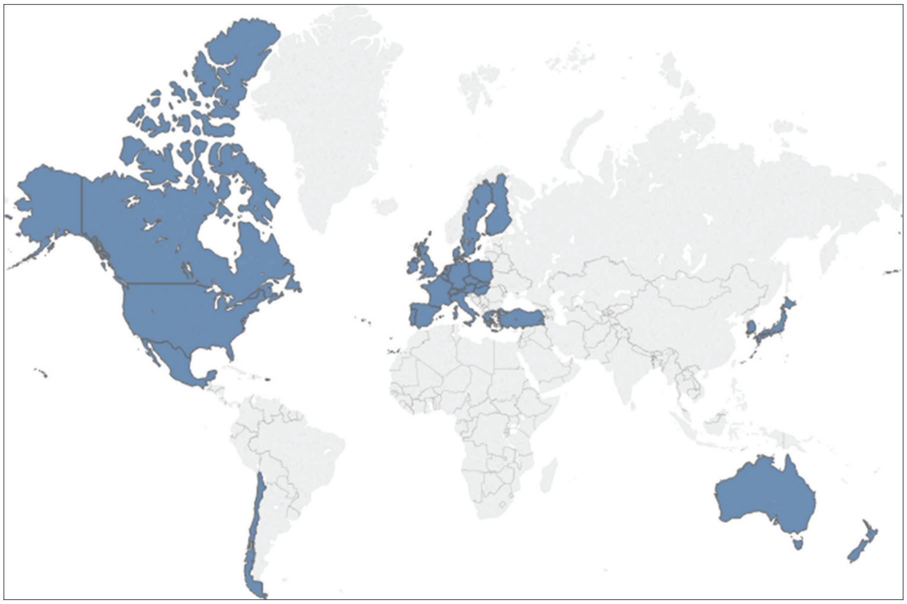
Of the 34 present-day members of the OECD, 5 countries were dropped from our sample due to the non-availability of data. Estonia, Iceland, Israel, Norway and Slovenia were removed due to missing price data or zero recorded demand of natural gas. Figure 3 shows the exact countries used for our study. Each country of the sample is observed every year; thus, the data set is balanced. Table 1 presents the descriptive statistics for the remaining 29 members:

Taking into account the demographic approach of the paper, three key variables in our model are the elderly, the urban population and the population density. The density is calculated as the mid-year population divided by the land area in square kilometers.

1 Heating degree day (HDD) is a quantitative index reflecting demand for energy to heat buildings or businesses.

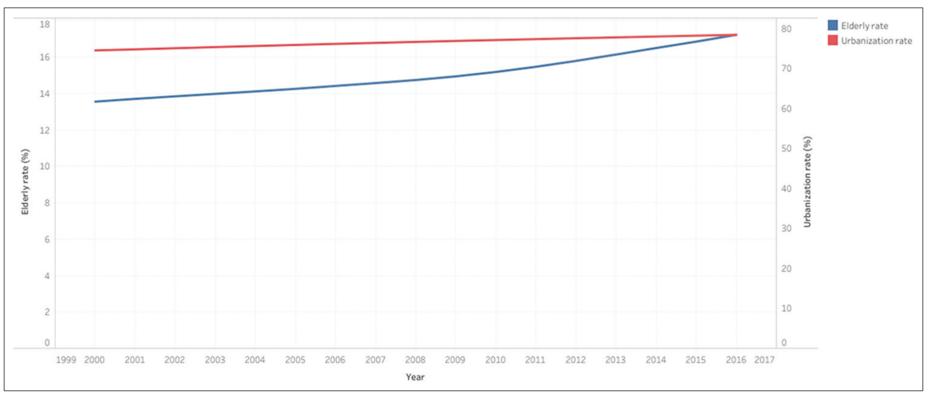
2 Cooling degree day (CDD) is a quantitative index reflecting demand for energy to cool buildings or businesses

Figure 3: Countries in our study



Source: Own elaboration with Tableau Public software

Figure 4: Elderly and population rate (percentage, 2000-2016)



Source: Own elaboration based on World Bank data (with Tableau Public software)

We display the evolution of the elderly population (over 65 years) and the urbanization rate (the proportion of urban population) of the OECD countries in Figure 4. Figure 4 shows that the percentage of the population aged of more than 65 years old and the population living in urban areas are increasing progressively over time. These two variables are of a major importance as they account for about 17% and 79% respectively in 2016.

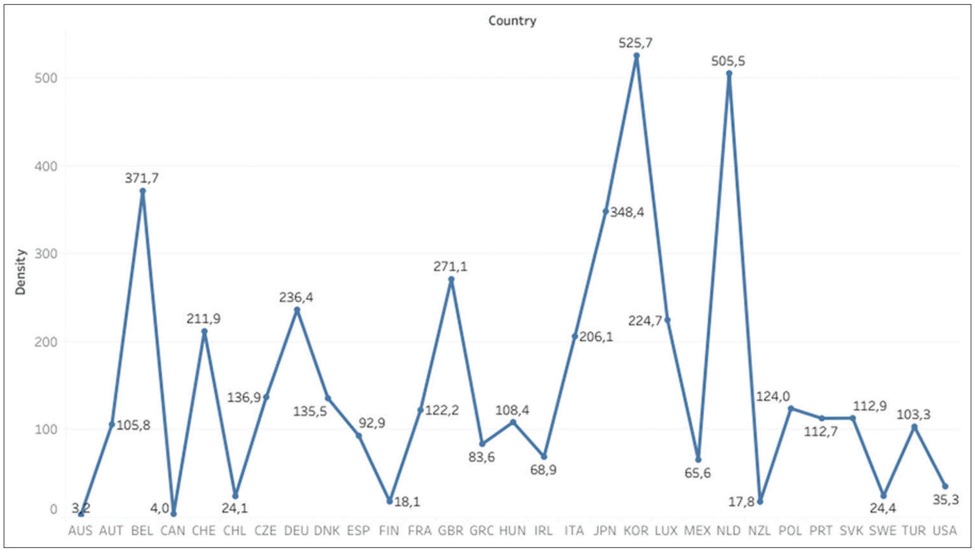
Then, we expose the population density[3] of different OECD countries in 2016 as our year of reference (the most recent one). Figure 5 shows that population density varies dramatically across countries and Korea, Japan, Belgium and Netherlands are the most dense countries.

Our empirical model contains the total population aged 65 or above in the total population at the national level, which indicates the aging of each country. In addition, the urbanization rate is included to investigate the role of the growing rate of population moving from rural to urban areas. Moreover, our study takes into account population density to examine the effects of compacted countries on residential consumption for natural gas. Furthermore, our model includes some other control variables. Accurately, our study incorporates the total population (POP_{it}), end-user natural gas price (GP_{it}), gross domestic product per capita (INC_{it}) to seizure the income level. Moreover, we include the price of electricity (EP_{it}) as the closest substitute as well as the Heating and cooling degree days (HDD_{it}) and CDD_{it}), respectively to control for the weather effects.

To show the statistical correlation between the dependant variable and the regressors, we use the correlation matrix. Table 2 reveals that the proportion of the elderly (ELD_{it}) and population density (DEN_{it}) are positively correlation with per capita natural gas demand (GT_{it}).The matrix also show that the urbanization rate (URB_{it}) is negatively correlated with natural gas demand. In addition, natural gas consumption is negatively correlated with its own prices (GP_{it}) and the cooling degree days (CDD_{it}) while it is positively correlated with per capita income (INC_{it}), the population (POP_{it}), the price of electricity (EP_{it}) and the heating degree days (HDD_{it}). However, the correlation matrix is a simple statistical relationship between two variables; hence, a more accurate

3 Inhabitants/km^2

Figure 5: Population density (inhabitants/km^2, 2016)



Source: Own elaboration based on World Bank data (with Tableau Public software)

Table 2: Correlation matrix

	lGT	lELD	lURB	lDEN	lPOP	lGP	lINC	lEP	lHDD	CDD
lGT	1.0000									
lELD	0.1264	1.0000								
lURB	−0.0953	0.0758	1.0000							
lDEN	0.3230	0.1224	−0.1979	1.0000						
lPOP	0.0840	0.9737	0.0640	0.0751	1.0000					
lGP	−0.0783	−0.0391	0.0245	0.4051	−0.1324	1.0000				
lINC	0.2804	−0.1861	0.3879	−0.0331	−0.3078	0.2021	1.0000			
lEP	0.1619	−0.1635	−0.0334	0.2615	−0.2900	0.6016	0.4029	1.0000		
lHDD	0.2240	−0.1373	−0.0499	0.1075	−0.2208	0.1814	0.2796	0.0572	1.0000	
CDD	−0.2327	0.2219	0.1113	−0.258	0.2995	−0.3060	−0.2887	−0.1846	−0.8953	1.0000

specification is needed to examine the impact of demographic variables on natural gas demand.

3.2. Econometric Technique

Considering the consumer as a firm, household production theory[4] assumes that households use inputs (natural gas in our case) to produce nonmarket goods or utility-yielding. Thus, household utility is not directly derived from natural gas, but the requirement for welfare services namely space heating, water heating, cooking etc. To meet these needs, households use natural gas fuel.

The production function of the welfare services S can be written as:

$$S=S(G) \quad (1)$$

Where G refers to natural gas. The output, namely welfare services (S), is given by the quantity of natural gas acquired. In fact, welfare services S are considered to be a part of the household's utility function as well as total consumption X. This utility function is impacted by the demographic characteristics Z and the weather of the household's country denoted W. This gives:

$$U=U(S(G),X,Z,W) \quad (2)$$

The above utility function is maximized by the household under a budget constraint:

$$Y\text{-}P.S\text{-}X=0 \quad (3)$$

Where Y is the household income and P is the price of natural gas. Solving this optimization issue involves demand function for natural gas:

$$G^*=G^*(P,Y;Z,W) \quad (4)$$

Based on the Eq.(4) and employing a log linear specification, we do have our static model as follows:

$$lnGT_{it}= B_0+B_1lnELD_{it}+B_2lnURB_{it}+B_3lnDEN_{it}+B_3sumlnX_{it}+e_{it} \quad (5)$$

Where GT_{it} is per capita residential consumption for natural gas, ELD_{it} is the aged population, URB_{it} is the urban population, DEN_{it} is the population density in the country i in year t, X_{it} are the sum of the control variables likely to impact per capita natural gas consumption, e_{it} is the error component to capture the effect of unobserved factors. We transformed the dependent variable and regressors into logarithm[5] , so that the parameters are simply interpreted as demand elasticities.

4 See Muellbauer (1974), Deaton and Muellbauer (1980), Thomas (1987). See Flaig (1990) for an application to electricity demand.

5 The variable CDD remains in the base because it contains some zero values.

While estimating a static energy demand model with panel data, it is commonly to take into consideration the endogeneity problem by applying the fixed or the random effects with the Within estimator or GLS (Baltagi and Baltagi, 2001), respectively to encounter the heterogeneity bias with a constant term from which the OLS could suffer.

However, Nerlove (2000) argues that economic behaviour models are dynamic in nature, through which the present behaviour depends on the state of the system describing it. Besides, Gutiérrez (2003) points that the fact of ignoring the effect of path-dependency can lead to biased estimates of the whole variables. More over, Baltagi, (2008) explained that the fixed effects type of models are subject to a simultaneous equation bias from the endogeneity between lagged dependent variables and the error term. Assuming that natural gas demand in the residential sector is affected by its previous levels, we introduce the lagged dependent variable on the right hand side of the equation to control for the inherent dynamic feature of our demand function. The dynamic version of our natural gas demand model is therefore given by:

$$lnGT_{it}= B_0+B_1lnGT_{it-1}+B_1lnELD_{it}+B_2lnURB_{it}+ B_3lnDEN_{it}+B_3sumlnX_{it}+e_{it} \quad (6)$$

Achen (2000) has stated that the lagged dependent variable will not only capture the impact of the omitted variables but also of the already included ones, with the possibility of changing their impact or decrease it, sometimes making it insignificant.

In fact, adding a lagged dependent variable to our static model will lead to biased estimates because the later variable might be correlated with the error component e_{it}. Thus, the within transformation and GLS will be biased since ($Yi,_{t-1}$ - $\bar{Y}._{-1}$), where y is the log natural gas consumption per capita and $\bar{Y}._{-1}$ are the average lagged log per capita natural gas consumption within country i, is correlated with (e_{it}-$\bar{e}i.$) and its consistency depends upon T being large (Baltagi, 2001). To address this issue, one can first difference the model to get rid of the country-fixed effects:

$$\Delta lnGT_{it} = B_0\Delta lnGT_{it-1}+\Delta lnELD_{it}B_1+\Delta lnURB_{it}B_2+\Delta lnDEN_{it}B_3+\Delta sumlnX_{it}B_4+\Delta e_{it} \quad (7)$$

And then using $\Delta Yi,_{t-2}$ as an instrument for $\Delta Yi,_{t-1}$ (Anderson and Hsiao, 1982). This instrumental variable estimation method leads to consistent but not necessarily efficient estimates of the parameters in the model because it does not make use of all the available moment conditions (Ahn and Schmidt, 1995). Arellano and Bond proposed a generalized method of moment (GMM) which consists of adding additional instruments by employing the orthogonality conditions that exist between lagged values of Y_{it} and the disturbances e_{it} in Eq(7). Therefore, based on this discussion and the fact that our dataset has n = 29 and t = 17, we estimate the dynamic demand function expressed in Eq.(6) with a dynamic system GMM as shown by Hayakawa 2007, the small sample bias of the "system" GMM estimator is not significant. The system GMM imposes the cross-equation restrictions that the coefficients entering in the two models be the same, and uses the full set of instruments (corresponding to the full set of orthogonality conditions for both models). The consistency of our system GMM estimator depends on the validity of the orthogonality assumptions in the estimation process. As recommended by Arellano and Bond, 1991; Arellano and Bover, 1995; and Blundell and Bond, 1998, two specification tests are used. The Sargan/Hansen test used for over identifying restrictions to check for the validity of the instruments and the Arellano-Bond tests (AR1) and (AR2) to check the first and second serial correlation among error terms. These tests help us to estimate the appropriate model for natural gas demand in the national level.

4. EMPIRICAL RESULTS

This section presents the estimated results and their implications on how the demand for natural gas responds to demographic and non-demographic factors in OECD countries. Table 3 reports the estimation results for the static model using the fixed effect to control for the unobserved heterogeneity. This shows that most of the coefficients are statistically significant and are almost in line with the results from the earlier literature. As for the overall image, urbanization rate, electricity prices, the heating and cooling degree days are statistically significant and positively correlated with per capita residential demand, while elderly, population density and natural gas prices are negatively correlated with per capita natural gas consumption.

However, since static models are not preferred for measuring the economic behaviors over time; we use a dynamic panel model that may be more accurate than static one for estimating energy demand. Furthermore, adding a lagged dependent variable as a regressor to examine residential natural gas demand violates the strict exogeneity condition in the static models; hence, this study uses the lagged dependent variable in the explanatory variables in the dynamic model. Table 4 presents the dynamic estimation model for residential natural gas demand.

Table 4 displays the regression results for the dynamic model obtained using the two step system GMM estimator. First, the results show that demand for natural gas is positively impacted

Table 3: Estimation results: Static model-FE

Dependant variable Log residential natural gas consumption per capita	Coefficients
lELD	−0.6316979*** (0.163)
lURB	1.956051** (0.676)
lDEN	−0.3136096** (0.146)
lPOP	0.5355508 (0.453)
lGP	−0.1177438** (0.057)
lINC	0.0688453 (0.084)
lEP	0.1951713** (0.08)
lHDD	0.3809647*** (0.092)
CDD	0.0003722** (0.0002)
Intercept	−10.75795* (6.502)
Sample size 348	
R^2 within 0.1303	
R^2 between 0.0548	
Overall 0.0524	

Coefficients in ( ) are the standard error. *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level

Table 4: Estimation results: Dynamic GMM estimation

Dependant variable: Log residential natural gas consumption per capita	Two-step system GMM
Lagged lGT	0.0920831* (0.05)
lELD	−0.6084994** (0.186)
lURB	1.10136* (0.645)
lDEN	−0.162396* (0.09)
lPOP	0.8196367** (0.259)
lGP	−0.2120276*** (0.054)
lINC	0.1511994 (0.093)
lEP	0.079582 (0.087)
lHDD	0.7826714*** (0 0.105)
CDD	0.0003477*** (0.0001)
Intercept	−15.88543*** (3.01)
Sample size	319
Hansen test	3.96 (0.785)
Arellano-bond test for AR (1)	−1.62 (0.106)
Arellano-bond test for AR (2)	−0.71 (0.478)

Coefficients in ( ) are the standard error. *Significant at the10% level, **significant at the 5% level, ***significant at the 1% level

by its lagged value. Moreover, the estimated results show that the coefficient of the elderly (ELD_{it}) is significantly negative in the residential natural gas demand dynamic equation. That is, as far as the society gets older, natural gas consumption decreases. The point estimates of elderly elasticity of per capita natural gas demand is −0.6. This seems to be not intuitive since older people are more sensitive to temperature and tend to use more natural gas to meet comfort needs, particularly in terms of space heating and water heating and tend to spend more time at home (Yamasaki and Tominaga, 1997). Nevertheless, possible interpretations of negative effect of ELD on residential natural gas consumption could be related to the fact that either old people tend to have an economic behavior in OECD countries, or OECD old population do not spend lot of time inside the house and tend to have more activities outside. It can also be related to the fact that old people prefer to use electric appliances rather than gas ones. A further explanation is that a large portion of appliances in OECD countries required for daily life at home may be electric appliances especially with the recent prevalence of electrified houses. Revealing a negative effect on residential natural gas demand in our estimation, confirms the above arguments.

Second, the coefficient of the urbanization rate (URB_{it}) is significantly positive in the residential natural gas demand dynamic equation. Ceteris paribus, the elasticity of per capita natural gas demand in response to urbanization rate is estimated at +1.1. The outcome seems is in line with earlier literature since natural gas is highly used in the urban areas and less in rural areas where the coal and wood are often used. In fact, with increased urbanization and rural population moving to cities and towns, coal, wood and other traditional fuels are replaced by cleaner energy sources, especially natural gas and electricity.

Third, concerning the effect of the population density (DEN_{it}), the analysis finds that the coefficient of DEN_{it} is significantly negative. An increase in the population density, produces a decrease in per capita natural gas consumption. The point estimates of population density elasticity of per capita natural gas demand is approximately −0.16. Countries with high density areas tend to consume less amounts of per capita residential natural gas. A reasonable explanation of our finding is that, the majority of OECD countries adopt some energy efficiency procedures and tend to use central heating system which equips the entire interior of the building with warming space and water.

Almost all estimated coefficients for the control variables are statistically significant, have the expected sign, and their magnitudes seem reasonable. The results indicate that gas prices (GP_{it}) have a negative impact on per capita natural gas demand, while population (POP_{it}), heating degree days (HDD_{it}) and cooling degree days (CDD_{it}) have a positive impact on residential natural gas consumption noting that natural gas demand is more sensitive to hot than to cold weather.

As for testing our dynamic model, the AR1 and AR2 test indicates that there is no significant autocorrelation in our model, which is a condition for the validity of the instruments. Besides, the Hansen test shows that the null hypothesis, that the over-identifying restrictions are valid, is not rejected.

5. CONCLUSION

In this study, we examine per capita natural gas demand in the residential sector in the OECD countries using a static and a dynamic model over the period 2005-2016. The objective of our paper is to contribute to the empirical literature on residential natural gas demand studies by considering the effect of population characteristics, particularly, urbanization rate, density and elderly population, on natural gas consumption in the OECD context.

To our knowledge, no previous study has used as complete model as possible to estimate residential natural gas demand in the OECD context. Previous studies have often focused on the price and income. We anticipate that adding demographic variables will be helpful for policymakers.

Using a dynamic framework, we find a significant effect of urbanization, density and elderly population on residential natural gas consumption. Rapid urbanization leads to the use of more natural gas per capita while population density leads the use of less per capita natural gas due to policy efficiency, especially in buildings. Moreover, old people consume less natural gas per capita and may have preference to electric appliances.

Although it is generally revealed by earlier studies that old people consume more energy for heating, our findings looks rather counter intuitive from an economic behavior, the preference point of view, or the prevalence of such appliances in OECD buildings.

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