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The Effect of Information and Communication Technology on Energy Consumption in the European Union Countries

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Abstract
The effect of information and communication technology on energy consumption has become an important issue in recent years. However, in the existing literature the number of studies which analyze this issue empirically is very low. This study examines the influence of information and communication technology on electricity consumption in the European Union countries over the period 1990-2012. The results of the empirical analysis indicate that information and communication technology leads to an increase in electricity consumption in the European Union countries over the long-run.
Keywords: Information and communication technology, electricity consumption, European Union countries.
Jel Codes: C33, E21, O33, O52, Q43.

1. Introduction

The development of information and communication technology has intensively influenced both developed and developing economies since the begining of 1990s. The main reason behind this big influence is that information and communication technology is pretty much the same general purpose technology generated by industrial revolution almost 120 years ago (Takase and Murota, 2004: 1291). Information and communication technology leads to an economic structure in which more activities are carried out digitally and hence helps to make these activities more simply and efficiently (Wissner, 2011: 14).

Without doubt, the development and diffusion of information and communication technology have notable effects on energy consumption. As stated by Romm (2002) information and communication technology can reduce energy consumption in two ways: 1- Since the energy consumption of the information and communication sector is lower than the traditional manufacturing sectors the development of information and communication sector generates less incremental growth of energy consumption, 2- Information and communication technology can decrease energy consumption in every sector of an economy by increasing efficieny. However, the development of information and communication technology can also lead to an increase in energy consumption due to the fact that information and communication technology equipment operates with electricity (Cho et al., 2007: 4730). Hence, the net effect of the development and diffusion of information and communication technology is an open empirical question.

Although the relationship between information and communication technology and energy consumption is considerably important because of its economic and environmental effects the number of studies which investigate this issue in the existing literature is very low (Cho et al., 2007: 4730). Thus, the main aim of this study is to investigate the effect of information and communication technology on energy consumption empirically and therefore to contribute to the existing literature by providing new empirical evidence.

In the empirical analysis, the effect of information and communication technology on electricity consumption is examined for a panel of 20 European Union countries over the period 1990-2012 by using Mean Group (MG) (Pesaran and Smith, 1995), Pooled Mean Group (PMG) (Pesaran et al., 1999) and Dynamic Fixed Effects (DFE) (Blackburne and Frank, 2007) estimators.

The remainder of the paper is structured as follows: In section 2 the existing empirical literature which analyzes the impact of information and communication technology on energy consumption is presented. In section 3 the empirical methodology and the data set used in the empirical analysis are explained. In section 4 the results of the empirical analysis are discussed and finally, in section 5 concluding remarks and the policy implications of the empirical analysis are presented.

2. Literature Review

Although the relationship between information and communication technology and energy consumption has become a crucial issue in terms of its economic and environmental impacts there are very few studies which empirically analyze this relationship in the existing literature (Cho et al., 2007: 4730). Here, the results of the empirical analyses which investigate the effect of information and communication technology on energy consumption are summarized.

Schaefer et al. (2003) calculate the energy usage of German mobile telephone sector in 2000. The authors find that only 7% of the total electricity usage of German mobile sector is consumed by handsets and the remaining 93% is consumed by network components. Moreover, by comparing their results with an earlier study Schaefer et al. (2003) put forward that the electricity usage of the mobile telephone sector in Germany decreased. However, according to the authors, this decrease mainly originated from the higher usage of networks instead of energy efficiency.

Takase and Murota (2004) analyze the influence of information technology on energy consumption in Japan and the US by developing an economic model. According to the simulation results, Takase and Murota (2004) suggest that while information technology investment lowers energy intensity in Japan it increases energy intensity in the US.

Collard et al. (2005) examine the effect of information and communication capital on electricity intensity of production in the French service sector over the period 1986-1998. In the empirical analysis, Collard et al. (2005) estimate a factor demand model by using non linear least squares and two-stage non linear least squares estimators. According to the results of the empirical analysis, Collard et al. (2005) argue that while computers and software increase electricity intensity of production the diffusion of communication devices decreases electricity intensity in the service sector.

Cho et al. (2007) assess the impact of information and communication technology investment on electricity intensity which is measured by the ratio of electricity consumption to value added in 11 South Korean industries during the period 1991-2003. In the empirical analysis, the authors use a dynamic logistic diffusion model and find that information and communication technology investment raises electricity intensity in the service and manufacturing sectors.

Laitner and Ehrhardt-Martinez (2008) investigate the energy saving impacts of information and communication technology for the US economy by using existing evidence and find that for every extra kilowatt-hour of electricity demanded by information and communication technology the energy savings of the US economy raised by a factor of almost 10. Laitner and Ehrhardt-Martinez (2008) argue that this energy savings mainly stems from the widespread use of information and communication technology.

Ropke et al. (2010) evaluate the transformations of everyday practices which result from information and communication technologies by conducting qualitative interviews in Denmark in 2007-2008. By taking into account the results of the interviews, Ropke et al. (2010) conclude that the diffusion of information and communication technologies to everyday life practices leads to increasing electricity consumption.

Sadorsky (2012) examines the effect of information and communication technology on electricity consumption in emerging countries over the period 1993-2008. The author uses a panel data set which covers 19 emerging economies. By drawing on Generalized Method of Moments estimator developed by Arellano and Bond (1991) Sadorsky (1992) comes to the conclusion that information and communication technology variables have a positive and statistically significant effect on electricity consumption in emerging countries over the period under investigation.

Saidi et al. (coming soon) investigate the effect of information and communication technology and economic growth on electricity consumption for a panel of 67 countries over the period 1990-2012. The authors use Generalized Method of Moments estimator developed by Arellano and Bond (1991) in their empirical analysis and find that information and communication technology has a positive and statistically significant effect on electricity consumption.

In summary, as it is clearly seen from the above explanations the number of studies which focus on the effects of information and communication technology on energy consumption is very low and the results of the existing studies change with regard to the different methodologies, time periods and countries used in the empirical analyses. Hence, more studies are needed in order to reach firm conclusions and thereby to determine the necessary policy changes which help to increase energy efficiency by applying information and communication technologies. This study aims to fill in this gap in the existing literature.

3. Empirical Methodology and Data

In this study, the effect of information and communication technology on electricity consumption is investigated by estimating an electricity demand equation for a panel of European Union countries.

Since Autoregressive Distributed Lag (ARDL) model is generally used in order to estimate country specific energy demand equations in the literature (Liu, 2004; Sadorsky, 2012) Mean Group (MG) and Pooled Mean Group (PMG) estimators developed by Pesaran and Smith (1995) and Pesaran et al. (1999) respectively are employed to estimate the dynamic panel specification form of the ARDL model. While MG estimates regressions for each group separately and then calculate the means of coefficients over groups (Pesaran and Smith, 1995) PMG allows the intercepts, short run coefficients and error variances to be different but, assumes that long run coefficents are equal across groups (Pesaran et al., 1999). Together with MG and PMG estimators dynamic fixed effects (DFE) estimator is used in this empirical analysis as well. Similar to the PMG estimator, DFE estimator assumes cointegrating coefficients to be equal across all panels (Blackburne and Frank, 2007: 206). Furthermore, DFE estimator also assumes the speed of adjustment and short-run coefficients to be equal across panels (Blackburne and Frank, 2007: 206). After estimating the regressions by using these three different estimators Hausman (1978)'s

specification test is used in order to determine which results are more consistent and hence which estimator should be preferred.
The dynamic panel specification form of the ARDL model is stated as follows (Blackburne and Frank, 2007: 198):

$$y_{it} = \sum_{j=1}^{p} \alpha_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} x_{i,t-j} + \mu_i + \varepsilon_{i,t} \quad (1)$$

where x_{it} is a k x 1 vector of explanatory variables, δ_{ij} are k x 1 coefficient vectors, α_{ij} are scalars and μ_i is the group-specific effect. This equation can be reparameterized as an error correction equation (Blackburne and Frank, 2007: 198, 199):

$$\Delta y_{it} = \varphi_i \left(y_{i,t-1} - \rho'_i x_{it} \right) + \sum_{j=1}^{p-1} \alpha^*_{ij} \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \delta'^*_{ij} \Delta x_{i,t-j} + \mu_i + \varepsilon_{it} \quad (2)$$

where $\varphi_i = -(1 - \sum_{j=1}^{p} \alpha_{ij})$, $\rho_i = \sum_{j=0}^{q} \delta_{ij} / (1 - \sum_k \alpha_{ik})$, $\alpha^*_{ij} = -\sum_{m=j+1}^{p} \alpha_{im}$, j= 1, 2, ..., p-1 and

$\delta^*_{ij} = -\sum_{m=j+1}^{q} \delta_{im}$, j=1, 2, ..., q-1.

In equation 2, two parameters are especially important. The first one is the speed of adjustment term (φ_i).This parameter should be significantly negative in order to have a long run equilibrium relationship between the variables (Blackburne and Frank, 2007: 198, 199). The second parameter is ρ'_i which represents the long run relationship between the variables (Blackburne and Frank, 2007: 199).
In line with the above explanations, the electricity demand equation which is estimated in the empirical analysis is as follows:

$$ed_{i,t} = -\sigma_i \left(ed_{i,t-1} - \alpha_1 gdppc_{i,t} - \alpha_2 cpi_{i,t} - \alpha_3 ict_{i,t} - \alpha_4 crisis_{i,t} - \alpha_{0,i} \right) + \theta_{1,i} \Delta gdppc_{i,t} + \theta_2 \Delta cpi_{i,t} + \theta_3 \Delta ict_{i,t} + \theta_4 \Delta crisis_{i,t} + \varepsilon_{i,t} \quad (3)$$

In equation 3, ed is the electric power consumption kW per capita, gdppc is the gross domestic product per capita (constant 2005 US $), cpi is the consumer price index (2010=100), ict is the information and communication technology variable which is represented by two indicators, i.e. internet users (per 100 people) and mobile cellular subscriptions (per 100 people), crisis is a dummy variable which stands for the 2008 Global Economic Crisis, ε is the error term and i and t are the country and time subscripts respectively. Consumer price index is used as a proxy for electricity prices since in the existing literature many researchers used this indicator especially when the data for electricity prices are not reliable or available (see for example; Mahadevan and Asafu-Adjaye, 2007; Odhiambo, 2010 and Sadorsky, 2012). All data are taken from the World Bank-World Development Indicators Data Base (2015).

Equation 3 is estimated for a panel of 20 European Union countries[1] over the period 1990-2012. The countries and the time period are determined according to the data availability. The variables are used in their natural logarithmic forms in the estimations. In order to evaluate the effect of information and communication technology on electricity consumption two different models are estimated. While in the first model internet users (per 100 people) are used as information and communication technology variable in the second model mobile cellular subscriptions (per 100 people) are employed.

4. Results

As it is very well-known, the ARDL methodology can be employed as long as the series are stationary (I(0)) or integrated in the first order (I(1)) (Pesaran and Smith, 1995; Pesaran et al., 1999). Thus, in order to ensure that the variables are either I(0) or I(1) Im-Pesaran-Shin (Im et al., 2003) and Fisher type unit root tests (Fisher-ADF) (Choi, 2001) are calculated before the main estimations. Table 1 presents the results of these unit root tests. As it is clearly seen from the table, all of the variables are either stationary or integrated in the first order. So, the ARDL methodology can be used in order to estimate the models.

[1] These countries are Austria, Belgium, Bulgaria, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Spain, Sweden and the United Kingdom.

Table 1: Unit Root Test Results

Variables	Im-Pesaran-Shin	ADF-Fisher Chi-Square	ADF-Choi-Z Stat
Ed	-0.71601	46.6440	-0.49620
Gdppc	-0.33162	44.9433	-0.20142
Cpi	-2.52022***	121.321***	-1.12657
int. Users	-23.1608***	463.937***	-17.6548***
mobile subs.	-12.3262***	224.883***	-10.6871***
Δed	-5.76921***	138.820***	-4.66225***
Δgdppc	-7.60636***	133.882***	-7.17803***
Δcpi	---	157.631***	-8.19300***
Δint. users	---	---	---
Δmobile subs.	---	---	---

Note: *, **, *** indicate 10%, 5% and 1% significance levels respectively. For both the Im-Pesaran-Shin and Fisher-ADF tests H_0 hypothesis states that all panels contain unit roots. All test statistics are estimated by adding an intercept to the models. Lag length is chosen according to the Akaike Information criterion.
Source: Author's estimations.

Besides the order of integration of the variables it is important to determine the lag structure of the ARDL model before the estimations. Since the data set used in this empirical analysis has only twenty three observations for each country and hence does not cover a long period of time a common lag structure of ARDL(1, 1, 1, 1, 1) is imposed to the variables.

Table 2 and table 3 summarize regression results. Whilst table 2 shows the results of the regressions in which internet users (per 100 people) are used as information and communication technology variable table 3 presents the results of the regressions in which mobile cellular subscriptions (per 100 people) are employed as an indicator of information and communication technology. On both of the tables, while the first and second columns show the results of the model which is estimated by PMG estimator the third and fourth and the fifth and sixth columns present the results of the models which are estimated by MG and DFE estimators respectively. The Hausman test statistic which is employed to choose the most consistent estimator is also presented in the tables.

In order to evaluate the impact of information and communication technology on electricity consumption the estimator which is more consistent than the other estimators shoud be decided at first. According to the results of the Hausman test statistic, PMG estimator is the most consistent and hence the most efficient estimator. Therefore, the results of the regressions which are estimated by PMG estimator should be taken into account while assessing the effect of information and communication technology on electricity consumption.

When the results in table 2 (column 1 and column 2) are examined it is seen that the control variables (GDP per capita, consumer price index and crisis) are statistically significant and generally have the expected signs both in the short-run and the long-run. The information and communication technology variable (internet users per 100 people) is also statistically significant and has a positive effect on the electricity consumption in the long-run. Therefore, it is stated that an increase of the internet users raises the electricity consumption in the European Union countries in the long-run.

The results in table 3 (column 1 and column 2) are similar to the results in table 2 with regard to the control variables. Once again, control variables are statistically significant and have generally the expected signs both in the short-run and the long-run. In addition to this, the information and technology variable (mobile cellular subscriptions per 100 people) is statistically significant and has a positive impact on electricity consumption in the long-run. This result is in line with the previous results. However, the information and communication technology variable is also statistically significant in the short-run. According to the short-run coefficient estimates, the information and communication technology variable has a negative effect on electricity consumption. Hence, these results indicate that while the usage of information and comunication technology leads to a decrease in electricity consumption in the short-run it causes an increase in electricity consumption in the long-run.

Table 2: Regression Results with the Internet Users (per 100 people)

	PMG		MG		DFE	
Explanatory Var.	**Long Run**	**Short Run**	**Long Run**	**Short Run**	**Long Run**	**Short Run**
gdppc	0.4891***		0.9120**		0.4624**	
	(0.0257)		(0.3937)		(0.2357)	
cpi	-0.0938***		-0.2126		-0.1076	
	(0.0270)		(0.1508)		(0.0708)	
int. users	0.0178***		0.0296**		0.0037	
	(0.0019)		(0.0134)		(0.0194)	
crisis	-0.0461***		0.2693		-0.0510	
	(0.0049)		(0.2798)		(0.0512)	
ec		-0.4089***		-0.8598***		-0.0861***
		(0.0970)		(0.1016)		(0.0233)
Δgdppc		0.3970***		0.1732*		0.5357***
		(0.0737)		(0.0920)		(0.0611)
Δcpi		-0.1584*		0.0397		-0.0337***
		(0.0861)		(0.1842)		(0.0080)
Δint. users		-0.0047		-0.0087		-0.0018
		(0.0067)		(0.0060)		(0.0062)
Δcrisis		0.0150***		0.0176*		0.0032
		(0.0052)		(0.0105)		(0.0063)
cons		1.7593***		4.0658***		0.3911*
		(0.4357)		(1.2414)		(0.2179)
Hausman Test	1.54 (0.8193)				2.80 (0.5920)	

Note: *, **, *** indicate 10%, 5% and 1% significance levels respectively. Standard errors are in paranthesis. While the first, third and fifth columns show long run coefficient estimates the second, fourth and sixth columns show both short run coefficient estimates and the speed of adjustment (ec) parameter. The chosen lag structure is ARDL(1, 1, 1, 1, 1). The models are estimated by using xtpmg routine in Stata. Hausman test indicates that PMG estimator is more consistent and more efficient than the MG and DFE estimators.
Source: Author's estimations.

Table 3: Regression Results with the Mobile Cellular Subscriptions (per 100 people)

	PMG		MG		DFE	
Explanatory Var.	**Long Run**	**Short Run**	**Long Run**	**Short Run**	**Long Run**	**Short Run**
gdppc	0.4373***		0.5653**		0.1688	
	(0.0331)		(0.2363)		(0.1832)	
cpi	-0.0866***		-0.2223		-0.1435***	
	(0.0194)		(0.1950)		(0.0481)	
mobile subs.	0.0181***		0.0258**		0.0277	
	(0.0030)		(0.0103)		(0.0190)	
crisis	-0.0259***		0.0811		-0.0422	
	(0.0056)		(0.1002)		(0.0376)	
ec		-0.3789***		-0.8112***		-0.1117***
		(0.0733)		(0.0892)		(0.0230)
Δgdppc		0.5380***		0.3624***		0.5496***
		(0.0691)		(0.0670)		(0.0541)
Δcpi		-0.1214		-0.1480		-0.0257***
		(0.1445)		(0.2029)		(0.0060)
Δmobile subs.		-0.0317**		-0.0482***		-0.0176**
		(0.0141)		(0.0140)		(0.0069)
Δcrisis		0.0091**		0.0258**		0.0047
		(0.0042)		(0.0118)		(0.0058)
cons		1.8044***		5.1383***		0.8478***
		(0.3753)		(1.3574)		(0.2207)
Hausman Test	1.80 (0.7718)				7.71 (0.1026)	

Note: *, **, *** indicate 10%, 5% and 1% significance levels respectively. Standard errors are in paranthesis. While the first, third and fifth columns show long run coefficient estimates the second, fourth and sixth columns show both short run coefficient estimates and the speed of adjustment (ec) parameter. The chosen lag structure is ARDL(1, 1, 1, 1, 1). The models are estimated by using xtpmg routine in Stata. Hausman test indicates that PMG estimator is more consistent and more efficient than the MG and DFE estimators.
Source: Author's estimations.

In summary, the regression results demonstrate that the usage of information and communication technology raises electricity consumption in the European Union countries in the long-run. Although the results of the regressions in which mobile cellular subscriptions (per 100 people) are used as the information and communication technology variable indicate that information and communication technology reduces electricity consumption in the short-run this effect disappears in the long-run. Thus, it is stated that even though the usage of information and communication technology can lead to efficiency gains and thereby a decrease in electricity consumption in the short-run these gains and the reduction in electricity consumption disappear in the long-run.

5. Conclusion

In recent years, the development and diffusion of information and communication technology have influenced both developed and developing economies dramatically. One of the major impacts of information and communication technology is related to energy consumption. While the development and diffusion of information and communication technology can lead to a reduction in energy consumption by increasing efficiency it also causes more energy demand because of its electricity requirement for operation. Hence, the effect of information and communication technology on energy consumption is an open question.

Although the impact of information and communication technology on energy consumption is not clear there are very few studies which empirically analyze this issue in the existing literature. In this study, it is tried to fill in this gap in the literature by investigating the effect of information and communication technology on electricity consumption for a panel of 20 European Union countries over the period 1990-2012.

According to the results of the empirical analysis, information and communication technology has a positive effect on electricity consumption in the European Union countries in the long-run. Although the results indicate that information and communication technology can decrease electricity consumption in the short-run (when the information and communication technology represented by mobile cellular subscriptions per 100 people) this effect disappears in the long-run. So, it is argued that while the development of information and communication technology leads to energy savings by increasing efficiency in the short-run these effects are reversed in the long-run. Therefore, the electricity requirement of information and communication technology overrides its efficiency gains and hence causes an increase in electricity consumption in the long-run.

When the unprecedented penetration of information and communication technology into everyday life is taken into account together with these empirical results it is suggested that electricity consumption will continue to increase in the European Union countries in the future. For this reason, policy makers should urgently take the necessary steps in order to meet this rise in energy consumption.

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