The effects of private sector companies' research and development investments on the adoption of cloud computing services in the European Union

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Abstract: *As European economies rely more and more on know-how and technology, the importance of investment in research and development, especially from the private sector, is increasing. Private investment in research and development leads to innovation and the creation of know-how and technologies that can increase productivity, competitiveness and contribute to economic growth. Private investment in research and development is particularly important in dynamic sectors with high added value, such as the IT&C sector. Cloud computing is one of the most popular IT&C technologies in recent years, particularly because it bridges the gap between large and small and medium-sized companies in terms of IT&C infrastructure investment needs. Due to cloud computing, small companies can benefit from the same technology and infrastructure as the bigger ones, but at lower costs, without having to make large-scale investments in IT&C infrastructure elements such as: computing power, networks, data storage, specialized software products, etc. This paper analyzes the link between the intensity of investments in research and development (R&D), calculated as the share of research and development expenses made by companies in the business environment (business enterprise sector) in GDP or as a percentage of total research and development expenses, in relation to the adoption of cloud computing technology within companies in the Member States of the European Union. The research results indicate a direct and moderate relationship between the intensity of private R&D spending and the adoption of cloud computing technologies among companies in the Member States. This result can be attributed to both the increase in the overall digitization of the countries most active in terms of private R&D investment, as well as the need for affordable and strong IT&C infrastructure to maximize future returns and drive economic growth.*

Keywords: *Research and development, cloud computing, private companies, correlation and regression analysis, European Union.*

JEL Classification: *O32, O33, M12, C10.*

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Introduction

Innovation is a determining factor for economic growth and competitiveness among national economies. Investments in research and development (R&D) represent a good indicator for evaluating the degree of innovation and the potential for economic growth among the Member States of the European Union. Gross Domestic Expenditure on R&D (GERD – Gross Domestic Expenditure on R&D) is the main indicator of R&D intensity and refers to the total amount of R&D expenditure in an economy by commercial enterprises, governments, higher education institutions and the non-profit private sector organizations. Research and development expenses of companies include all expenses incurred by private companies in a certain period of time: salaries of employees involved in the R&D process, costs of materials, equipment and patents (Borahan, 2022).

For the purpose of this analysis, the expenditure of the business sector for research and development is expressed as a share in the Gross Domestic Product of national economies (BERD – Business Enterprise Expenditure on R&D as a % of GDP) or depending on the source of financing (Gross Domestic Expenditure on R&D by source of funds, business enterprise sector – % of total). Research and development expenditure is one of the main determinants of innovation performance among businesses, including IT&C, which is considered one of the most innovative sectors in the economy. The European Union's innovation policies often focus on supporting high-tech industries, and the IT&C sector is considered a key factor in increasing the competitiveness of knowledge-based economies. According to the OECD, the "knowledge-based economy" describes the trends in advanced economies towards greater reliance on knowledge, information and a high level of skills, as well as the growing need for easy access to all of these by the public and private sectors of business (European Commission, 2022).

Cloud computing has quickly become one of the most popular technologies among companies, allowing them to facilitate collaboration between suppliers, customers and employees. Cloud computing is a general term that describes access to networked computing resources over the internet, which are often provided by third parties. These computing resources include: web servers, applications, services, network access and data storage. Cloud computing allows businesses and consumers to remotely access data using any computer or device with internet access and use applications without being limited to local installation of specialized software. This technology increases the overall efficiency of computing by centralizing the storage and processing of information and refers to both the applications provided as services over the internet and the hardware and software in the data centers that provide these services (Kavitha, 2014). The development of network infrastructure that enables high-speed internet bandwidth, along with the evolution of virtualization technologies and universal software interoperability have contributed to the widespread adoption of cloud-based digital solutions in recent years, becoming one of the most popular and successful technologies.

Cloud computing creates a wide range of opportunities, helping organizations improve their business models through more efficient use of technology and remain competitive (Sunyaev, 2020). Cloud computing technologies have removed the size of an enterprise as a critical factor in its economic success, allowing small and medium-sized companies to have access to powerful technologies without the need to generate large expenses for building complex digital infrastructures. According to Raghavendran et al. (2016), cloud computing has five essential characteristics: (i) on-demand digital services with direct access, (ii) extended network access, (iii) resource sharing, (iv) rapid elasticity, and (v) measurable services.

The objective of this paper is to determine and analyze the dependence between the intensity of research and development expenses of private companies and the adoption of cloud computing services, within the Member States of the European Union.

The paper presents the theoretical framework and the current context regarding the use of cloud computing services as reflected by the specialized literature and available statistical data. The trends regarding research and development expenses in the European Union are also presented. The study of the dependence between the degree of use of cloud computing services among enterprises in the member states of the European Union and Gross domestic expenditure on R&D by source of funds, 2020 – business enterprise sector (% total) was carried out by means of correlation and regression analysis. The conclusions of this research are analyzed and validated in relation to other similar research from the specialized literature, and future research directions are also highlighted.

1. Theoretical framework

The benefits offered by the implementation of cloud computing technologies by optimizing the flow of information (Heier et al., 2012) are complemented by the efficiency of resources and the reduction of IT costs (Karim, 2022). All the same, Bardhan et al. (2013) emphasizes the importance of IT spending for increasing the market value of companies, but also of stimulating investments in research and development, with a complementary effect on the company's performance (Bardhan et al., 2013; Sheehan & Wyckoff, 2003). In this sense, it is necessary to identify a strategy to increase the level of funding for research and development, which will lead to sustainable economic growth (Moncada-Paternò-Castello & Grassano, 2021; Sheehan & Wyckoff, 2003).

In general, the analysis of the impact of investments in research and development varies at the level of the EU states, but also at the level of the internal structure – depending on the source of funding, which leads to different effects (Ginevičius et al., 2022). Also, in the specialized literature, the quantification of the impact of R&D investments on the economic development of countries is carried out by means of correlation and regression analysis (Ginevičius et al., 2022; Kaur & Singh, 2016; Lee, 2018).

There are studies that put forward the idea that the interdependence between IT and R&D spending determines added value for companies, investment in cloud computing technologies being important for business development and, implicitly, having a significant impact on the overall competitiveness of a country (Bardhan et al., 2013; Mamonov & Peterson, 2021; Ravichandran, 2018).

On the other hand, other studies support the fact that although policies can improve the development and implementation of new technologies by encouraging investment and financing R&D expenditure, they will also affect/influence the evolution of the labor market or the unemployment rate in the long term (Oţoiu & Șițan, 2015; Tansel & Ozdemir, 2018). At the same time, the implementation of new technologies can lead to an increase in income inequalities (Kharlamova et al., 2018), which can cause economic imbalances and represents a real challenge for the development of a sustainable society (Toma et al., 2021). Thus, it is very important to develop strategies that can lead to the creation of a balance regarding the implementation of new technologies on the labor market but also to identify sources of funding for R&D so that the long-term economic implications lead to sustainable economic growth.

1.1 Research and development expenditure of private commercial enterprises in the European Union

The volume of investments in research and development is a reference point for the technological development of the private sector, being determined by the organizational culture and internal development strategies of the companies, but also by the external political environment. In the European Union, governments finance about 30% of total R&D spending, while the private sector accounts for just under 60%. In general, the European Union has a much lower rate of R&D investment by the business sector than its international competitors. Data from 2019 shows that the business sector finances 59% of R&D investment in the EU, compared to 63% in the US, 76% in China, 77% in South Korea and 79% in Japan (European Commission, 2022). The sectoral composition of the European economy determines companies to spend less on research and development as compared to other countries. According to data available from the European Commission (2022), less than half of EU business R&D expenditure is in R&D-intensive sectors such as IT&C services, manufacturing companies or healthcare industries and, about 40% in sectors with medium-high

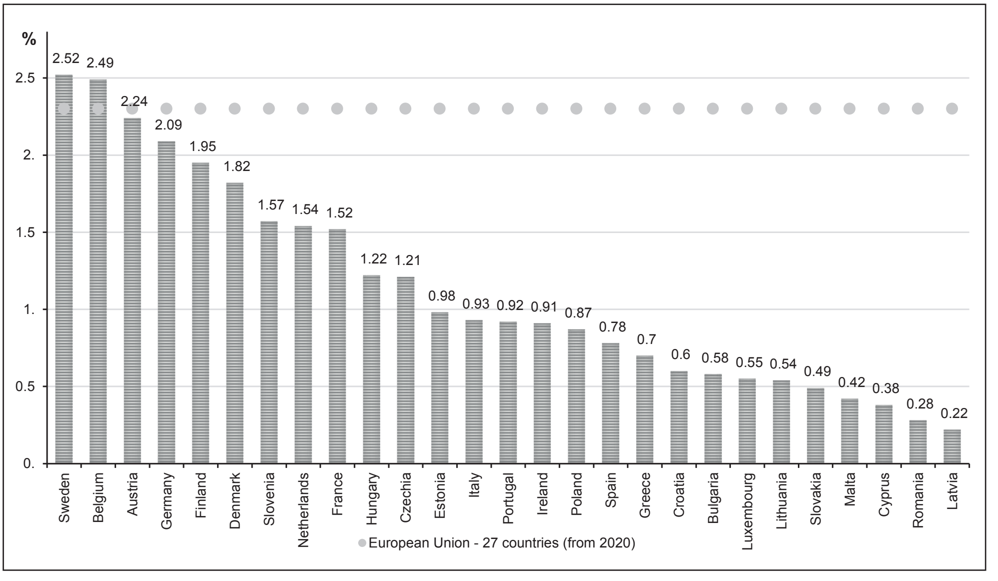
R&D intensity, such as, for example, the automotive and aerospace industries.

The ratio of R&D spending to GDP provides insight into the contributions of public budgets and private companies over the business cycle. Business R&D trends depend mainly on their expectations of the economic environment, while public R&D tends to be countercyclical, mitigating the effects of economic contraction. Although the intensity of business R&D spending varies considerably between EU Member States (Fig. 1), the increase in business spending seems to lead to overall positive developments in many countries (Borunsky et al., 2020).

The amount of private investment in research and development depends on the expected return in terms of future profitability. Therefore, companies show a greater tendency to invest in R&D in countries with greater resources of skilled labor, a strong research infrastructure and a performing public administration. At the same time, investments in R&D can generate new innovations, developed internally or in cooperation with other firms (Audretsch & Belitski, 2020; Rijnsoever van et al., 2017). Countries such as Sweden (2.52%), Belgium (2.50%) and Austria (2.23%) show the highest intensities of private R&D investment relative to their GDP while Cyprus (0.37%), Romania (0.27%) and Latvia (0.21%) are in the last places.

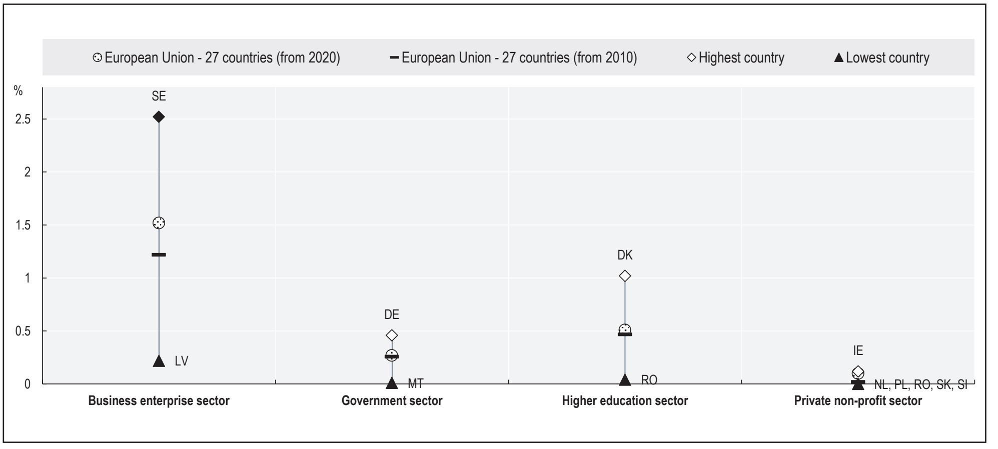
In terms of the level of R&D spending intensity in each of the four performance sectors (Fig. 2): the business enterprise sector, the government sector, the higher education sector and the private non-profit sector, in 2020 the majority of R&D spending were carried out in the business enterprise sector – spending on research and development increased from 1.39% of GDP in 2016 to 1.52% of GDP by 2020. In the case of the other three sectors, there were small fluctuations during this period: for the higher education sector, R&D intensity increased by 0.04 percentage points in 2020 compared to 2016, the R&D intensity of the government sector was 0.27% of GDP in 2020 vs. 0.25% in 2016; and for the non-profit private sector in 2020, a double value was recorded compared to 2016 (0.02% of GDP in 2020).

Fig. 1: Business enterprise expenditure on R&D (BERD; % of GDP for the EU Member States; 2020)



Source: own (based on Eurostat data)

Fig. 2: **Gross domestic expenditure on research and development by sector (% of GDP)**



Source: own (based on Eurostat data)

Compared to other economies internationally, private investment in research and development in the European Union is relatively low. European private investment in research and development represents 1.48% of GDP, below other economies such as South Korea (3.72%), Japan (2.53%), the USA (2.27%) or China (1.71%) (European Commission, 2022). Stimulating private investment in R&D is therefore extremely important for European governments, but still remains a challenge. Companies intending to invest in research and development face various obstacles that may lead to underinvestment compared to the expected level. Obstacles such as market uncertainty, financing constraints, high risks, high sunk costs and lack of full appropriation of results (Borunsky et al., 2020) can reduce the total volume of private investment in research and development and can concentrate the market to a limited number of enterprises, leading to a productivity gap between large enterprises with access to considerable resources and small and medium-sized enterprises with small budgets. Most large enterprises are also technology leaders with access to extensive IT&C infrastructure and high computing power, while smaller enterprises may lack the resources for large IT&C infrastructure investments. Technologies such as cloud computing balance the situation, giving smaller businesses easy, fast and reliable access to large IT&C infrastructures and increased computing power at a fraction of the cost of a similar in-house investment. In addition to the obvious benefits, new technologies – including cloud computing, come with challenges related to the security of internal or customer data, the responsibility being largely attributed to the companies that manage cloud data solutions (Maiorescu et al., 2021; Sunyaev, 2020). Therefore, we can assume that, to a certain extent, a large-scale adoption of cloud computing services would partially overcome some financial constraints in terms of R&D investment in small and medium-sized enterprises.

1.2 Cloud computing technology in the European Union

Cloud computing technology is fast becoming an integral part of the world's IT infrastructure, especially because of the pay-per-use business model and the flexibility it offers in terms of convenience and cost. It enables on-demand network access to a range of highly customizable computing resources such as servers, storage, applications and web services. Companies can connect to the available physical or virtual computing environments and access the corresponding resources online, anytime and from a variety of devices such as desktop and laptop computers, tablets or smartphones (Attaran & Woods, 2018). The pay-per-use payment model provides a more accurate measurement of the business value of IT&C services, as companies replace capital expenditures with operating expenditures (Lynn et al., 2020).

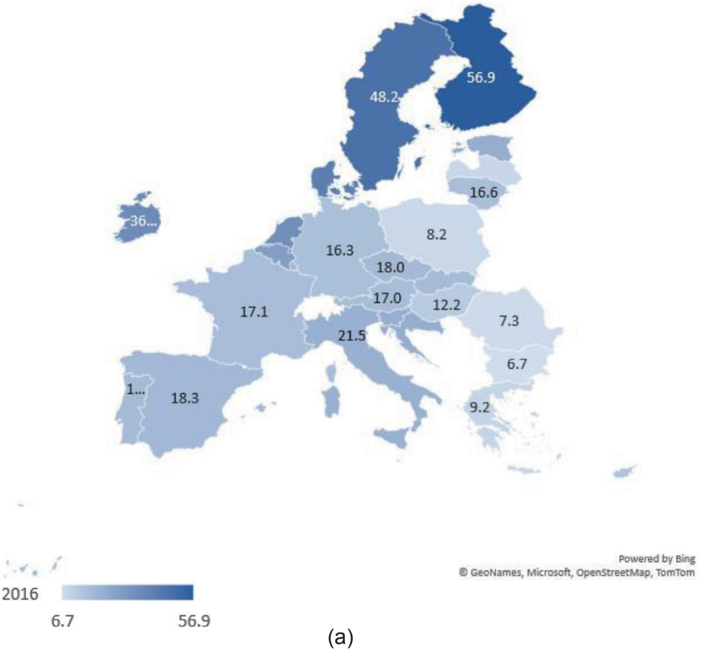
According to Attaran and Woods (2018), there are five main models for providing cloud computing services:

- Software as a Service (SaaS) refers to applications delivered on demand over the internet via a web browser of a software interface;
- Platform as a Service (PaaS) provides a software environment that enables rapid application development and deployment, eliminating the need to invest in dedicated hardware and software;
- Infrastructure as a Service (IaaS) provides infrastructure support services, allowing users to control operating systems and deployed applications;
- Storage as a Service (StaaS) provides users with hardware solutions and a scalable software interface for data storage;
- Desktop as a Service (DaaS) enables the secure delivery of a desktop operating system and applications over a remote infrastructure.

Using cloud computing technology, companies can instantly scale up or down their IT&C resources as needs evolve, enabling better business continuity planning by protecting data and systems (Attaran & Woods, 2018). At the same time, cloud computing services can increase the productivity of companies by improving collaboration between employees located in different geographical locations, as can be seen in the medical field, where cloud-based software models are increasingly used (Vries de et al., 2021; Zaidi et al., 2018). In 2020, 36% of EU businesses used cloud computing services for business purposes, almost double from 2016, as also seen Fig. 3 (Eurostat, 2022a).

Although the share of businesses with Internet access is at very similar high levels in

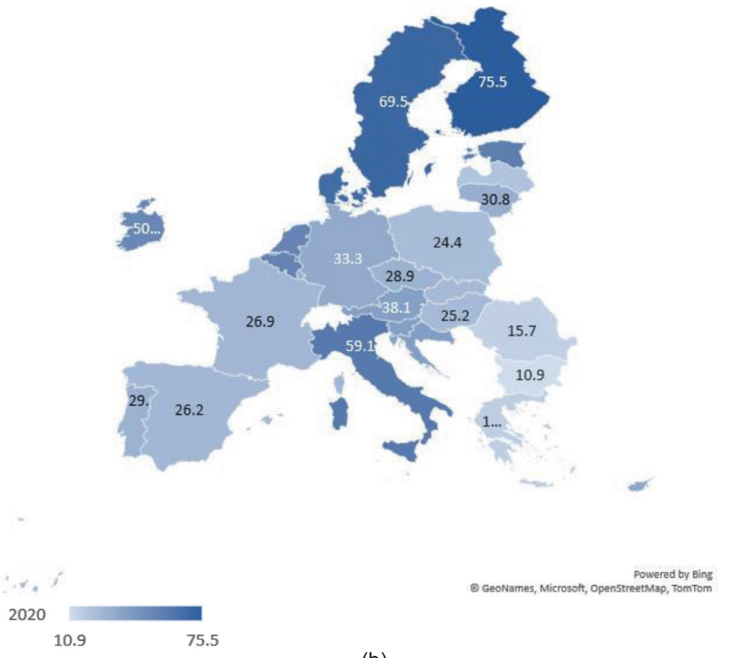
Fig. 3: Use of cloud computing services (2020 vs 2016) – Part A



(a)

Source: own (based on Eurostat data)

Fig. 3: Use of cloud computing services (2020 vs 2016) – Part B



(b)

Source: own (based on Eurostat data)

Note: Cloud computing services by size class of enterprise; Size classes in number of persons employed: 10 persons employed or more; Information society indicator: buy cloud computing services used over the internet; Unit of measure: percentage of enterprises.

all EU Member States (Eurostat, 2022b), the use of cloud computing for business purposes varies significantly between them. Cloud computing is commonly used in the Nordic Member States, with the highest shares reported in Finland (75%) and Sweden (70%). At the opposite pole, cloud computing services were used by less than one in five enterprises in Bulgaria (11%) and Romania (16%).

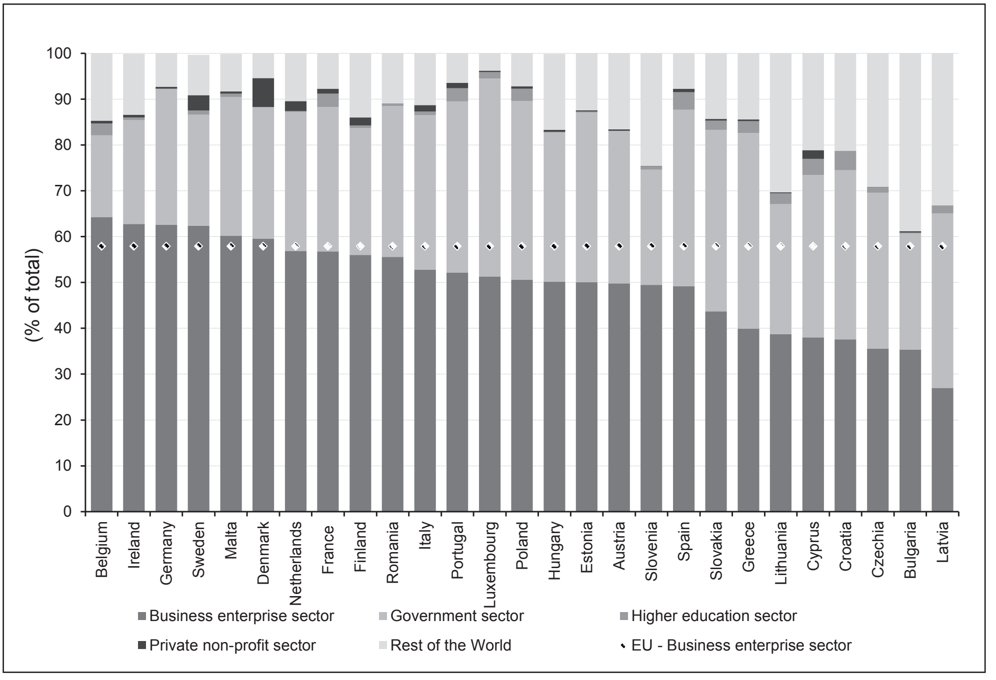
Among companies using cloud computing services in the European Union, 76% used email as a cloud service, more than half purchased cloud office software (58%) and 67% purchased cloud services for file storage. More sophisticated cloud services, such as financial or accounting software, were accessed by 45% of companies, while only 27% used customer relationship management (CRM) software (Eurostat, 2022b).

2. Research methodology

The use of cloud computing technology can be seen as a measure of the digitalization of the private sector. While cloud computing services are traditionally considered a component of the IT&C industry, companies using cloud technologies are not limited to this area. On the other hand, the generalization of cloud computing in all sectors can facilitate research and development activities even for smaller enterprises that do not have sufficient resources to invest in their own IT&C infrastructure for research, by providing access to resources scalable at significantly lower costs.

Still and all, private sector companies represent the main source of funding for R&D expenditure, in 2020, bearing approximately 58% of the total R&D expenditure in the EU. The exceptions are Latvia and Greece, where most

Fig. 4: Gross domestic expenditure on research and development by funding source (% of total, ordered by the expenditure in the business enterprise sector; 2020)



Source: own (based on Eurostat data)

of the funding is from the government sector. Government funding is about 30%, followed by foreign funding (9.6%), while funding from the higher education sector and the private non-profit sector have the smallest share (Fig. 4).

As a result, we can formulate the research hypothesis:

H: A high level of funding of R&D expenses from the private sector influences the adoption of cloud computing services, which implies a greater degree of digitization of states in terms of these services.

The analysis refers to 27 countries in the European Union, the data are presented for the year 2020 or the latest available value, and the processing and analysis was performed with XLSTAT statistical and data analysis solution (Addinsoft, 2023). The variables included in the analysis are presented in Tab. 1.

The identification of the effects of R&D funding sources on the level of use of cloud services will be done with the help of correlation and regression analysis. The application of the regression method requires the prior establishment of the causal relationship, which represents the deterministic model that expresses the dependence between the analyzed variables [Equation (1)]:

$$Y = f(X) = f(x_1, x_2, \ldots, x_n) \quad (1)$$

where: $X = (x_1, x_2, \ldots, x_n)$, exogenous variable – *BERD_SF*; *Y*, endogenous variable – *CCS*.

The possibility of the appearance of some random factors, with insignificant influence on the outcome variable, leads to the probabilistic model [Equation (2)] also takes into account the possibilities of the appearance of such factors:

$$y = f(x) + \varepsilon = f(x_1, x_2, \ldots, x_n) + \varepsilon \quad (2)$$

where: ε – random error (residual variable) that reflects the influence of the random factors.

The general probabilistic model for simple linear regression [Equation (3)] will be used:

Tab. 1: Variables

Code	Name of the indicator (link to the data source)	Source
GERD	Gross domestic expenditure on R&D by sector of performance (%, relative to GDP) https://ec.europa.eu/eurostat/databrowser/view/RD_E_GERDTOT__custom_4689372/default/table?lang=en	Eurostat, OECD
BERD_SP	Gross domestic expenditure on R&D by sector of performance Business enterprise sector (%, relative to GDP) https://ec.europa.eu/eurostat/databrowser/view/RD_E_GERDTOT__custom_4689372/default/table?lang=en	Eurostat, OECD
BERD_SF	Gross domestic expenditure on R&D by source of funds Business enterprise sector (% of total) https://ec.europa.eu/eurostat/databrowser/view/rd_e_fundgerd/default/table?lang=en	Eurostat, OECD
CCS	Use of cloud computing services – buy cloud computing services used over the internet as a percentage of enterprises with ten or more persons employed (all activities, without financial sector) https://ec.europa.eu/eurostat/databrowser/view/isoc_cicce_use/default/table?lang=en	Eurostat

Source: own

$$y_i = b_0 + b_1 \times x_i + \varepsilon_i,\ i = \overline{1, n} \qquad (3)$$

where: (x_i, y_i) – numerical values of the cause-and-effect variables recorded at the level of the statistical unit *i*; *Y* – *CCS* (% of enterprises); *X* – *BERD_SF* (% of total); b_0 and b_1 – coefficients of the regression function; ε_i – residual component (random error) for statistical unit *i*.

The actual value y_i of characteristic *Y* includes a theoretical, predictable component:

$$\hat{y}_i = b_0 + b_1 \times x_i\ ,\ i = \overline{1, n} \qquad (4)$$

and a residual component (ε_i).

The literature review on R&D development concepts in private enterprises and cloud computing services was followed by a visual inspection and an analytical method to determine the type and strength of the relationship between the two variables.

3. Research results

To test the research hypothesis, the correlation between R&D expenditure in the business enterprise sector (% of total) and the use of cloud computing services in private companies (as a percentage of all enterprises) in all EU Member States for 2020 will be analyzed.

Tab. 2: Normality tests

	Shapiro-Wilk test	
	CCS	***BERD_SF***
W	0.940	0.943
P-value (two-tailed)	**0.119**	**0.145**
Alpha	0.050	0.050

Source: oown (using XLSTAT)

Note: Test interpretation: *H0*: *The variable from which the sample was extracted follows a normal distribution*. H_a: *The variable from which the sample was extracted does not follow a normal distribution*. As the computed *p*-value is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis *H0*.

Fig. 5: Correlation analysis

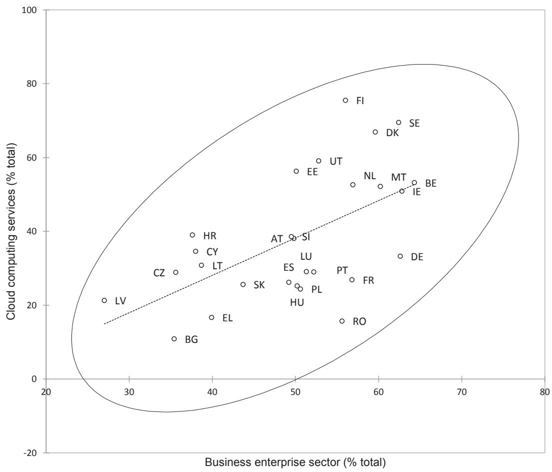
Correlation matrix (Pearson)

Variables	*BERD_SF*	*CSS*
BERD_SF	**1**	**0.578**
CSS	**0.578**	**1**

Note: Values in bold are different from 0 with a significance level alpha = 0.05.

***P*-values (Pearson)**

Variables	*BERD_SF*	*CSS*
BERD_SF	0	0.002
CSS	0.002	0



Source: own (using XLSTAT)

Data normality was checked with the Shapiro-Wilk test, the results showing that the distributions are approximately normal for a significance level of 5% (Tab. 2).

Correlation analysis demonstrates the existence of a linear, direct and medium intensity dependence between *BERD_SF* and *CCS* (Fig. 5).

Fig. 6: Regression analysis – Part 1

Regression of variable *CCS*
Goodness of fit statistics (*CCS*):

Observations	27
Sum of weights	27
DF	25
R^2	0.334
Adjusted R^2	0.308
MSE	209.908
RMSE	14.488
MAPE	38.559
DW	1.359
Cp	2.000
AIC	146.282
SBC	148.874
PC	0.772

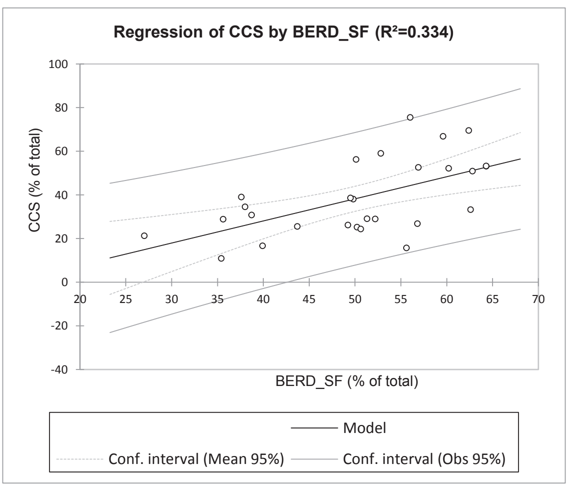


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Fig. 6: **Regression analysis – Part 2**

Analysis of variance (*CCS*):

Source	DF	Sum of squares	Mean squares	*F*	*Pr > F*
Model	1	2636.774	2636.774	12.562	**0.002**
Error	25	5247.706	209.908		
Corrected total	26	7884.480			

Note: Computed against model Y = Mean(Y).

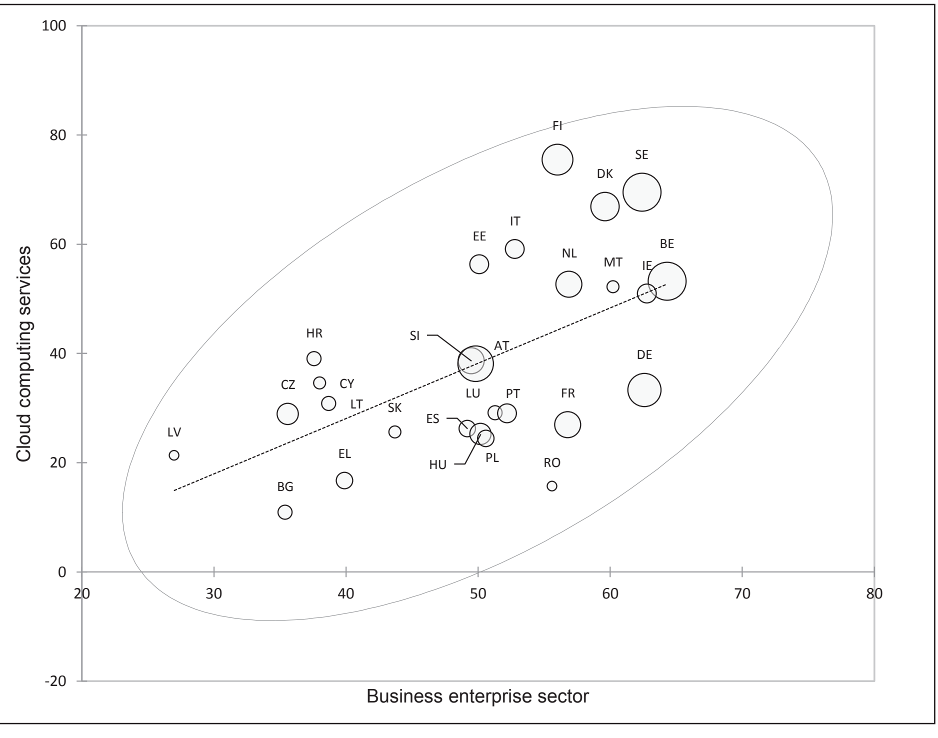
Model parameters (*CCS*):

Source	Value	Standard error	*t*	*Pr* > |*t*|	Lower bound (95%)	Upper bound (95%)
Intercept	−12.428	14.545	−0.854	0.401	−42.384	17.528
BERD_SF	1.013	0.286	3.544	**0.002**	0.424	1.601

Equation of the model (*CCS*): *CSS* = −12.428 + 1.013 × *BERD_SF*.

Source: own (using XLSTAT)

Fig. 7: **Scatter plot – cloud computing services vs business enterprise sector (2020)**



Source: own (using XLSTAT)

The Pearson correlation coefficient ($r = 0.58$) is used to analyze the statistical correlation between the two indicators and shows a direct correlation, of medium intensity, the coefficient being statistically significant for a significance level of 5%, p-values < 0.002 (Fig. 5).

The regression model used to analyze the dependence between R&D expenditures in the business enterprise sector (% of total) and the use of cloud computing services in private companies (as a percentage of all enterprises), involved the estimation of the following model:

$$CSS\_2020(\%) = \beta_0 + \beta_1 \times BERD\_SF + \varepsilon \quad (5)$$

The model explains 33.4% of the *CCS* variation (Fig. 6), is valid for a significance level of 5% and verifies the hypotheses specific to its construction. The regression coefficient of the model is statistically significant for a significance level of 5%, increasing the funding of R&D expenditure financed from the business enterprises sector (% of total) by one percentage point causes an increase, on average, in the degree of use of the services of cloud computing in private companies (as a percentage of all enterprises) by about 1 percentage point (1.013%).

In Fig. 7, the inclusion of an additional exogenous variable compared to the previous model (the intensity of R&D expenditure of the business environment – as % GDP) is highlighted. This represents the third dimension of the diagram, the size of the dot (marker/bubble) associated with each state being proportional to the value of the indicator used.

Sweden stands out with the highest value of intensities in terms of private investments in research and development in relation to GDP (2.52%), at the opposite pole is Latvia with 0.21%. This is in line with the first position obtained by Sweden in terms of research and innovation according to the European Innovation Scoreboard 2022 – score: 135.7% of the EU average, respectively the last position in the case of Latvia – score: 13.178% of the EU average (Hollanders, 2022).

Conclusions

The results of the present research validate the hypothesis and suggest that there is a significant positive moderate correlation between the intensity of research and development expenditure and the use of cloud computing services among private companies in the Member States of the European Union. In general, countries with higher R&D spending intensity by private enterprises are likely to be more active in the adoption and use of cloud computing services. This hypothesis is also confirmed by Carrillo (2019) who considers it important to identify the efficiency of how R&D resources contribute to economic development (Carrillo, 2019). Nevertheless, in the development of sustainable policies regarding R&D expenses, Hurduzeu et al. (2022) considered that, in addition to the level of development of countries and performance sectors, it is necessary to include intellectual property rights and indications of financial development for R&D investments. Thus, new strategies can be determined, both in the public and in the private sector, to capitalize on research activities (Hurduzeu et al., 2022).

Since both R&D expenditures of private enterprises and the adoption of cloud computing technologies are measures of the technological development of the private sector in a country, the relationship between them appears to be bijective. Companies invest in research and development to maximize future returns and generate competitive advantage, contributing to an increase in digitization due to the need to use powerful technologies for research purposes. Cloud computing technologies are rapidly becoming an integral part of IT&C infrastructure, providing on-demand, fast, cost-effective and scalable computing resources. Due to cloud computing technologies, companies can access a powerful IT&C infrastructure without the need for large initial investments, thus providing the technological resources needed for research and development activities to smaller companies with limited financial resources.

A possible limitation of the current findings can be attributed to the time frame of the research. There may be some lagged effects between the dynamics of R&D investment and the adoption of cloud computing services, as some enterprises may adapt their technologies more slowly than others, prioritizing investments that generate immediate returns over future ones. Large companies, regardless of industry, with a strong track record of R&D investment were better prepared to capitalize on digital technologies during the global COVID-19 restrictions.

The implementation of new digital technologies will influence the development of companies, regardless of the activity sector, the use of services/concepts such as Cloud Computing, Big Data, smart objects, etc., as well as the creation of smart environments based on IoT being a necessity for the preparation of digital citizens and the creation a sustainable society (Georgescu & Popescu, 2015). This fact will determine the introduction in the subsequent analyzes of some digitalization-specific indicators that will complete the present study. Also, further research could focus on determining the dynamics and amplitude of the lagged effects between the two indicators, as well as highlighting ways to accelerate the adoption of the latest technologies in the field of research, to enhance national and European competitiveness and generate economic growth.

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