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The impact of disaggregated ICT capital on electricity intensity of production: econometric analysis of major European industries

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Abstract

In this paper we empirically analyse the impact of disaggregated ICT capital on the electricity intensity in five major European industries (chemical, food, metal, pulp & paper and textile). The analysis of each industrial sector is based on an unbalanced panel including data for eight EU member countries (Denmark, Finland, Germany, Italy, Portugal, Slovenia, Sweden and the UK) for the period 1991-2005. The panel-econometric approach, in which we account for country-specific fixed effects, is based on a factor demand model that is similar to the one derived in Collard et al. (2005) [Energy Economics 27 (2): 541-550] for the French services sector. On the one hand, the analysis provides evidence for an electricity-saving effect on production induced by communication technologies in all of the sectors considered. On the other hand, the effect of computers and software on the electricity intensity of industrial production is not that clear-cut, but rather seems to be strongly dependent on the sector-specific production processes involved. Overall, the net effect of ICT diffusion on electricity intensity of production appears to be in favour of an enhancement of electricity efficiency in production.

JEL classification: Q41, Q43

Keywords: Information and telecommunication technology; ICT; Electricity intensity; Panel data

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1. Introduction

Information and communication technologies (ICT) have played an increasing role in productive processes since the early 1980s. The current rise of interest in issues related to energy consumption levels and patterns in general, and that of electricity in particular, and the widespread belief that the diffusion of ICT might foster energy efficiency especially in energy-intensive production, motivated us to conduct an empirical analysis on the effect of ICT capital on electricity intensity in distinct industries.

ICT and e-business can help to reduce energy consumption and thus costs by reorganising business (production) processes, but it can also lead to additional demand for energy due to new products and services provided and the energy consumption of the ICT capital stock itself. Hence, the overall impact of ICT on energy consumption is ambiguous, and depends on the relative magnitude of two countervailing forces: (1) an *income effect* caused by the economic boost accruing from increased ICT use (increase in energy consumption) and (2) a *substitution effect*, caused by changes in the industrial structure and the capital stock towards higher productivity (decrease in energy consumption). Romm (2002) distinguishes between two types of energy savings related to the diffusion of ICT capital: *efficiency gains*, e.g. due to improved management of an assembly line, and *structural gains*, e.g. due to lowered individual transport needs because of increased Internet shopping. While such a distinction is conceptually appealing, it is usually very difficult to quantify these effects separately in empirical analyses.

Empirically, at the macroeconomic level, a certain decoupling between GDP and energy consumption has been observed in many industrialised countries, which some authors have attributed to the increasing role of ICT. Romm (2002), for instance, argues in a study for the U.S. that GDP and energy consumption grew on average by 3.2% and 2.4% per annum in the "pre-Internet era" (1992-1996) and by 4% and 1% in the "Internet era" (1996-2000). Laitner and Ehrhardt-Martinez (2008) find that ICT has dramatically increased economic productivity and energy efficiency of the U.S., and that ICT has decoupled the relationship between economic production and energy consumption throughout the economy. They conclude from their analysis that different applications and technologies enabled considerable energy savings, and that significant system-wide energy savings arose from the omnipresence of ICT.

Obviously, such an observed overall decrease in energy intensity, measured as the ratio between energy consumption and production, may not be the case in every single sector of the economy, and it may not be caused by the diffusion of ICT alone, but e.g. also due to a shift of the domestic economy towards less energy-intensive production sectors (and a corresponding shift of energy-intensive production to other, typically developing countries). Moreover, in contrast to energy intensity, the intensity of electricity use has in many countries been rising in recent years, or at least not been falling as markedly as energy intensity.

It is therefore interesting to study the relationship between the diffusion of ICT capital and the observed increase or decrease in electricity intensity of production. Cho et al. (2007), for example, by means of a dynamic logistic growth model and data from 1991-2003, study the impact of investment in ICT capital and energy price on industrial electricity demand in South Korea (for 11 different sectors). They find some evidence that (1) ICT investment in electricity-intensive manufacturing industries promotes factor substitution away from labour to electricity; (2) ICT investment in some manufacturing sectors reduces electricity consumption, while in most of the manufacturing and the services sector it increases electricity consumption; and (3) electricity price affects electricity consumption critically only in half of the industrial sectors studied.

In particular, studies within the e-Business Watch project (www.ebusiness-watch.org) have shown that generalisations have to be made with care, and that where computer & software and communications devices are analysed separately, this can yield important new insights. Disaggregate ICT capital data that has become available only recently via the EU-KLEMS project (www.eu-klems.net) enables an analysis of the relative impact of different ICT capital components.

Our econometric investigation is at the aggregate industry level, and thus neglects many micro-level issues veiled by aggregate data (e.g. the increasing embeddedness of ICT in products, or production- or location-specific issues), that can best be studied by qualitative analysis and case studies. It essentially builds upon a similar study for the French services sector by Collard et al. (2005), and extends the existing knowledge for the case of five key European industries – viz. chemical; food, drink and tobacco; metal and metal processing; pulp, paper and printing; and textile, leather and clothing. To our knowledge, at the time of writing, the data used in our study are the best available aggregate data with disaggregated ICT capital data for a set of countries. Further research in this field is both desirable and desperately needed, given the increasing importance of ICT in the economy, and pressing problems related to energy supply and use (e.g. rising energy prices, security of supply concerns, lack of investment in liberalised electricity markets) and its implications on society and the environment (e.g. climate change, urban smog).

The paper proceeds as follows. In section 2, we present a simple factor demand model that is used to derive an estimable equation. Section 3 discusses the data and estimation method applied, while section 4 presents the empirical results obtained. Section 5 concludes.

2. The Model

In a recent study, Collard et al. (2005) made a very welcomed first step in analysing the effect of ICT capital on electricity consumption in the French services sector. In particular, they derived a structural estimable equation from a simple factor demand model based on a constant returns to scale CES production function, with ω and σ denoting the share parameter and the elasticity of substitution, respectively (eq. (1); for further details see also Collard et al., 2005). The dependent variable E_t/Y_t represents the electricity intensity of production, $P_{E,t}/P_t$ the ratio of energy prices to production prices, and $K_{CS,t}$, $K_{C,t}$ and HA_t computer and software capital, communication devices, and heated area, respectively, all normalised by the total capital stock, K_t. The latter of the three right-hand-side terms in (1) represents electricity-augmenting technological progress, which consists of an endogenous component (the three capital variables) and an exogenous component (the log-linear time trend, t).

$$\begin{aligned}\log\left(\frac{E_t}{Y_t}\right) &= \sigma\log(\omega) - \sigma\log\left(\frac{P_{E,t}}{P_t}\right) \\ &\quad + (\sigma-1)\left[\theta_0 + \theta_T t + \theta_{CS}\log\left(\frac{K_{CS,t}}{K_t}\right) + \theta_C\log\left(\frac{K_{C,t}}{K_t}\right) + \theta_{HA}\log\left(\frac{HA_t}{K_t}\right)\right]\end{aligned} \tag{1}$$

3. Data and estimation method

We follow Collard et al. (2005) by using a panel data approach with cross-section fixed effects to estimate the relationship presented in (1) above. However, there is a major difference in our approach. While Collard et al. take different subsectors of the French services sector as the cross-sectional dimension, our analysis concentrates on one sector in each regression, attaining the cross-sectional dimension by including a number of European countries. Hence, in contrast to Collard et al., who implicitly assume that the estimated structural parameters (σ, θ_T, θ_{HA}, θ_C, θ_{CS}) are equal in all included sub-sectors, we assume the same elasticities in all included countries, as the extent of heterogeneity between countries within a sector is probably smaller than between different sectors in the same country.[1]

Our choice concerning the sectors and countries investigated was guided by the restricted data availability and the level of disaggregation required for the analysis that we aimed at. More specifically, data on electricity consumption and prices were obtained from EUROSTAT, while all other variables (i.e. gross output, production prices, and the capital variables) were taken from the most recent release of the EU-KLEMS data base (June 2008; www.eu-klems.org). As two separate data sets had to be matched, the congruency of the variables concerning their aggregation level had to be checked for. We did this by using the NACE classifications. Due to the data limitations encountered, we were left with an unbalanced panel of eight countries (Denmark, Finland, Germany, Italy, Portugal, Slovenia, Sweden and the UK) for a time span from, at the earliest, 1991 to 2005.[2] The five sectors covered in sufficient detail by both data bases are: [1] Chemical (24); [2] Food Processing, Beverages & Tobacco (15-16); [3] Metal (27-32)[3]; [4] Pulp, Paper & Printing (21-22); and [5] Textile & Leather (17-19).[4] Table A.1 provides an overview of the aggregational groupings available for the individual industries and the resulting matches used in our analysis. Unfortunately, data for the variable heated area (HA_t), which is used by Collard et al. to control for changes in the production process that are *a priori* uncorrelated with ICT capital, were unavailable to us. Instead, we decided to use 'Other Machinery and Equipment' ($K_{OM,t}$), a capital input variable also contained in the EU-KLEMS database, to control for the size of operations involved.

Figure 1 displays the data for the electricity intensity and ICT variables in the chemical industry as an example. Visual inspection reveals the following trends in the time series: a

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[1] Of course this assumption is dependent on the choice of countries in the one case, and the choice of sectors in the other case. Our panel mainly consists of older member states of the European Union (Slovenia, which entered the EU only in May 2004, being an exception).

[2] The time series for Finland, Portugal and Slovenia begin in 1995, whereas the earliest available complete data set for Sweden is only from 1996 onwards. Moreover, data for the metal industry in Denmark only start in 1993.

[3] Note that the metal industry is an aggregation of the 'Iron and Steel', 'Non-Ferrous Metals' and 'Machinery' industries (cf. Table A.1). Moreover, due to differing aggregational groupings in the two data sets, it was impossible to construct a perfect data match for the metal sector. More specifically, and in contrast to the electricity consumption variable, the variables from the EU-KLEMS database also cover the 'Medical, Precision and Optical Instruments' sector (NACE code 33).

[4] The figures reported in parentheses after the sector names are the corresponding NACE codes (Rev.1).

decline or stagnation of electricity intensity in most countries[5]; a strongly increasing ratio of computers and software to total capital; and an inconsistent behaviour of the ratio communication capital to total capital, which varies substantially among the countries studied.

(insert Figure 1 about here)

In order to account for possible endogeneity of the capital variables we, like Collard et al. (2005), estimate the structural parameters using a 2-stage nonlinear least squares (2SNLS) method. Specifically, we generate instrumental variables for K_C/K, K_{CS}/K and K_{OM}/K by estimating a VAR model (consisting of the three variables in logarithms) and then computing 1-step-ahead forecasts.

4. Estimation results

Table 1 provides an overview of the estimation results for all five sectors studied. In all sectors, the coefficient of the price ratio (σ) is significant and the sign reveals the expected negative relationship between price and demand, although the magnitude varies between -0.122 for the metal industry and -0.408 for the chemical industry.

(insert Table 1 about here)

The deterministic time trend (θ_T) included lends support for some exogenous electricity-augmenting progress in only two cases, namely the chemical and the metal industry. The three other sectors exhibit an upward-sloping trend, implying a slight growth in electricity consumption per unit of output.

The other machinery and equipment parameters (θ_{OM}) are significant, revealing the same sign in all sectors. Hence, the *OM* variable exerts a negative effect on electricity intensity throughout the industries analysed, although the magnitude of the calculated elasticities varies substantially from -0.083 in the food sector to -1.760 in the metal industry. This seems reasonable, as it probably reflects the effect that new, more electricity-efficient devices have on electricity intensity of the sectoral output.

[5] The Slovenian series shows a possible structural break in 2003.

Regarding ICT capital, the availability of disaggregated data proves useful, as the individual effects of the IC technology components can be assessed separately. While the diffusion of communication devices (*C*) has a decreasing effect on electricity intensity in all five industries, the effect of computer and software (*CS*) capital is somewhat ambiguous. Depending on the sector, it either reveals a positive impact (chemical industry), a negative impact (pulp and textile industries), or no statistical significance at all (food and metal industries). Hence, the only sector which is subject to two contrary effects of the ICT variables on electricity intensity of production is the chemical industry, with an elasticity of -0.313 attributable to communication technologies and one of 0.077 ascribed to computers and software. However, although the rise of productive efficiency of electricity caused by a one percent increase of communication capital is diminished by a one percent increase of the computer and software capital, it is not counterbalanced completely.

5. Conclusions

In this study, which was inspired by the work of Collard et al. (2005), we make use of the recent availability of disaggregated ICT data for assessing the relative impact of two ICT capital components on electricity intensity of production in a number of distinct European industries. In contrast to Collard et al., which tackles the impact of ICT on electricity intensity in a panel of six different service sectors of a single country (France), we estimate the relationship for each industrial sector covered separately, attaining the cross-sectional dimension by including a number of European countries.

On the one hand, our results show strong support for a negative impact of the diffusion of communication devices on electricity intensity in all five sectors. This is in line with the results obtained by Collard et al. for the French services sector. On the other hand, the impact of computers and software seems to be very much industry-specific, i.e. depending on the structure of the production processes involved. Overall, we find that the net effect of the diffusion of ICT capital seems to be in favour of decreasing electricity intensity of production.

A shortcoming of the analysis conducted, due to the limitations in the data, is the implicit exclusion of embedded ICT. An increasing range of products, such as automobiles, has a high ICT content (e.g. micro-processors in the drive train) that does not show up in aggregate data of the ICT capital stock, whose additional impact on electricity demand thus cannot be assessed in studies such as the one reported here.

For future research, a possible extension of our analysis could be the assessment of the effect of ICT capital on total energy consumption in each industry, as there is little reason to expect that ICT-induced efficiency gains are restricted to electrical energy.

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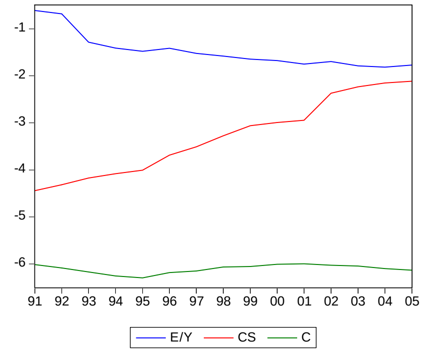
Table 1

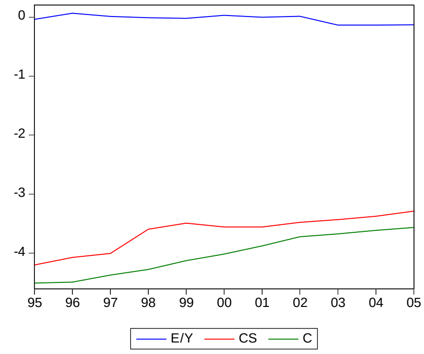
Estimated structural parameters and calculated elasticities

	[1]	[2]	[3]	[4]	[5]
Industry:	**Chemical**	**Food**	**Metal**	**Pulp**	**Textile**
(NACE codes)	(24)	(15-16)	(27-32)	(21-22)	(17-19)
Structural parameters					
σ	**-0.408**	**-0.135**	**-0.122**	**-0.158**	**-0.210**
	[0.0087]	[0.0014]	[0.0678]	[0.0122]	[0.0358]
θ_T	**0.031**	**-0.010**	**0.013**	**-0.028**	**-0.027**
	[0.0000]	[0.0499]	[0.0003]	[0.0000]	[0.0003]
θ_{OM}	**0.197**	**0.073**	**1.569**	**0.546**	**0.710**
	[0.0203]	[0.0886]	[0.0000]	[0.0000]	[0.0000]
θ_C	**0.222**	**0.100**	**0.503**	**0.219**	**0.157**
	[0.0000]	[0.0711]	[0.0000]	[0.0001]	[0.0000]
θ_{CS}	**-0.055**	***-0.031***	***0.015***	**0.174**	**0.147**
	[0.0877]	*[0.2419]*	*[0.4375]*	[0.0001]	[0.0000]
Calculated elasticities					
Price ratio	**-0.408**	**-0.135**	**-0.122**	**-0.158**	**-0.210**
Time trend	**-0.044**	**0.011**	**-0.015**	**0.032**	**0.033**
OM	**-0.277**	**-0.083**	**-1.760**	**-0.632**	**-0.859**
C	**-0.313**	**-0.114**	**-0.564**	**-0.254**	**-0.190**
CS	**0.077**	------	------	**-0.201**	**-0.178**
No. of observations	103	103	101	103	103

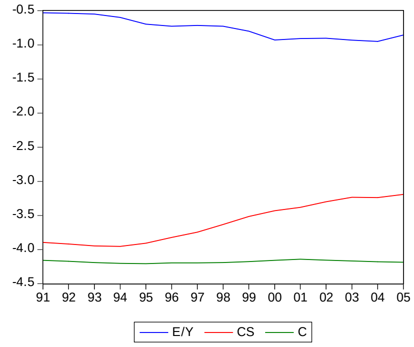
Note: Estimation is conducted with a **2-Stage Non-linear Least Squares** method. *p*-values are reported in brackets and insignificant estimates (at the 10% level of significance) printed in *italics*. We do not report the (country-specific) intercepts.



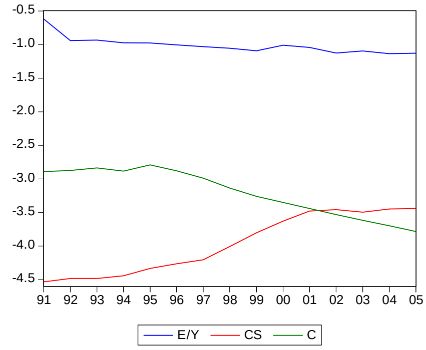
(a) Denmark



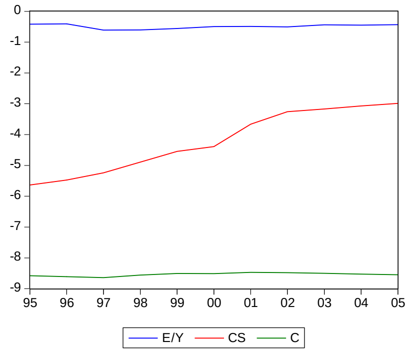
(b) Finland



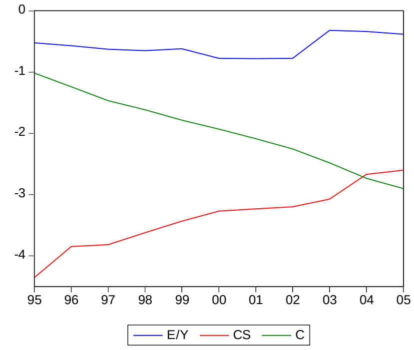
(c) Germany



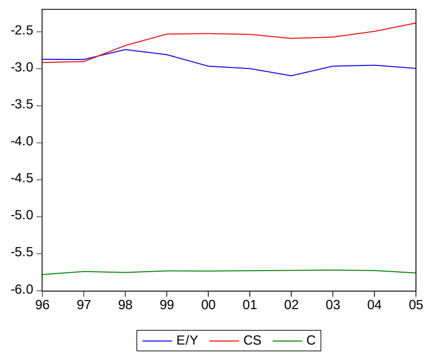
(d) Italy



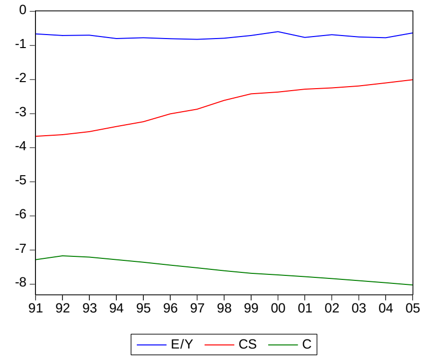
(e) Portugal



(f) Slovenia



(g) Sweden



(h) United Kingdom

Fig. 1. Electricity intensity (E/Y), computers and software (CS) and communication (C) capital for the chemical sector (all in logs).

Source: EUROSTAT, EU-KLEMS, own calculations and illlustration

Appendix

Table A.1

Data availability, aggregational groupings and matches

	EUROSTAT: Electricity consumption		**EU-KLEMS:** Output, production prices and capital variables	
	NACE Code (Rev. 1)	**Description**	**NACE Code** (Rev. 1)	**Description**
[1]	24	Chemical industry	24	Chemicals and chemical products
[2]	15-16	Food, drink and tobacco	15-16	Food, beverages and tobacco
			15	*Food and beverages*
			16	*Tobacco*
[3]	27.1-3; 27.51-52	Iron and steel industry	27-28	Basic metals and fabricated metal
	27.4; 27.53-54	Non-ferrous metals	*27*	*Basic metals*
	28-32	Engineering and other metal industry	*28*	*Fabricated metal*
			29	Machinery, NEC
			30-33	Electrical & optical equipment
			30	*Office accounting and computing machinery*
			31	*Electrical machinery and apparatus*
			32	*Radio, television and communication equipment*
		Incongruency {	*33*	*Medical, precision and optical instruments*
[4]	21-22	Paper and printing industry	21-22	Pulp, paper, printing and publishing
			21	*Pulp, paper and paper products*
			22	*Printing, publishing and reproduction*
[5]	17-19	Textile, leather and clothing industry	17-19	Textiles, textile, leather and footwear
			17	*Textiles*
			18	*Wearing apparel, dressing and dying of fur*
			19	*Leather, leather products and footwear*

Note: Sectors printed in *italics* are only available as part of a higher aggregation level. This applies mainly for the capital variables.

Source: Own illustration, based on EUROSTAT and EU-KLEMS documentation

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