The Impact of Digital Technologies on OECD Energy Demand

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Abstract
Information and Communication Technologies (ICTs) offer many opportunities for energy saving, such as optimising energy use in buildings and industrial processes, but the continuing increases in the number, power and range of applications of ICTs may act to increase energy demand. Thus, the overall nets impact of ICTs on energy demand is ambiguous. In this paper, we provide estimates of the equations for the share in energy in variable cost by employing ordinary least squares method as well as report the elasticity of energy use with respect to ICT capital services. Our results suggest that investment in ICTs is associated with a modest reduction in energy demand, with the impact being much larger in the service sectors. Furthermore, we find that ICTs reduce electricity demand whereas it has a negligible impact on non-electric energy demand. These results appear robust to a variety of specifications. The findings are relevant to the role of digitalisation in delivering net-zero emissions.

Keywords: Digital technologies, energy demand, energy efficiency

1. Introduction

Information and communication technologies (ICTs) have complex implications for energy demand. On the one hand, ICTs offer many opportunities for energy saving, such as optimising energy use in buildings and industrial processes, but the continuing increases in the number, power and range of applications of ICTs may act to increase energy demand. Thus, the overall impact is ambiguous and therefore we address the following question: What is the overall impact of ICTs on industrial energy demand? We construct a cross-country and cross-sector panel dataset for 17 countries (EU countries, Australia, Japan and USA) and 28 sectors covering the period 1995-2007 and show the effect of ICTs on industrial energy demand using ordinary least squares (OLS) regression techniques. We report the demand elasticity with respect to ICT capital services, to measure the size of the effect. Furthermore, we investigate the net effect of ICT capital services on electric and non-electric energy using OLS regression techniques. And finally, to provide additional confidence in our results, we conduct several robustness checks.

The results show that investments in ICTs have a modest reduction in energy demand across all sectors and countries taken together. However, there is evidence of relatively high negative effect of ICTs on energy demand in the service sector. Furthermore, we study the effect of ICT on electricity and non-electric energy demand and find that ICTs reduce electricity demand whereas it has a negligible impact on non-electric energy demand. These results are consistent across different samples and are robust to several specifications to provide additional confidence in our research outputs.

Previous studies have focussed on the impact of ICT on energy demand. For example, Schulte et al. (2016) examined the impact of ICT on energy demand from 1995-2007 for 10 OECD countries. They found a negative relationship between ICT and total energy demand. Furthermore, ICT had no significant effect on electric energy demand whereas increase in ICT lowered non-electric energy demand. Collard et al. (2005) investigated the effects of ICT on electricity consumption in six French service industries from 1978-1998. The authors concluded that electricity consumption increased with computers and software, and reduced with the diffusion of communication devices. Bernstein and Madlener (2010) used the same approach as Collard et al. (2005) and examined the impact of ICT capital on the electricity intensity of five European manufacturing industries. Similar to Collard et al. (2005), their results showed a negative effect of the diffusion of communication devices on electricity intensity. However, the impact of computers and software was not clear as there were variations across industries. Takase and Murota (2004) did a simulation analysis and investigated the impact of IT investment on energy consumption and CO_2 emissions in US and Japan. Their calculations showed that the substitution effect is dominant in Japan, however, the income effect is dominant in the US.

Other studies examining the effect of ICT on electricity consumption include the works of Sadorsky (2012) for 19 countries, Salahuddin and Alam (2016) for OECD countries, and Saidi et al. (2017) for 67 countries. The authors consistently found a significant and positive effect of ICT on electricity consumption. Similarly, Cho et al. (2007) discovered a positive effect of ICT on electricity consumption within the service sector and most manufacturing sectors in South Korea, however, a negative effect was found in the “primary metal product” manufacturing sector. A negative effect ICT on energy consumption was also found by Ishida (2015) for Japan.

Thus, while previous studies have examined the impacts of ICTs on energy demand, our study benefits from using an extensive dataset, covering more countries and industrial sectors than Schulte et al. (2016). The additional countries include Austria, Belgium, Czech Republic, France, Hungary, Ireland, Spain and Sweden. For industrial sectors, our data includes real estate, which was excluded by Schulte et al. (2016). Additionally, the energy quantity data in our study has information on renewable energy, i.e. industrial and municipal waste, bio gasoline, biodiesel, biogas, nuclear, hydroelectric, geothermal, solar, wind. Thus, this study uses a cross country and cross industry panel dataset and examines the net effect of ICTs on energy demand for 17 OECD countries, 28 sectors from 1995-2007, using the OLS techniques. To the best of our knowledge, previous studies have not used such a large dataset to examine the net effect of ICTs on energy demand. Our results show to what extent ICTs contribute in lowering energy use and can help achieve the net zero emissions targets.

This paper is set out as follows: Section 2 presents the data sources and explains the construction of the variables. Section 3 discusses the economic model and the empirical results are presented in Section 4. Section 5 draws the conclusion.

2. The Data

The collection and construction of the data used in the empirical analysis is described below.

EU-KLEMS database

The main data source is the EU-KLEMS growth and productivity accounts, November 2009 release. This gives a harmonised estimate of inputs (capital and labour), value added and other measures for 30 sectors at a two-digit industrial classification level (NACE 1.1) for 29 countries between 1995-2007. Our empirical analysis includes 17 countries as the ICT data in EU-KLEMS is available for only these countries. Two industrial sectors, i.e. 'electricity, gas and water' and 'coke, refined petroleum and nuclear fuel' are different because both are energy producing and are not included in the analysis. This gives us a total of 28 sectors for 13 years.

World Input Output Database (WIOD) and 'International Energy Agency (IEA) Energy Prices and Taxes' databases

The data for disaggregated energy use by industrial sectors is obtained from the WIOD 2013 Environmental Accounts with the same NACE 1.1 industrial classification as EU KLEMS 2009 and we use emission relevant energy use. We use the disaggregated energy use to construct electric and non-electric energy use. For electric energy aggregate, we add together the following energy commodities: electricity, nuclear, hydroelectric, geothermal, solar and wind for each industrial sector. For non-electric energy aggregates, we sum the following: hard coal and derivatives, lignite and derivatives, coke, crude oil, NGL and feedstocks, diesel oil, motor gasoline, jet fuel, light fuel oil, heavy fuel oil, other petroleum products, natural gas, derived gas, industrial and municipal waste, biogasoline, biodiesel, biogas, other combustible renewables, heat and other sources. Total energy is the sum of electric and non-electric energy.[1] Additionally, we calculate the share of electric and non-electric energy use using the disaggregated energy use data from WIOD.

Data on energy prices is taken from the IEA's Energy Prices and Taxes database. The energy prices for electric and non-electric energy is in US dollars per tonne of oil equivalent, and we use the industrial electricity prices.[2] The IEA dataset of prices is used to acquire prices of non-electric energy sources. Following Schulte et al. (2016), high-Sulphur fuel oil price is used for oil (replaced by low-Sulphur fuel oil or light fuel oil if prices were not available), natural gas price is used for gas (replaced by liquified petroleum gas if necessary), steam coal price is used for coal (replaced by coking coal if necessary), and automotive diesel price is used for petroleum. The price of electricity for electric energy is already available for each country and

[1] For more information, see the WIOD website http://www.wiod.org/database/eas13

[2] For more information on the IEA Energy Prices and Taxes Database, see http://stats2.digitalresources.jisc.ac.uk/

year. As the IEA dataset has the prices in US dollars per ton of oil equivalent, following Schulte et al. (2016), all energy prices are recalculated into US dollars per terajoule, in order to have a common unit between prices and quantities. The non-electric energy prices from IEA are then applied to the non-electric energy quantities of each country and year from the WIOD. A price of zero is applied to the quantities for the remaining non-electric components (waste, heat production and other sources). These quantities of non-electric energies are used as weights to calculate the weighted average non-electric energy price for each sector, country and year:

$$NonElecP_{c,t,s} = \frac{\sum_{ne=1}^{5} Price_{ne,c,t} Quant_{ne,c,t,s}}{\sum_{ne=1}^{5} Quant_{ne,c,t,s}} \quad (1)$$

where $NonElecP_{c,t,s}$ is the weighted average non-electric energy price for country c in year t and sector s, $Price_{ne,c,t}$ is the price of non-electric energy for category $ne = 1, \ldots, 5$ for country c in year t, $Quant_{ne,c,t,s}$ is the quantity of non-electric energy for category *ne* for country c in year t and sector s.

Total energy price is then calculated as below:

$$TotEnP_{c,t,s} = \sigma NonElecP_{c,t,s} + (1 - \sigma) ElecP_{c,t} \quad (2)$$

where $TotEnP_{c,t,s}$ is the total energy average price for country c in year t and sector s, $ElecP_{c,t}$ is the electric energy price for country c in year t, and σ is the share of non-electric energy use in the total energy use.

Multiplying total energy average price by total energy used then gives the total energy cost.

Transforming the nominal values to real values by using Purchasing Power Parity (PPP)

The total PPP is given in the OECD database and is used to transform nominal values to real values and common currency (US Dollars)[3]. If we take ICT capital as an example, we start by having the values of ICT capital compensation for each sector, country and year (from the KLEMS database). Using the value of ICT capital compensation in 1997 as the base year, we calculate the ICT capital compensation index (1997 = 100). From the KLEMS database, we have values of the ICT capital services quantity index (1997=100). Using the fact that ICT capital compensation should be equal to price of ICT capital service times the quantity of ICT capital service, we calculate the ICT capital services price index as below:

$$ICT_{cspi} = \frac{ICT_{cci}}{ICT_{csqi}} \times 100 \quad (3)$$

where ICT_{cspi} is ICT capital service price index, ICT_{cci} is ICT capital compensation index and ICT_{csqi} is ICT capital service quantity index.

[3] For more information on PPP values, see OECD - PPP

Once the ICT capital service price index is calculated, we proceed to construct the conversion factor that will change the ICT capital compensation from nominal to real values. The conversion factor takes the same form as in Schulte et al. (2016). It is calculated for each sector and country as:

$$CF_{c,t,s} = \left(\frac{ICTPI_{c,1997,s}}{ICTPI_{c,t,s}}\right) * \left(\frac{1}{PPP_{c,1997}}\right) \tag{4}$$

where $CF_{c,t,s}$ is the conversion factor for country c in year t and sector s, $ICTPI_{c,t,s}$ is the ICT capital price index for country c in year t and sector s, $PPP_{c,1997}$ is the total PPP value for country c in year 1997.

The conversion factor is then multiplied by the nominal values of ICT capital compensation and the result gives the real values of ICT capital compensation in real 1997 US dollars. The same approach is used to find the real values of other variables (see Table 2).

3. Economic Model

We follow Schulte et al. (2016) and use a similar economic model to investigate the impact of ICTs on industrial energy demand. Thus, the restricted variable cost is as follows:

$$VarCost = f\,(P_E, P_L, K_I, K_{NI}, Y, t) \tag{5}$$
$$VarCost = P_E E + P_L L$$

In the above equation, VarCost is variable cost. P_E represents energy price and E represents energy quantity. Similarly, P_L represents labour price and L represents labour quantity. K_I and K_{NI} are ICT and non-ICT capital services respectively. Y is real output and t represents time. Employing the translog function, which is flexible and is consistent with economic theory, it equals to the following equation:

$$\begin{aligned}\ln VarCost = {} & \beta_0 + \beta_Y \ln Y + \frac{1}{2}\beta_{YY}\ln(Y)^2 + \beta_T t + \frac{1}{2}\beta_{TT}t^2 + \sum_E \beta_E \ln P_E + \sum_I \beta_{K_I}\ln K_I \\ & + \frac{1}{2}\sum_E\sum_L \beta_{EL}\ln P_E \ln P_L + \frac{1}{2}\sum_I\sum_{NI}\beta_{K_I K_{NI}}\ln K_I \ln K_{NI} + \sum_E \beta_{EY}\ln P_E \ln Y \\ & + \sum_I \beta_{K_I Y}\ln K_I \ln Y + \sum_E\sum_I \beta_{EK_I}\ln P_E \ln K_I + \sum_E \delta_{ET}\ln P_E t \\ & + \sum_I \delta_{K_I T}\ln K_I t \\ & + \delta_{YT}\ln Y_t \end{aligned} \tag{6}$$

From the logarithmic differential of the cost function with respect to the price, the cost share equation is:

$$S_E = \beta_E + \beta_{EE}\, ln(\tfrac{P_E}{P_L}) + \beta_{EK_I}\, ln(\tfrac{K_I}{Y}) + \beta_{EK_{NI}}\, ln(\tfrac{K_{NI}}{Y}) + \beta^*_{EY} lnY + \delta_{ET}t \tag{7}$$

Equation 7 is the share of energy in variable costs (S_E), which forms the basis of our econometrics model, where $S_E= (\frac{P_E E}{\text{VarCost}})$.[4] We also include dummy variables for country, sector and years as well as include year as a continuous variable with the sector and country dummy variables in a separate model. The interpretation of the coefficients is as follows: β_{EKI} is the main variable of interest as it indicates the relationship between energy cost share and ICT capital. Following Schulte et al. (2016), the elasticity of energy demand ($\eta_{K_I}(E)$) with respect to ICT capital services is calculated using the following formula:

$$\eta_{K_I}(E) = \frac{\beta_{EK_I}}{S_E} - S_{K_I} \tag{8}$$

The elasticity of energy demand with respect to ICT capital depends upon the ICT coefficient (β_{EK_I}), the energy cost share (S_E) and S_{K_I}, where $S_{K_I} = \frac{P_{K_I} K_I}{VarCost}$, P_{K_I} represents the price of ICT capital services.

The own price elasticity of demand is calculated as follow:

$$\eta_{\beta_{EE}}(E) = \frac{\beta_{EE}}{S_E} + S_E - 1 \tag{9}$$

The own price elasticity of energy demand depends on the energy price coefficient β_{EE} and the energy cost share (S_E).

Furthermore, we investigate the effects of ICT on electric energy cost share and non-electric energy cost share by employing OLS. Equation 10 is used to estimate the disaggregated energy cost share.

$$SE_h = \beta_h + \beta_{helectric} \ln\left(\frac{Pelectricindex}{PL\ index}\right) + \beta_{hnonelectric} \ln\left(\frac{Pnonelectricindex}{PL\ index}\right) + \beta_{hK_I}\, ln\left(\frac{K_I}{Y}\right) + \beta_{hK_{NI}}\, ln\left(\frac{K_{NI}}{Y}\right) + \beta^{*}_{hY}\, lnY + \delta_{ET} t \tag{10}$$

where h ={electric, non-electric}

4. Results

4.1 The impact of ICT on total energy demand

Table 1 represents the main results using OLS method for 17 countries and 28 industrial sectors from 1995-2007.[5] The base model includes the main covariates of interest: relative energy prices, Ln (PE index/PL index); ICT capital services, Ln (KI/Y); non-ICT capital services, Ln (KNI/Y) and real output, Ln Y.

[4] Following Schulte et al. (2016), $\beta^{*}_{EY} = \beta_{EY} + \beta_{EK_I} + \beta_{EK_{NI}}$, which transforms the capital inputs into capital intensities.

[5] As the data is a panel dataset, we conducted a heteroskedasticity test using Breusch Pagan test. The Chi squared calculated is 12373.36, implying the presence of heteroskedasticity.

From model 1, the coefficient on ICT capital services is small and negative, and it is significant at 1 percent, whereas the coefficient on non-ICT is positive and significant. This indicates that ICT and non-ICT have a very small effect on the energy cost share. The average elasticity of energy demand with respect to ICT capital service is -0.1937, implying that a 1 percent increase in ICT results in lowering energy use by 0.19 percent. The coefficient on output is negative and is statistically significant at 1 percent, suggesting non-constant returns to scale; however, the coefficient is small. And the relative price of energy has no effect on energy cost share. Model 2 includes the main covariates of interest, and the country and sector dummy variables. The size of the ICT coefficient is small and statistically significant, suggesting an extremely small effect on energy cost share. Similarly, non-ICT is statistically significant with a small positive coefficient. Comparing the energy price variable from specification 1 to 2, relative energy price is now significant. The coefficient is negative implying that as energy price increases, the energy cost share falls. The average energy demand elasticity with respect to ICT capital services for model 2 is -0.0777, suggesting a reduction in energy use. In model 3, we include a time trend in order to capture technical change and other factors that might affect energy demand over time together with country and sector dummies in the model. We find that the time trend is significant, and country and sector dummies are mostly significant. And model 4 includes dummy variables for year, country and sector. We find that country, sector and year dummies are mostly significant. In both models 3 and 4, the ICT coefficient is small but insignificant, and all covariates show similar signs to model 2. Own price elasticity of energy demand is also reported in Table 1 and as expected, it is negative for all specifications.

Table 1: OLS results on ICT and total energy demand

Variables	Model 1	Model 2	Model 3	Model 4
Ln (PE index/PL index)	-0.0058	-0.0238***	-0.0279***	-0.0468***
	(0.0042)	(0.0029)	(0.0029)	(0.0038)
Ln (KI/Y)	-0.0070***	0.0026**	-0.0009	0.0003
	(0.0010)	(0.0011)	(0.0014)	(0.0014)
Ln (KNI/Y)	0.0400***	0.0105***	0.0118***	0.0111***
	(0.0019)	(0.0012)	(0.0012)	(0.0012)
Ln Y	-0.0077***	0.0089***	0.0067**	0.0073**
	(0.0006)	(0.0028)	(0.0030)	(0.0030)
Constant	0.2956***	-0.1696***	-2.5143***	-0.1383**
	(0.01646)	(0.0653)	(0.4926)	(0.0684)
Time trend	No	No	Yes	No
Year DVs	No	No	No	Yes
Country DVs	No	Yes	Yes	Yes
Sector DVs	No	Yes	Yes	Yes
Average demand elasticity with respect to ICT	-0.1937	-0.0777	-0.1205	-0.1049
Own price elasticity of energy demand	-0.9881	-1.2072	-1.2576	-1.4869
Number of observations	5109	5109	5109	5109

*Notes: Robust standard errors shown in parentheses. All estimation outputs are corrected for heteroskedasticity by using robust command. Significance levels are the following: *** p<0.01, ** p<0.05 and *p<0.1.*

In summary, Table 1 shows that the coefficients of the main covariates and demand elasticities are quantitatively consistent across different specifications. Overall, investments in ICTs are associated with a modest reduction in energy demand across all industries and countries taken together.

Next, we split the sample into three broad sectors, i.e. 'manufacturing', 'services' and 'other sectors'. Table 2 shows the impact of the main covariates on the energy cost share for all countries from 1995-2007 separately for the manufacturing sector (model 5), service sector (model 6) and the other sectors (model 7) using OLS regression technique. First, investigating the manufacturing sector in model 5, the ICT coefficient, i.e. Ln (KI/Y) is positive and significant at 10 percent. The coefficient for non-ICT, i.e. Ln (KNI/Y) is positive and significant. And the relative energy price coefficient is negative and significant at 1 percent. The average elasticity of energy demand with respect to ICT capital is -0.0149, indicating that ICT capital does not contribute much to energy savings in the manufacturing sectors. For services, we find that the ICT coefficient is negative and significant at 1 percent (model 6). Non-ICT has a positive coefficient whereas energy price and output have negative coefficients. Interestingly, the estimated demand elasticity for the service sector is -0.3509, suggesting that a 1 percent increase in ICT decreases energy demand by 0.35 percent. This indicates that there is evidence of relatively larger energy savings in the service sectors.

Table 2: OLS results on ICT and total energy demand for different sectors

Variables	Model 5: Manufacturing	Model 6: Services	Model 7: Other sectors
Ln (PE index/PL index)	-0.0633***	-0.0227***	-0.0464***
	(0.0065)	(0.0028)	(0.0137)
Ln (KI/Y)	0.0067*	-0.0066***	0.0117**
	(0.0034)	(0.0012)	(0.0047)
Ln (KNI/Y)	0.0116***	0.0045***	0.0083**
	(0.0026)	(0.0008)	(0.0033)
Ln Y	-0.0007	-0.0100***	0.0185***
	(0.0031)	(0.0017)	(0.0069)
Constant	0.1579**	0.2312***	-0.2325
	(0.0691)	(0.0400)	(0.1671)
Year DVs	Yes	Yes	Yes
Country DVs	Yes	Yes	Yes
Sector DVs	Yes	Yes	Yes
Average demand elasticity with respect to ICT	-0.0149	-0.3509	0.0337
Own price elasticity of energy demand	-1.4872	-1.6111	-1.1597
Number of observations	2228	2163	718

*Notes: Robust standard errors shown in parentheses. All estimation outputs are corrected for heteroskedasticity by using robust command. Significance levels are the following: *** p<0.01, ** p<0.05 and *p<0.1.*

Table 2 also shows the effect of ICT on energy cost share for the other sectors in model 7. The results show that ICT coefficient is significant at 5 percent and average demand elasticity calculated is 0.0337, which is different from other estimations. Therefore, in summary, after splitting the sample into sectors, we find energy savings in the service sectors whereas ICT capital services do not contribute much to energy savings in the manufacturing sectors.

4.2 The impact of ICT on electric and non-electric energy demand

To address the impact of ICT capital services on electric demand, Table 3 shows the results from OLS regression technique. Model 8 is the base model and includes the main covariate of interest, i.e. relative electric energy prices, Ln (Electric price index/labour price Index); relative non-electric energy prices, Ln (Non-electric price index/labour price index), ICT capital services, Ln (KI/Y); non-ICT capital services, Ln (KNI/Y) and real output, (Ln Y). Model 9 includes the main covariates of interest, country dummy and sector dummy variables. In model 10, we include a time trend with country and sector dummy variables to see the impact of the covariates on the energy cost share. And model 11 shows the impact of the covariates including dummy variables for year, countries and sectors.

Table 3: OLS results on ICT and electric energy demand

Variables	Model 8	Model 9	Model 10	Model 11
Ln (ElectricPI /PLIndex)	-0.0100***	-0.0072***	-0.0026	-0.0037
	(0.0025)	0.0017	(0.0018)	(0.0025)
Ln (NonelecPI / PLIndex)	0.0139***	0.0058***	-0.002	0.0019
	(0.0026)	0.0018	(0.0020)	(0.0020)
Ln (KI/Y)	-0.0059***	-0.0011	-0.0045***	-0.0028***
	(0.0005)	0.0007	(0.0009)	(0.0008)
Ln (KNI/Y)	0.0198***	0.0024***	0.0035***	0.0030***
	(0.0008)	0.0006	(0.0006)	(0.0006)
Ln Y	-0.004***	-0.0047***	-0.0066***	-0.0056***
	(0.0004)	0.0012	(0.0013)	(0.0013)
Constant	0.1367***	0.1160***	-2.5142***	0.1371***
	(0.0083)	0.0290	(0.3196)	(0.0295)
Time trend	No	No	Yes	No
Year DVs	No	No	No	Yes
Country DVs	No	Yes	Yes	Yes
Sector DVs	No	Yes	Yes	Yes
Average demand elasticity with respect to ICT	-0.2687	-0.1396	-0.2308	-0.1863
Own price elasticity of energy demand	-1.2358	-1.1593	-1.0348	-1.0644
Number of observations	5109	5109	5109	5109

*Notes: Robust standard errors shown in parentheses. All estimation outputs are corrected for heteroskedasticity by using robust command. Significance levels are the following: *** p<0.01, ** p<0.05 and *p<0.1.*

From the results, ICT capital service has a significantly negative coefficient on electric energy cost share for models 8, 9 and 11, and is significant at 1 percent. The average elasticity of electric energy demand with respect to ICT is -0.1396 for model 9 and -0.1863 for model 11. This indicates that investments in ICTs contribute to reducing electricity use. Furthermore, the own price elasticity of energy is -1.1593 for model 9, implying that a 1 percent increase in price decreases energy demand by 1.16 percent. The coefficient on non-ICT capital services is positive and highly significant, whereas the coefficient on real output is negative and significant at 1 percent for all models.

Focussing on non-electric energy, model 12 includes only the covariates of interest and the ICT coefficient is not significant. Model 13 shows the effect of the main covariates of interest, including country and sector dummy variables, and we find that the coefficient on ICT is positive and significant. The average elasticity with respect to ICT capital service is -0.0097, indicating a negligible impact on energy demand. The demand elasticity in model 15 is -0.0069 after including country, sector and time dummy variables, indicating a negligible impact. The coefficient on relative electric energy price is positive and the coefficient on relative non-electric energy prices is negative for all the models. The own price elasticity is also negative, as expected . Thus, in summary ICT capital services reduce electricity use but has a negligible effect on non-electric energy demand.

Table 4: OLS results on ICT and non-electric energy demand

Variables	Model 12	Model 13	Model 14	Model 15
Ln (ElectricPI/PLIndex)	0.0204***	0.0107***	0.0114***	0.0063*
	(0.0038)	(0.0026)	(0.0026)	(0.0037)
Ln (NonelecPI/PLIndex)	-0.0186***	-0.0179***	-0.0192***	-0.0199***
	(0.0028)	(0.0024)	(0.0025)	(0.0026)
Ln (KI/Y)	-0.0008	0.0046***	0.0040***	0.0047***
	(0.0008)	(0.0010)	(0.0013)	(0.0012)
Ln (KNI/Y)	0.0207***	0.0076***	0.0078***	0.0075***
	(0.0016)	(0.0010)	(0.0011)	(0.0011)
Ln Y	-0.0039***	0.0147***	0.0144***	0.0146***
	(0.0005)	(0.0028)	(0.0030)	(0.0029)
Constant	0.1667***	-0.3115***	-0.7562*	-0.3091***
	(0.0129)	(0.0646)	(0.4495)	(0.0665)
Time trend	No	No	Yes	No
Year DVs	No	No	No	Yes
Country DVs	No	Yes	Yes	Yes
Sector DVs	No	Yes	Yes	Yes
Average demand elasticity with respect to ICT	-0.1251	-0.0097	-0.0219	-0.0069
Own price elasticity of energy demand	-1.3537	-1.3394	-1.3677	-1.3831
Number of observations	5109	5109	5109	5109

*Notes: Robust standard errors shown in parentheses. All estimation outputs are corrected for heteroskedasticity by using robust command. Significance levels are the following: *** p<0.01, ** p<0.05 and *p<0.1.*

4.3 Robustness checks

We conduct some robustness checks in order to provide additional confidence in our results. Therefore, we divide our full sample into three categories by country. In other words, using our model 4 (with country, sector and year dummy variables), we conduct the following checks: First, the sample excludes the post-communist countries, i.e. Czech Republic and

Hungary (model 16), leaving 15 countries.[6] Second, our estimation sample has missing data for Australia, Sweden and Belgium, and thus the energy cost share equation is estimated excluding these three countries from the sample (model 17). Third, the sample excluding both post-communist countries and countries with missing data is shown in model 18. Table 5 shows the results for the three samples using OLS regression technique. Analysing model 16, the coefficient on ICT capital service is not significant. The coefficients on non-ICT capital service and real output is positively significant. As expected, relative energy prices are negative and significant at 1 percent. After excluding countries with missing data, model 17 shows that the coefficient on ICT capital service is small and negative but insignificant. The coefficient on non-ICT capital service is positive and significant at 1 percent. As expected, the sign of the coefficient on energy price is negative and the sign for the coefficient on output is positive. And lastly, model 18 shows that the coefficient on ICT capital service is positive but insignificant. Non-ICT capital service coefficient is positive but significant at 1 percent. The sign of the coefficient on relative energy prices and output are expected to be negative and positive respectively. These results are consistent with our main results and confirm that ICTs have a modest reduction on total energy demand after including sector and country dummy variables.

Table 5: Robustness checks

Variables	Model 16	Model 17	Model 18
Ln (Pe/Pl)	-0.0461***	-0.0477***	-0.0478***
	(0.0051)	(0.0039)	(0.0053)
Ln (KI/Y)	0.0012	-0.0003	0.0006
	(0.0016)	(0.0016)	(0.0018)
Ln (KNI/Y)	0.0092***	0.0114***	0.0094***
	(0.0013)	(0.0013)	(0.0014)
Ln Y	0.0150***	0.0069**	0.0156***
	(0.0035)	(0.0032)	(0.0038)
Constant	-0.3267***	-0.1140*	-0.3774***
	(0.0815)	(0.0679)	(0.0995)
Year DVs	Yes	Yes	Yes
Country DVs	Yes	Yes	Yes
Industry DVs	Yes	Yes	Yes
Average demand elasticity with respect to ICT	-0.0861	-0.1154	-0.0942
Own price elasticity of energy demand	-1.4589	-1.4978	-1.4763
Number of observations	4381	4753	4025

*Notes: Robust standard errors shown in parentheses. All estimation outputs are corrected for heteroskedasticity by using robust command. Significance levels are the following: *** p<0.01, ** p<0.05 and *p<0.1.*

5. Conclusion

We estimate the effect of ICT capital services on industrial energy demand and report the demand elasticity with respect to ICT capital services. Next, we split the whole sample into manufacturing, service and other sectors to study the impact of ICTs on energy demand.

[6] In order to check the consistency and robustness of the results, we chose to exclude the post-communist countries because there are structural breaks as Czech Republic and Hungary joined the EU in 2004.

Furthermore, we estimate the effect of ICT capital services on electric and non-electric energy demand. And finally, we conduct some robustness checks to provide additional confidence in our results. The results show that ICT capital services have a modest reduction in energy demand across all industries and countries taken together. Increasing efficiency of ICTs may be offset by the greater use of the ICTs themselves. These results are consistent across different samples and are robust to several specifications to provide additional confidence in our research outputs. Furthermore, splitting the sample into manufacturing, services and other sectors, we find that there is evidence of energy savings in the service sectors but ICT capital services do not contribute much to energy savings in the manufacturing sectors. And ICT capital services reduces electricity demand whereas it has a negligible impact on non-electric energy demand. These results demonstrate the contribution of ICTs in lowering energy use and are important in accomplishing the goals of net zero emissions. Future research can aim to study the impacts of ICT on energy demand in more recent years.

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