Aging in Population and Energy Demand

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Abstract

This paper investigates the effect of aging in population on the demand for energy using the dynamic panel model. The principal objective is to find the dynamic relationship between the demographic changes and its consequential effect on the energy demand. The aging population appears prevalent world-wide, and naturally its effect on energy demand requires special attention. In this paper, we develop an economic model with demographic changes and derive a dynamic relationship between aging population and primary energy demand. An empirical model of dynamic panel, composed of 53 countries for the period 1976-2009, is applied to assess the relationship. From this, we get meaningful results that energy demand is influenced by aging and they have an inverted U-shaped relationship. This indicates demand for energy can vary according to the level of population aging.

Keywords: demand for energy, inverted U-shaped curve, population aging

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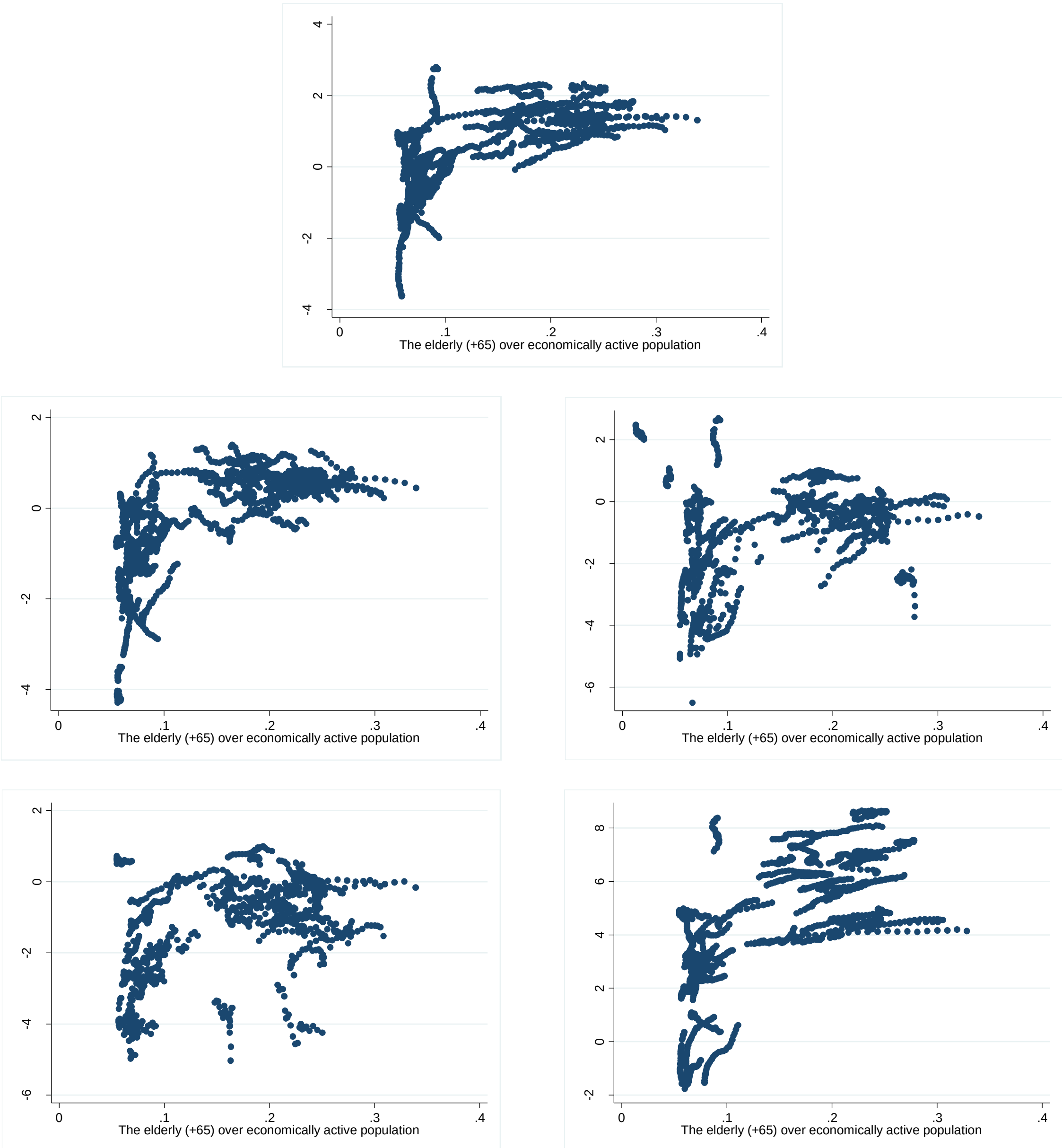
1. Introduction

In this paper, we study impact of population aging on the demand for energy to analyze relationship between demographic change and energy use. Underproduction stemmed from improper forecast of the the energy demand can interrupt steady economic growth and lower quality of life. And, long-run overproduction brings about inefficiency throughout the economy. So, analyzing the demand for energy appropriately should be preceded over the energy production. It is worthwhile to remind that energy is also one of normal goods. Thus, to analyze its demand, demographic change, especially aging structure, should be treated as essential factor. In other words, scrutinizing influences of population aging on energy consumption is an initial point of stable economic growth and comfortable life based on proper the production of energy.

[Figure 1] Relationship between the ratio of elderly people and the energy demand



[Figure 1] shows what effects the ratio of the elderly to economically active people has on the per capita energy demand, especially electricity and primary energy, such as oil, natural gas, and coal. Data set is composed of 1976~2009 yearly data of 53 countries. These graphs help us understand what specific goal of this study is. We can find an interesting fact that the increase of the per capita energy demand declines at first as population aging proceeds, and then, the energy demand starts to slightly lower down after the ratio of elderly people reaches around 20%. This indicates inverted U-shaped relationship may exist between population aging and energy use.

Despite the fact that study about a relationship between population aging and the energy demand is well worth enough, few papers have treated this issue. As the best of our knowledge, the only paper that analyzes relationship between aging and energy demand is Tonn, B. and J. Eisenberg (2007), which argues population aging raises the residential use. However, this is implemented depending on a simple statistical data analysis and qualitative analysis. Moreover, this limits its research scope in a residential sector. The restricted research scope is a common limitation to other studies about the energy demand which are irrelevant to aging. Since the energy is produced based on prediction of total use, demand analysis without consideration of an industrial sector cannot derive any practical implication. Some literatures dealing with the energy demand as well as its relationship with population are summarized in the following table.

<Table 1> Literature Review

Study	Estimation method	Variables	Data
Anderson, K. P. (1971)	Simultaneous equation model	Industrial energy, Wage rate, Value added	U.S
Kamerschen, D. R. and D. V. Porter (2004)	Simultaneous equation model	Total electricity, GDP, Price, Weather condition	U.S
Bigano, A., F. Bosello, and G. Marano (2006)	Dynamic Panel models	Total energy, Temperature	OECD Non-OECD
Tonn, B. and J. Eisenberg (2007)	Qualitative analysis	Residential electricity, Population aging	U.S
Halicioglu, F. (2007)	VAR	Residential electricity, GDP, Price, Urbanization rate	Turkey
Ziramba, E. (2008)	VECM	Residential electricity, GDP, Price	South Africa
Nakajima, T. and S. Hamori (2010)	Panel VECM	Residential electricity, GDP, Price, Weather condition	U.S
Costantini, V. and C. Martini (2010)	Panel VECM	Residential electricity, GDP, Price	OECD
Alberini, A. and M. Filippini (2011)	LSDV and Dynamic Panel models	Residential electricity, GDP, Price, Weather condition	U.S

2. Theoretical Framework

To construct a theoretical economic model, overlapping generation is employed.

Each period, two-period-lived young agents are born, and each is endowed with one unit of labor in the first period of life. And in the second period, they become unable to work. Both two types of agents, the young and the elderly, obtain their utility by consuming energy at their home as well as consumption good. In period 0, there are some old agents who live for one period and disappear, are endowed with k_0 units of capital. Denote c_{yt}, c_{ot} and e_{yt}, e_{ot} consumption and residential energy use per young agent and old agent at time t, respectively. Then, at time t, the representative young agent has preference given by,

$$\mathrm{u}(c_{yt}, c_{0t+1}, e_{yt}, e_{ot+1}) \quad \text{(eq.1)}$$

It is assumed that the utility function is strictly increasing and strictly concave, in each argument. And to prevent corner solution, $\lim_{c\to 0} u_c{}' = \infty$ and $\lim_{e\to 0} u_e{}' = \infty$ are assumed to be satisfied in both agents cases.

Not only simultaneous allocation between consumption and residential energy use, but also inter-temporal allocation between present and future are decided only when agents are young, under an assumption that the young agents can forecast future prices of consumption good (p_{t+1}), energy (q_{t+1}), and nominal interest rate (i) perfectly. So, the young face the following budget constraints (eq.2) when they try to maximize their life-time utility.

$$p_t * c_{yt} + q_t * e_{yt} + s_t = w_t$$
$$p_{t+1} * c_{ot+1} + q_{t+1} * e_{ot+1} = (1+i) * s_t \qquad \text{(eq.2)}$$

In (eq.2), s_t and w_t represent saving and nominal wage. Since labor force of the elderly is dissipated, their budget is constrained as transferred saving from the previous.

Then, the inter-temporal budget constraint takes the form

$$p_t * c_{yt} + q_t * e_{yt} + \frac{p_{t+1} * c_{ot+1} + q_{t+1} * e_{ot+1}}{1+i} = w_t \ . \qquad \text{(eq.3)}$$

By combining (eq.1) and (eq.3), the first-order condition of the household utility maximization problem can be obtained as following.

$$\mathrm{u}'_{c_{yt}} = \lambda * p_t, \ \mathrm{u}'_{c_{0t+1}} = \lambda * \frac{p_{t+1}}{1+i}$$
$$\mathrm{u}'_{e_{yt}} = \lambda * q_t, \ \mathrm{u}'_{e_{0t+1}} = \lambda * \frac{q_{t+1}}{1+i}$$

Then, inter-temporal allocation of consumption and residential use are characterized as

$$\mathrm{u}'_{c_{0t+1}} = \frac{p_{t+1}}{p_t * (1+i)} * \mathrm{u}'_{c_{yt}}$$
$$\mathrm{u}'_{e_{0t+1}} = \frac{q_{t+1}}{q_t * (1+i)} * \mathrm{u}'_{e_{yt}}$$

For more specific discussion, define utility function as simple summation of two log functions, one is utility at time t and the other is at time t+1. And utility function at each period is composed of linear combination of log utility of consumption and residential energy use.

$$\mathrm{u}\left(c_{yt}, c_{0t+1}, e_{yt}, e_{ot+1}\right) = (1-\phi) * \ln c_{yt} + \phi * \ln e_{yt} + (1-\psi) * \ln c_{ot+1} + \psi * \ln e_{ot+1} \qquad \text{(eq.3)}$$

In (eq.3), it is noteworthy that ψ is larger than ϕ. This is quite intuitive, now that the elderly pursue comfortable life by using energy at their home rather than going around and consuming good. They tend to use heater more than the younger, because the elder is vulnerable to the external weather condition. And, they are more likely to drive their car even short distance. Thus, tendency that agents obtain utility from residential energy use is higher as they get older.

Using (eq.3), we can get

$$c_{ot+1} = \frac{1-\psi}{1-\phi} * \frac{p_t*(1+i)}{p_{t+1}} * c_{yt}$$
$$e_{ot+1} = \frac{\psi}{\phi} * \frac{q_t*(1+i)}{q_{t+1}} * e_{yt} \qquad \text{(eq.4)}$$

Since investment of one unit of money at time t brings about $1+i$ unit of money, real interest rate takes form as following.

$$1 + \mathrm{r} = (1+i) * \frac{p_t}{p_{t+1}}$$

Assume that energy price (q_t) is directly proportional to consumption good price (p_t) for all t. Then, by applying this to (eq.4), inter-temporal allocation of consumption and residential energy use become

$$c_{ot+1} = \frac{1-\psi}{1-\phi} * (1+i) * c_{yt}$$
$$e_{ot+1} = \frac{\psi}{\phi} * (1+\mathrm{r}) * e_{yt} \qquad \text{(eq.4)}$$

Since ψ is larger than ϕ, e_{ot+1} is larger than e_{yt}. And this means that per capita residential energy demand grows as portion of the elderly in the total population increases.

In a firm side, population aging drags down production of consumption good, because it results in lower productivity in the economy. Denote N_{yt} and N_{ot} population of the young agent and the old agents in the economy. And, variable, θ_t, representing population aging at t, is

$$\theta_t = \frac{N_{ot}}{N_{yt}+N_{ot}} \ . \qquad \text{(eq.5)}$$

For convenience, consumption good production is implemented using only energy and labor, and the labor can be provided by only young as mentioned above. And it is assumed that firms in this economy hire all labor forces $\left(N_t^D = N_{yt}\right)$, so that they choose only how much energy they use for production. And, to reflect inefficiency that population aging brings about in productivity, total factor productivity is assumed to be a function of θ_t. Then, a profit function that a firm has to maximize is

$$\mathrm{A}(\theta_t) * \widehat{E_t}^{\gamma} * N_{yt}^{1-\gamma} - q_t * \widehat{E_t} - w_t * N_{yt}$$

where $\widehat{E_t}$ is total energy demand used for production, and $\mathrm{A}(\theta_t)$ represents productivity. $\mathrm{A}(\theta_t)$ decreases as θ_t increases, now that population aging drags down efficiency in productivity. And let assume that the rate of decrease be constant for convenience. i.e. $\mathrm{A}(\theta_t)' < 0, \mathrm{A}(\theta_t)'' = 0$

The first-order conditions for a maximum are the usual marginal conditions

$$\gamma * A_t * \widehat{E_t}^{\gamma-1} * N_{yt}^{1-\gamma} = q_t \ .$$

And, we can rewrite this as following.

$$\widehat{E_t} = \left(\frac{\gamma * A_t}{q_t}\right)^{\frac{1}{1-\gamma}} * N_{yt} \qquad \text{(eq.6)}$$

Let $\widehat{E_t}$ represent per capita industrial energy use. Then, we get

$$\hat{e_t} = \frac{\widehat{E_t}}{N_{yt}+N_{ot}} = \left(\frac{\gamma * A_t}{q_t}\right)^{\frac{1}{1-\gamma}} * (1-\theta_t) \ . \qquad \text{(eq.7)}$$

Since A_t and $(1-\theta_t)$ are in inverted proportional to θ_t, population aging leads to decrease of industrial energy demand. This fact is quite intuitive, now that breakaway of labor force caused by aging makes economy less productivity so that production becomes less activity. And this results in decline of energy demand in industrial part.

Now, using (eq.4) and (eq.6), we are able to obtain per capita energy demand $(\tilde{e_t})$ as following.

$$\tilde{e_t} = \frac{\left[N_{yt} * e_{yt} + N_{ot} * \frac{\psi}{\phi} * (1+\mathrm{r}) * e_{yt}\right] + \left(\frac{\gamma * A_t}{q_t}\right)^{\frac{1}{1-\gamma}} * N_{yt}}{N_{yt} + N_{ot}}$$

$$= \left[(1-\theta_t) + \theta_t * \frac{\psi}{\phi} * (1+\mathrm{r})\right] * e_{yt} + (1-\theta_t) * \left(\frac{\gamma * A_t}{q_t}\right)^{\frac{1}{1-\gamma}}$$

And since per capita production of consumption good (y_t) is

$$y_t = \frac{A_t * \widehat{E_t}^{\gamma} * N_{yt}^{1-\gamma}}{N_{yt}+N_{ot}} = (1-\theta_t) * A_t * \left(\frac{\gamma * A_t}{q_t}\right)^{\frac{\gamma}{1-\gamma}} \ ,$$

per capita energy demand varies as population aging proceeds.

$$\frac{\mathrm{d}\tilde{e_t}}{\mathrm{d}\theta_t} = \left(e_{ot} - e_{yt}\right) + \left(\frac{\gamma}{1-\gamma} * \frac{A_t'}{A_t} - \frac{1}{1-\theta_t}\right) * \frac{q_t}{\gamma} * y_t \qquad \text{(eq.7)}$$

The first term in (eq.7) is positive, because e_{ot} is larger than e_{yt} as explained in (eq.4). This shows increase of the residential energy demand caused by increase of the ratio of elder people. And this term stays constant as population aging proceeds. In a case of the second term, since A_t falls as θ_t grows, a sign of this term is negative. This represents decrease of the industrial energy demand made by breakaway of labor force and increase of inefficiency due to population aging. Although this term is always negative, the size is changed according to the ratio of elder agents in the total population. This is because a size of y_t, which is positive, becomes smaller, but contrastively sizes of $\frac{A_t'}{A_t}$ and $-\frac{1}{1-\theta_t}$, who have negative sign, get larger as θ_t increases.

The reason why per capita energy demand shows inverted U-curve as aging proceeds ([Figure 1]) is that the size of the second term is smaller than that of the first term, which is constant irrelevant to θ_t, at first, however, starts to overwhelm at some level of θ_t.

3. Empirical study

In this part, an empirical model of dynamic panel is applied to support the argument of the theoretical model. For this, demand for primary energy, such as oil, natural gas, and coal, is analyzed. And, electricity demand is also included for the richer analysis.

(1) Data

Analysis of primary energy and oil demand is implemented using 45 countries data from 1976 to 2009. However, natural gas, coal, and electricity demand are studied using 45 countries data from 1986 to 2009 and 46 countries from 1987 to 2009, and 45 countries data from 1976 to 2008, due to lack of data, respectively. And Among 51 countries, only 39 countries are included in common and the other are excluded from some energy demand analysis, because not enough data sets are secured. Per capita energy demand, real energy price, the elderly over economically active population, per capita real GDP, per capita real government consumption share, per capita real investment share, and openness are used as variables. <Table 2> shows notation used in this paper and sources. And, <Table 3> summarizes descriptive statistics.

<Table 2> Explanation about variables

Variables	Data	Sources
$Demand_{it}$	Per capita energy demand (logarithm)	British Petroleum
$Price_{it}$	Real price of energy (logarithm) - Primary energy, oil, electricity: WTI - Natural gas: European union cif - coal: Northwest Europe marker price	
$Aging_{it}$	The elderly (+65) over economically active population	World Bank
GDP_{it}	Per capita real GDP (logarithm)	Penn. World Tables
$Govt_{it}$	Per capita real government consumption share of GDP (logarithm)	
Inv_{it}	Per capita real investment share of GDP (logarithm)	
$Open_{it}$	Openness in real (logarithm)	

<Table 3> Descriptive statistics

Variables		Obs.	Mean	Std. Dev.	Min.	Max.
$Demand_{it}$	Primary energy (Tons)	1530	2.7807	2.4145	0.0266	16.4407
	Oil (Tons)	1530	1.1770	0.8538	0.0136	4.0384
	Natural gas (Tons oil equivalent)	1080	0.9794	1.7888	0.0015	14.8089
	Coal (Tons oil equivalent)	1058	0.5052	0.5455	0.0065	2.6866
	Electricity (Kwh)	1485	507.2115	986.6072	0.1724	5735.7920
$Price_{it}$	WTI (US dollars per barrel)	1530	30.5982	19.2438	12.2300	100.0600
	European union cif (US dollars per million Btu)	1080	3.9954	2.4715	1.8785	11.5612
	Northwest Europe marker price (US dollars per ton)	1058	49.9376	25.6659	28.7900	147.6737
$Aging_{it}$		1530	0.1426	0.0725	0.0549	0.3392

GDP_{it}		1530	11099.2600	10426.5000	140.9984	42132.9200
$Govt_{it}$		1530	8.9275	3.4482	2.5800	25.6600
Inv_{it}		1530	23.4836	7.0861	10.0700	57.0000
$Open_{it}$		1530	54.2371	32.6026	8.3600	213.7500

(2) Model Strategy

To measure the relationship between demand for energy demand and population aging, dynamic panel model is employed. For the long-run analysis, macroeconomic variables are considered.

Let us consider the following panel model.

$$lnDemand_{it} = \alpha + \beta_1 * lnDemand_{it-1} + \beta_2 * lnPrice_{it} + \beta_3 * lnGDP_{it}$$
$$+ \beta_4 * Govt_{it} + \beta_5 * Inv_{it} + \beta_6 * Open_{it} + \sum_t \delta_t * D(time = t) + u_i + e_{it} \quad \text{(Eq.8)}$$

A subscript "i" country code and "t" is time. Among variables, per capita energy demand, real energy price, and per capita real GDP are taken logarithm, while the others are not, now that they are expressed as ratio. u_i signifies an time-invariant individual effect caused by specific conditions of each country. This term can capture effects which cannot be directly observed or defined specifically, such as geological feature, energy reserves, and energy policy of the country. And e_{it} is an error term which is assumed to be strictly exogenous. $D(time = t)$ is a time dummy which reflect world-wide economic condition or changes of world energy markets that are common to all countries. We can expect easily that all of the macroeconomic variable, except for price, will have positive sign. And since increase of the energy consumption in the last year can draw the same situation of this year by itself, lagged term of energy demand is included as explanatory variable.

What we should be concern about in this model is an endogeneity problem. For more concrete discussion, consider a simple dynamic panel model as following.

$$y_{it} = \beta * y_{it-1} + (u_i + e_{it})$$

In a case of Random effect estimation, the simplest one, severe biasness problem is bought about, when correlation between dependent variable and individual effect exists. Since energy demand cannot avoid country-specific condition intuitively, other methods should be considered. Fixed effect estimation is an alternative, now that individual effect can be removed by using Within group transformation or First differencing transformation. However, in the both cases, transformed error terms still are correlated with transformed lagged energy demand variable, because the formers contain e_{it-1} and the latters have y_{it-1}.

To deal with these problems, Arellano and Bond (1991) considered GMM. They suggested estimation of differenced equation, $\Delta y_{it} = \beta * \Delta y_{it-1} + \Delta e_{it}$ using y_{is} $(where\ s \le t-2)$ as instruments in moment condition. However, in a case of the AR coefficient in a level equation is near 1, $\Delta y_{it-1} (\approx u_i + e_{it-1})$ becomes uncorrelated with instruments y_{is} $(where\ s \le t-2)$. Thus, weak instrumental problem occurs. Blundell and Bond (1998) proposed another estimation method based on GMM. In this model, system equation composed of differenced equation using level instruments and level equation using difference instruments in each moment condition are estimated. In a case of level equation with difference instruments Δy_{is} $(where\ s \le t-1)$, Δy_{is} from lagged twice contains no u_i so that exogeneity can be guaranteed. Moreover, weak instrument problem can be avoided, now that Δy_{it-1} is correlated with y_{it-1}. Since energy demand tends to have a persistent impact on the next period demand, GMM proposed by Blundell and Bond is employed in this study.

To analyze relationship between population aging and energy demand, $Aging_{it}$ is included in our model as following.

$$lnDemand_{it} = \alpha + \beta_1 * lnDemand_{it-1} + \beta_2 * lnPrice_{it} + \beta_3 * lnGDP_{it} \quad \text{(Eq.9)}$$
$$+ \beta_4 * Govt_{it} + \beta_5 * Inv_{it} + \beta_6 * Open_{it} + \gamma_1 * Aging_{it} + \gamma_2 * Aging_{it}^2 + \sum_t \delta_t * I(time = t) + u_i + e_{it}$$

The quadratic term of $Aging_{it}$ reflects an effect of aging on energy demand, which is composed of the opposite movements in residential sector and industrial sector. The quadratic term of $Aging_{it}$ enables this conflicting impact on energy demand to be detected by ascertaining existence of inverted U-shaped relationship between population aging and per capita energy demand.

The first condition for inverted U-shaped relationship is γ_2 has a negative sign. And the second one is γ_1 is positive, otherwise, population aging always influences energy demand negatively.

(3) Empirical results

Estimation of energy demand using macroeconomic variables helps us know about long run energy demand. To know how energy demand is determined basically in long run, (Eq.8) is estimated. The result is shown in <Table 4>.

<Table 4> Estimation result of Dynamic Panel model

Variables	*Primary energy*	*Oil*	*Gas*	*Coal*	*Electricity*
Constant	-0.233610*** (0.039477)	-0.780849*** (0.065090)	-0.439638*** (0.108372)	-0.615528*** (0.151921)	-0.211977*** (0.030989)
$lnDemand_{it-1}$	0.958996*** (0.005771)	0.886591*** (0.008219)	0.902570*** (0.008105)	0.938690*** (0.011916)	0.978724*** (0.002785)
$lnGDP_{it}$	0.022804*** (0.004652)	0.071737*** (0.006800)	0.073074*** (0.012768)	0.034676** (0.014281)	0.024190*** (0.004360)
$lnPrice_{it}$	0.016501*** (0.004500)	0.017653*** (0.006508)	0.056830*** (0.018204)	0.036161 (0.023585)	0.016302*** (0.003886)
$Govt_{it}$	-0.002134*** (0.000753)	0.000886 (0.001091)	-0.004710 (0.003113)	0.007572* (0.004279)	0.001453* (0.000675)
Inv_{it}	0.002789*** (0.000224)	0.003216*** (0.000321)	-0.000132 (0.000870)	0.003562*** (0.001179)	0.002425*** (0.000209)
$Open_{it}$	-0.000018 (0.000077)	0.000167 (0.000108)	0.000158 (0.000303)	0.000965*** (0.000296)	0.000198*** (0.000070)

The results report that coefficient of lagged energy demand is always less than 1 in all energy sources. Although 5% of confidence intervals do not include 1, an obvious fact is that energy demand is highly persistent. This indicates that GMM suggested by Arellano and Bond (1991) is not appropriate to be employed in this analysis.

Per capita real GDP has also a positive effect on energy use. It is clear that people tend to use more energy if they become wealthier, because energy is also one of normal goods. And energy input to production will increase, as economy gets more active. Both of the two effects raise energy demand. However, the low figure of the coefficient shows energy is a necessary good.

In a case of real price of energy, counter-intuitive result is reported. Since energy is normal good, a sign of the coefficient, which represent price elasticity of demand, should be negative. This is interpreted that increase of energy price cannot drag down its demand. This may happen because the most of governments tend to suppress domestic energy price even though price in the world market inclines. Since nominal domestic price cannot increase, its relative price gets lower. So, there is no motivation for firms and households to reduce energy use. One more possible explanation of this result is that motivation to use more energy stemmed from economic growth is strong enough to overwhelm price effect. Thus, demand for energy increases, despite of a steady rise of its price.

Most of the coefficients of the other factors, government expenditure over total GDP, investment over total GDP, and Openness, coincide with our common knowledge. Since government expenditure, investment, and international trade revitalize economy, these should raise up energy demand.

What an influence aging has on demand for energy in the economy is able to be discussed by analyzing estimation results of Dynamic Panel model including population aging as an explanatory variable (Eq.9). <Table 5> provides some important information.

<Table 5> Estimation result of Dynamic Panel model with population aging

$Variables$	$Primary\ energy$	Oil	Gas	$Coal$	$Electricity$
$Constant$	-0.245779*** (0.045082)	-0.884603*** (0.074047)	-0.696021*** (0.137574)	-0.583865*** (0.171532)	-0.200338*** (0.034383)
$lnDemand_{it-1}$	0.955955*** (0.005929)	0.878441*** (0.008531)	0.897884*** (0.008383)	0.927024*** (0.012473)	0.979570*** (0.002833)
$lnGDP_{it}$	0.019119*** (0.006158)	0.082302*** (0.009199)	0.110111*** (0.015926)	-0.000578 (0.020749)	0.019095*** (0.005683)
$lnPrice_{it}$	0.014196*** (0.004695)	0.009618 (0.006842)	0.046892** (0.018334)	0.035594 (0.023778)	0.015372*** (0.004085)
$Aging_{it}$	0.660449*** (0.211368)	0.360836 (0.300407)	-1.658526*** (0.568889)	3.083017*** (1.043054)	0.408492** (0.193933)
$Aging_{it}^2$	-1.838248*** (0.513742)	-1.655011** (0.730939)	2.386769 (1.559707)	-6.634918*** (2.420688)	-1.090995** (0.484242)
$Govt_{it}$	-0.002142*** (0.000779)	0.001607 (0.001113)	0.003038 (0.003649)	0.002492 (0.005006)	0.001432** (0.000686)
Inv_{it}	0.002711*** (0.000226)	0.003055*** (0.000322)	-0.000444 (0.000890)	0.004048*** (0.001197)	0.002441*** (0.000210)
$Open_{it}$	0.000011 (0.000077)	0.000151 (0.000109)	0.000184 (0.000304)	0.001024 (0.000296)	0.000199 (0.000071)

There are not remarkable changes in the estimation results of coefficients common to (Eq.8).

It is noteworthy that inverted U-shaped relationship between population aging and per capita energy demand is confirmed in for energy sources, primary energy, oil, coal, and electricity. This is because in the analysis of these energy sources, the linear term and the square terms of aging show positive and negative signs, respectively. This fact indicates that while energy demand increases as a portion of the elderly grows in the total population at first, aging starts to drag down the demand after population aging exceeds some level. However, in the case of natural gas, both linear term and squared term show unexpected signs. This may occur because of some outlier countries shown in [Figure 1], which have low level of aging and high level of energy demand such as Trinidad and Tobago or UAE or South Africa. By inverted U-shaped relationship is broken due to these countries, only negative relation after the inflection point of inverted U-curve is captured.

Population aging leads energy demand in residential sector and that in industrial sector to the opposite directions as mentioned above. In the residential part, aging can have a positive impact on the demand for electricity. The elderly are more likely to stay at home and use residential energy rather than going around. When they go out, they drive their car even short distance that the young tend to walk. And, they use heating appliance or air-conditioning more than the young, now that they are vulnerable to the weather condition like the cold and heat. Moreover, they tend not to substitute their old appliances with new ones, so that they use more electricity inadvertently due to low efficiency of the old ones. However, in the industrial part, aging drags down demand for energy. Larger ratio of the elderly over total population means smaller ratio of economically active people. In other words, aging leads to breakaway of labor forces. What's more, aging induces decline of productivity in the economy. This makes energy demand decrease faster as aging proceeds.

The inversion of effect of population aging on energy demand, i.e. inverted U-shaped relationship, happens because aging effect on residential use is larger than on industrial use when the level of population aging is low, but contrastively, the latter exceeds the former after population aging overs some level. Remind what happens as population aging proceeds based on Section 2(Theoretical Framework). The rate of increase in residential use is constant regardless of the level of aging. However, one more loss of labor force, in a case that the level of aging is already high, decreases production efficiency larger than in a case that the level of aging is not severe. Moreover, substitution of labor with other inputs becomes harder as labor forces decline. Thus, decrease of industrial use can overwhelm increase of residential use eventually. By simple calculation using estimated aging coefficients in primary energy, coal, and electricity, the inflection point of the elderly ratio that makes energy demand start to decline is around 18 ~ 23%.

4. Conclusion

This paper investigates the influences of population aging on the per capita demand for electricity and primary energy, such as oil, natural gas, and coal. In a theoretical analysis, we show that population aging leads the energy demand in the residential sector and that in the industrial sector to the opposite directions. This may happen because the elder people use more energy on account of their poor health conditions, but contrastively, production becomes less active due to breakaway of labor forces and increasing inefficiency in production as aging proceeds. And it is noteworthy that the decreasing size of the industrial use gets larger as aging proceeds, now that one unit of labor force breakaway when labor force is low has a more severe impact on productivity than when labor force is high. In contrast, the increasing size of the residential use remains constant regardless of the level of population aging. This situation makes possible the relationship between aging and energy demand have inverted U-shape. The empirical study is implemented, using the panel data of 53 countries for a span of 1976~2009. The GMM econometric methodology is employed. Since population aging term and its squared term included as independent variable in the energy demand model show positive and negative sign respectively, an inverted U-shape relationship is confirmed. This indicates that the effect of aging on residential use is larger than on industrial use when the level of population aging is low. However, the latter exceeds the former after population aging exceeds some level. And the level which is served as the inflection point is around 18 ~ 23% of the elderly over economically active people.

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