A Work Project, presented as part of the requirements for the Award of a Master's degree in International Development and Public Policy from the Nova School of Business and Economics.

THE IMPACT OF ICT ADOPTION ON PORTUGUESE FIRMS' PRODUCTIVITY - THE CASE OF ARTIFICIAL INTELLIGENCE, BIG DATA, AND CLOUD COMPUTING IN LARGE ENTERPRISES

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Abstract (group)

This work project has the purpose of analyzing if there is an association between ICT adoption and Total Factor Productivity (TFP) on Portuguese firms. The EU digital transition is described, along with some literature and the Portuguese framework on the topic, and the individual analysis use data from Portuguese firms throughout the years 2008-2021, including a wide range of ICT topics. Overall, results show that there are several different positive and significant associations between different technologies adopted and TFP, varying on firm size. The study also poses different limitations that are addressed.

Abstract (individual)

While being a minority in the business environment, large enterprises contribute around 40% to Portugal's total gross value added. This study investigates the effect of advanced digital technologies – cloud computing, big data, and AI – on total factor productivity (TFP). A statistically significant effect is not found between single technologies and TFP. However, the simultaneous adoption of multiple technologies is significantly and positively associated with TFP. This research ends by describing the main study limitations and with recommendations for further research on this topic.

Keywords: Productivity; Cloud Computing; Big data; AI; Large enterprises.

This work used data and resources provided by GPEARI (Gabinete de Planeamento, Estratégia, Avaliação e Relações Internacionais Ministério das Finanças) and INE (Instituto Nacional de Estatística).

Abbreviations

AI	Artificial Intelligence
BDA	Big Data Analytics
CAE	Classificação Portuguesa das Atividades Económicas
CTIC	Council for Information and Communication Technology
DESI	Digital Economy and Society Index
DII	Digital Intensity Index
DMA	Digital Markets Act
DSA	Digital Services Act
EU	European Union
FTTP	Fiber to the Premises
GEE	Gabinete de Estratégia e Estudos
GPEARI	Gabinete de Planeamento, Estratégia, Avaliação e Relações Internacionai
GPT	General-Purpose Technology
ICT	Information and Communication Technology
INE	Instituto Nacional de Estatística
IoT	Internet of Things
IUTICE	Inquérito à Utilização de Tecnologias da Informação e da Comunicação nas Empresas
NACE	European Classification of Economic Activities
NSI	National Statistical Institutes
NSS	National Skills Strategy
OECD	Organization for Economic Cooperation and Development
R&D	Research and Development
RRF	Recovery and Resilience Facility
RRP	Recovery and Resilience Program
SCIE	Sistema de Contas Integradas das Empresas
SMEs	Small and Medium-sized Enterprises
TFP	Total Factor Productivity

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Introduction

European Framework on Digital Transition and Skills

We define digital transformation as the strategic adoption of digital technologies like analytics, big data, and cloud computing to significantly enhance business performance and productivity. This process also reshapes organizational operations through technology-driven evolution[1].

In its agenda "Shaping Europe's digital future", published in February 2020, the European Commission introduced the European data strategy and the White Paper on Artificial Intelligence (EC 2020a). The Commission's plan recognized the need to not only ensure digital transformation for the benefit of society at large but also to set up regulatory frameworks which support businesses, secure social and environmental sustainability for society, and guarantee a "digital environment that respects privacy, dignity, integrity and other rights in full transparency" (EC 2020a). Moreover, taking into consideration the possible interplay with the European Green Deal, the Commission highlighted the opportunity for the Information and Communications Technology (ICT) sector to undergo its own green transition (EC 2020a). The 2021 proposed "Path to the Digital Decade" includes four cardinal points: enhancing digital skills, building secure digital infrastructures, digitizing businesses, and modernizing public services, with a comprehensive review scheduled for 2026 to account for to new technological, economic, and societal shifts (EC 2021a).

Since 2014, the Commission has annually been publishing the Digital Economy and Society Index (DESI), a comprehensive assessment and measurement of the digital performance and progress of EU member states (EC 2022a). DESI's analysis is subdivided into four main

[1] The rationale behind this definition is provided in the chapter "Digital Transformation" below

topics: Human Capital, Connectivity, Integration of Digital Technology, and Digital Public Services. It includes countries' profiles and intends to help Member States to identify areas for action and provide analysis on key digital policy areas (EC 2022a). In 2022, the four leading countries were Finland, Denmark, the Netherlands, and Sweden (EC 2022a).

The Commission's 2022 Digital Economy and Society Index report outlines a strategic agenda focused on bolstering digital competencies across the continent. By 2030, the Commission seeks to provide at least 80% of its population with basic digital skills and increase the number of ICT specialists to 20 million, equivalent to approximately 10% of the total employment, maintaining an equitable gender balance (EC 2022a). Further, the European Skills Agenda, initiated in 2020, aims at empowering individuals and businesses with superior skills and has set a target of 70% of adults aged 16-74 having at least basic digital skills by 2025. In pursuit of this goal, the agenda fosters large-scale partnerships with major industries, such as automotive, consumer goods, and digital. The Commission lends support to Member States in formulating national skills strategies in association with the Organization for Economic Cooperation and Development (OECD), with 13 states having begun the development process and six already implementing theirs (EC 2023a). Portugal, which initiated the Building a National Skills Strategy (NSS) project under its XIX government, is currently in the implementation stage. In 2017, the XXI Constitutional Government collaborated with the OECD on the NSS Action Phase, which involved comparative analysis, inter-ministerial teamwork, and extensive stakeholder engagement to identify concrete actions for improving adult learning (OECD 2018a).

As of June 2023, 54% of EU citizens exhibit basic digital skills, a figure that is expected to rise significantly in the coming years. The proliferation of the internet has been a catalyst in this digital revolution. From 2007 to 2021, internet subscription surged from 53% to 92% across the union, marking an 91% increase. Nonetheless, disparities in internet connectivity remain, with Bulgaria and Greece trailing at the lower end of the spectrum. Rural areas are less connected than urban centers; Portugal's rural zones, for instance, registering less than 80% of internet subscriptions (EC 2022a).

Moreover, the Commission's analysis discloses significant discrepancies across other various socio-demographic backgrounds. Younger populations exhibit more digital proficiency than their older counterparts; individuals in rural areas demonstrate lower basic digital skills (46%) than those in urban areas (61%). Education also plays a central role, with 78% of individuals with high formal education displaying basic digital skills this figure drops to 50% among those with medium formal education and further decreases to 32% among individuals with no or low formal education. In the active labor force, accounting for both employed and unemployed individuals, 62% possess basic digital skills. However, among the unemployed, this figure drops to only 49% (EC 2022a).

Economically, the EU is investing an impressive €65 billion in training initiatives. Germany and France lead in terms of ICT specialists, accounting for 22.5% and 13.9% of the EU's workforce respectively. With digital skills deemed essential for both businesses and workforces, the Commission stresses the "critical shortage of digital experts" that even the front-running member states encounter. On the e-commerce side, the Commission has introduced the Digital Markets Act (DMA) and Digital Services Act (DSA) to strengthen digital rights and establish fair competition. It is noteworthy that approximately one in five EU small and medium-sized enterprises (SMEs) conducted online sales in 2021, contributing to 12% of the total turnover (EC 2022a).

The ICT sector in the European Union has shown considerable development over recent years. The sector's value-added rose from €590 billion in 2018 to €642 billion in 2019. While 2020 likely experienced a slight drop due to the COVID-19 pandemic, it was anticipated that 2021 would see a rebound to an impressive €666 billion. A closer look reveals a shift within the sector's sub-sectors; manufacturing's share declined from 29% in 2019 to an estimated 21% in 2021, while services saw an uptick from 71% in 2019 to a projected 79% in 2021. Telecommunications remained steady at 8% (Cardona et al. 2022).

ICT employment also trended upwards, with 6.1 million workers in the sector in 2019 and an estimated 6.2 million by 2021. Similar to the value-added trend, employment in manufacturing dropped from 10% in 2019 to a predicted 8% in 2021, while the services sub-sector boosted its share from 90% in 2019 to a projected 92% in 2021. Telecommunications maintained its share of 14% (Cardona et al. 2022).

Productivity in the ICT sector per person employed showed a steady rise, from €105 thousand per person in 2019 to an estimated €107 thousand per person in 2021. Sub-sector data mirrored this trend with manufacturing productivity increasing from €89 thousand per person in 2019 to an estimated €97 thousand per person in 2021. Service sector productivity slightly increased from €106 thousand per person in 2019 to an estimated €108 thousand per person in 2021. Telecoms also followed suit with an increase from €173 thousand per person in 2019 to an estimated €174 thousand per person in 2021. These figures demonstrate the resilience and potential of the ICT sector within the EU, even in the face of global challenges like the Pandemic (Cardona et al. 2022).

The digital transition by firms is supported by a variety of technologies and extensive infrastructures. To assess their diffusion, the Digital Economy and Society Index, within the dimension of "Integration of digital technology", measures the degree of digital technologies adoption by enterprises. These range from more simple products, such as electronic information sharing and the use of social media, to more complex ones, such as artificial intelligence (AI), big data analytics, and cloud computing (EC 2022a).

Based on the number of digital technologies they have implemented (out of a set of 12), a score of the Digital Intensity Index (DII) is assigned to firms. In 2021, more than half (56%)

of European firms had a basic level of digital intensity – achieved with the usage of four of such technologies. In general, a greater share (88%) of large enterprises (250+ persons employed) reach a basic level on the DII compared to small and medium-sized enterprises (SMEs) (55%). Only around 21% of SMEs have reached a level of high (7-9) or very high (10+) digital intensity. To the contrary, almost 4 out of 5 SMEs show low or very low DII scores (less than 7 technologies used) (EC 2022i).

A clear digital divide is then present in the EU, depending not only on the size of the enterprise but also on the sector in which it operates. Large companies are more likely to adopt digital technologies – especially more advanced ones – compared to small-to-medium enterprises, which, nonetheless, account for 99% of EU businesses. In 2021, only 7% of European SMEs used at least one type of AI system, whereas, among large companies, 29% made use of the technology. Given the large number of SMEs relative to large enterprises, the overall rate of adoption in the EU was 8%. With respect to big data analytics, in 2020 14% of companies (with 10+ employees) analyzed data internally or externally; like the case of artificial intelligence, more large firms make use of the technology relative to smaller ones (34% vs 14%). Unlike other advanced digital technologies, cloud computing services have been adopted more extensively – with 41% of companies using these products in 2021. Although they significantly lag behind large enterprises (which show a cloud computing purchase rate of 72%), 40% of SMEs have purchased cloud computing services. Analogous differences can be found when analyzing the adoption rates across sectors. For instance, the ICT sector relies much more on this technology, with 74% of enterprises purchasing it compared to 40% in manufacturing (EC 2021f).

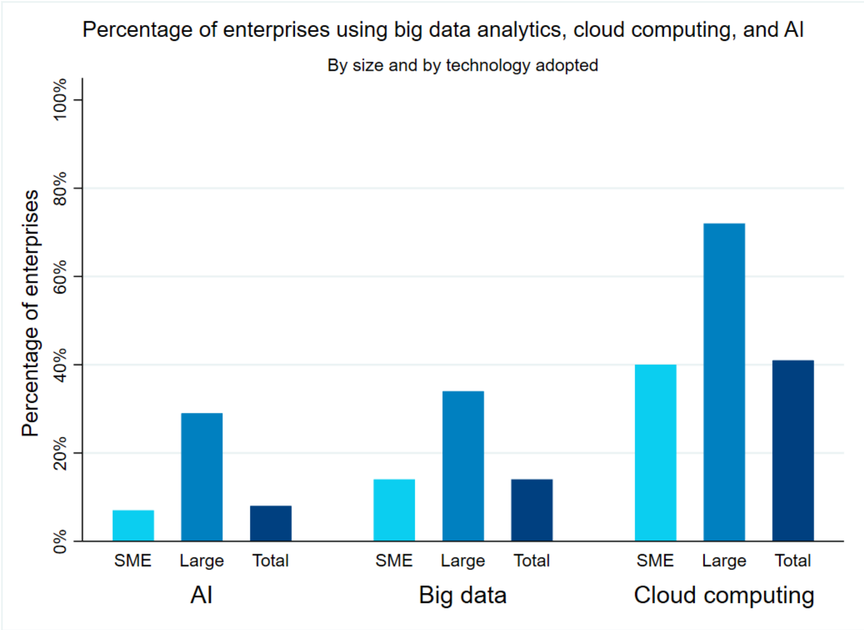

Figure 1. Percentage of enterprises using big data analytics, cloud computing and AI; Source: Eurostat

The Portuguese case

In 2022, according to the Digital Economy and Society Index, Portugal ranked in the fifteenth place out of the 27 countries of the European Union (EU), just below the average. Although Portugal scores slightly above the EU average in most of the topics analyzed by the Index, a poorer performance in the Connectivity area drives down the country in the overall ranking. 5G coverage is one of the main unsatisfactory indicators, with Portugal lacking any 5G coverage in 2021 - compared to the European average of 66%. The country has strong positive indicators regarding AI usage by enterprises (17% vs 8% of the European average), and Fiber to the Premises (FTTP) coverage (88% vs 50%). The percentage of graduates in ICT fields, as seen in Table 1, is lower than the EU average (2.6%, compared to 3.9%). However, the percentage of ICT specialists in employment in Portugal is slightly higher than the EU value. This increase in ICT specialists can be seen as a positive trend for the future, as digital transformation and overall ICT sector is of increased importance, giving Portugal an opportunity to compete and match the digital skills with other international labor markets (EC 2022b).

	Portugal			EU
	DESI 2020	DESI 2021	DESI 2022	DESI 2022
1a1 At least basic digital skills % individuals	**NA**	**NA**	**55%** 2021	**54%** 2021
1a2 Above basic digital skills % individuals	**NA**	**NA**	**29%** 2021	**26%** 2021
1a3 At least basic digital content creation skills[4] % individuals	**NA**	**NA**	**61%** 2021	**66%** 2021
1b1 ICT specialists % individuals in employment aged 15-74	**3.5%** 2019	**4.0%** 2020	**4.7%** 2021	**4.5%** 2021
1b2 Female ICT specialists % ICT specialists	**18%** 2019	**21%** 2020	**21%** 2021	**19%** 2021
1b3 Enterprises providing ICT training % enterprises	**28%** 2019	**23%** 2020	**23%** 2020	**20%** 2020
1b4 ICT graduates % graduates	**2.2%** 2018	**2.3%** 2019	**2.6%** 2020	**3.9%** 2020

Table 1: Human Capital Indicator, Digital Economy and Society Index (Portugal, 2022)

Despite all the improvements that Portugal has been doing in the past years, the county still has some catching up to do. Namely, as seen in Figure 3, Portugal still lags behind in the spending on Research and Development (R&D), being far below – close to half - the OECD average (close to 1.5% of GDP vs the OECD average of close to 3%). More specifically, regarding the R&D spending in the ICT sector, Portugal is placed in an even worse position, with less than 0.2% of the budget being placed in the ICT sector. Countries such as the United States (US), Japan and Sweden are some of the countries that lead this indicator, setting the OECD average at 0.4% of GDP (OECD 2021a).

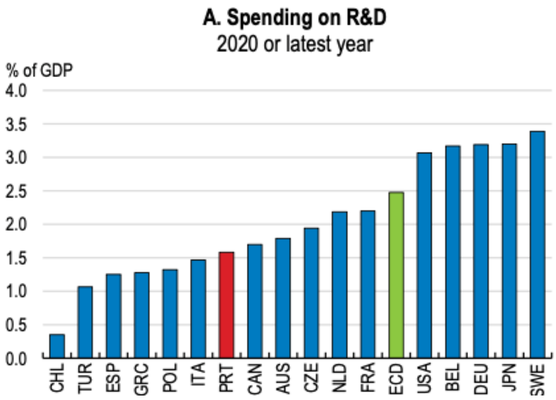

Figure 2: Spending on Research and Development (Source: OECD, 2021)

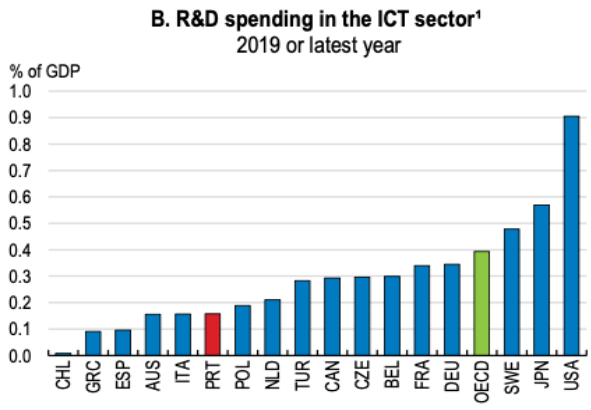

Figure 3: Spending on Research and Development in the ICT sector (Source: OECD, 2021)

The following figure (Figure 4) shows how both Portuguese Small and Medium Enterprises and large firms are performing on four ICT indicators, compared to the EU28[2] average, and to the best performer. Firstly, almost all the Portuguese enterprises use some type of ICT security measure which is in line with the best performer and above the EU28 average. Secondly, 80% of the Portuguese large firms have an ICT security policy, being positioned close to the EU average. However, in comparison to the best performer, there is still room for improvement. The same applies for SMEs, where only close to 30% of them have this security policy (comparing to close to 60% of the top performer, and close to 40% of the EU average) (OECD, 2021).

Portugal is also behind on enterprises having document(s) on measures, practices, or procedures on ICT security. The frame is similar to the previous one: while Portuguese firms are approaching the European average, especially the largest ones, Portugal still lags behind, when compared to the best performers of this indicator. Finally, on enterprises that make employees aware of their obligations in ICT security related issues, Portugal is slowly catching up to not only the EU average, but also to the best performer. Around 90% of the Portuguese large firms are making their employees aware, and, slowly, so are the SMEs (OECD 2021a).

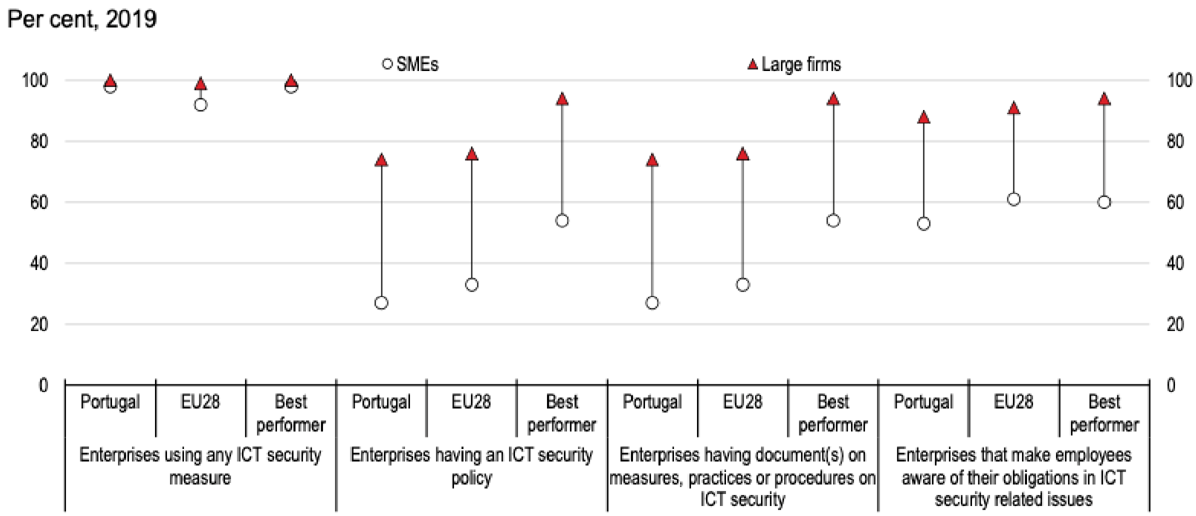

Figure 4: Adoption of Digital Security measures among SMEs and Large Firms (Source: OECD, 2021; EUROSTAT, 2021)

[2] The data is from 2019, when Great Britain was still part of the European Union.

Overall, there is still room for improvement regarding the Portuguese performance on digitalization, and in the ICT sector. In several indicators, although close, the country is still not above the EU average. This shows that the right investment and the providing of the right set of skills to employers and employees can turn this scenario around, boosting the Portuguese case for digitalization and productivity.

In 2016, the Digital Economy and Society Index placed Portugal in the 14th place, above the EU average. The country was the second European country with the most progress from 2015 and 2016 (EC 2016f). Among the several indicators studied in this index, there was a clear improvement in broadband network coverage, online public services, and business digitalization. However, between 2016 and 2021, Portugal saw itself falling behind, going from the 14th to the 19th place in just five years (EC 2021e).

Until 2020, the European Commission noted the low digital literacy of the Portuguese population and the overall lack of digital skills as one of the major challenges the country was facing. On that year, and although Portugal made significant progress in that area, there was still a concern regarding the use of internet services and overall human capital (EC 2020d). There was a steady rise from 2020 to 2021, improving three steps in the European placement (from the 19th to the 16th place), with important actions being taken on increasing the proportion of ICT specialists in the country, and on improving the basic digital skills to its population.

In the past years, the Portuguese government has developed several initiatives to improve the country's performance in digital transformation. Giving the right set of digital skills to both firms and the workers has been a priority, with the creation, among several others, of a National Initiative for Digital Skills, Portugal INCoDe.2030, in 2017, and a governance structure - the Council for Information and Communication Technologies (CTIC). The goal is to give the population the opportunity to further develop their digital skills, with the purpose of facilitating the fast adoption of ICT technologies.

Adding to these initiatives, Portugal's Action Plan for Digital Transition, created in 2020, focuses on three different pillars of action: Capacity building and digital inclusion; Businesses' digital transformation; and public services' digitalization. Regarding the second pillar, it is crucial to note that aiding Portuguese firms in their digital transformation can boost their competitiveness in a globalized market, improving the Portuguese economy. Among the different measures, support for investment and training take on as two of the most important ones (Ministério da Economia e Transição Digital, 2020).

Context

This work project was developed with the support of the Gabinete de Planeamento, Estratégia, Avaliação e Relações Internacionais (GPEARI). GPEARI is the Office of Economic Research and International Affairs of the Ministry of Finance, and its mission consists in: supporting policy making and strategic and operational planning, ensuring, directly or under its coordination, international relations; and monitoring and evaluating the implementation of policies, planning tools and the outcomes of the organization and management systems, in conjunction with other ministry services (GPEARI 2023a.).

To conduct the mentioned activities, GPEARI collaborates with different authorities and gathers information from various sources. It collaborates with governmental agencies and academic organizations to conduct research papers and assessments on specific topics, such as the impact of structural reforms (ex-ante and ex-post assessment). At a national level, GPEARI has been closely monitoring the Recovery and Resilience Program (RRP), conducting an ex-ante evaluation of the macroeconomic impact reforms and policies, based on QUEST III R&D model developed by the European Commission.

At the European level, GPEARI contributes to the discussion and formulation of policies and plans on various topics, including the European fiscal policy orientation for 2023, contributing to Draft the Budgetary Plan and the Stability programme, the analysis of EU different initiatives in support of Ukraine, the debate on the reform of the European budgetary framework, and the development of EU legislative initiatives in financial services (GPEARI 2023b). Additionally, at the international level, GPEARI aims at efficiently using the available financial instruments to support other states, Portuguese-speaking African countries, such as Mozambique, Cape Verde, Angola, and São Tomé and Príncipe (PALOP) (GPEARI, 2022).

Furthermore, GPEARI, together with the Office of Strategy and Studies (GEE), coordinates the National Productivity Board, a council overseeing and monitoring public policies in the area of productivity (EC 2019a). This Board is responsible for promoting monthly seminars, delivering annual reports, and providing research and analysis, and it supports an annual conference to foster international debate in the field. The RRP advises that each Member State dedicates at least 20% of its Recovery and Resilience Plan's total allocation to measures contributing to the digital transition (EC 2022j). GPEARI inserts himself in this equation, as it monitors and evaluates structural reforms and its developments.

GPEARI's goal is to understand the impact of the reforms presented, recently focusing on the policies that affect the digital transition into the Portuguese economy, as it is a crucial pillar of the Portuguese economic development strategy. They are also keen on studying the effects of such polices on productivity: examining if and how digital transition is having a positive impact in the economy, which digital technologies are more relevant, and which firm characteristics are more important for the adoption (possible heterogeneity) of it. This research and evaluation process allows GPEARI to know what policies could be promoted to boost businesses lagging behind.

Motivation

This work project aims at studying the impact of digital transformation in Portuguese firms, using large datasets from Sistema de Contas Integradas das Empresas (SCIE) and Inquérito à Utilização de Tecnologias da Informação e da Comunicação nas Empresas (IUTICE), covering most of the Portuguese firms throughout the period between 2008 and 2021. As it has five different questions of interest, this paper provides various insights on several topics, namely e-commerce, ICT staff and internet usage. All individual parts will use Regression Analysis as the main methodology, after predicting Total Factor Productivity (TFP).

The goal of this paper is to determine what influences and what are the consequences of digital adoption by Portuguese firms, in various sectors of activity, including ICT training to its employees, online platforms, and fast internet connection. With the increasing worldwide connection, and as firms need to reinvent themselves and fast adapt to these changes in order to remain competitive, the topics on ICT usage by firms and overall digitalization is of growing importance. It is crucial to not only provide managers and clients with updated information and training, but also the workers, fundamental in the production chain.

The results show that (name main results), which has several policy implications. On the one hand, (state two or three policy implications)

This study relates to the existing literature on digital transformation, with the advancements that have been done in the past two decades, and its impact on productivity. It also relates to the impact of Information and Communication Technology, as each individual part presents a different tool that firms may adopt, including big data, cloud computing and social media usage.

The remaining structure of this work project is as follows: the next section will present an analysis of the development in the digital transition of European countries, through the usage of Eurostat data; afterwards, a small chapter will show what the Portuguese government has been doing in what regards to this topic, showing policies and plans that have been adopted. Moreover, a review of the existing literature on digital transformation, the productivity paradox, among other topics, will be shown. After a brief description of the datasets this work project will use, all six individual parts will be presented. Finally, the main conclusions and limitations will be described, along with some policy implications.

Developments in the European Union

As previously described, the main goal of this work project is to study the possible impact of incorporating several ICT tools in the enterprises' businesses has on the productivity of these firms. This section will present the evolution of some ICT indicators, such as the employment of ICT specialists, employed people with ICT education, among other indicators. The goal will then be to compare the Portuguese case with the rest of the European Union, focusing on several countries that are described just below.

The macro data of the following analysis was taken from the Digital Economy and Society database, from Eurostat. The data concerns topics such as Digital Skills, the overall ICT sector, ICT usage in enterprises, among other indicators.

The data concerns all the European Union countries[3], in addition to other European ones, including Serbia, the United Kingdom, Norway and Montenegro. The goal of this analysis is to not only place Portugal in the European sphere, comparing it in the different topics described above, but also to perform a more in-depth analysis with a few selected countries. The countries selected were based on differences or similarities, along with both their placement in the DESI report and overall digitalization intensity. It goes as follows:

- Spain, considered to be the most similar country to Portugal. Although similar in various aspects, Spain ranked in 7th place in the 2022 DESI report (EC 2022e). With a strong performance on connectivity (3rd place, out of the European countries), along with serious improvements both on digital public services and integration of digital technology, the country has been having a strong investment in digitalization. Regarding its national Recovery and Resilience Plan, Spain has the most ambitious framework regarding its digital transition, with 28.2% of its budget allocated on this area (EP 2023).

[3] Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden.

- Italy and Greece, both considered to be alike Portugal. When the 2008 financial crisis hit, these three countries were particularly negatively affected (Investopedia, 2021). Greece takes a step further as, much like Portugal, had to receive an EU/IMF bailout and implement an austerity program. On the one hand, Italy ranked 18th in the DESI 2022 report, and, although the country is advancing in some indicators, there is still a gap between it and the EU average, for instance, in the access to basic digital skills, and the percentage of digital specialists in its workforce (EC 2022d). On the other hand, Greece ranked 25th place, out of the 27 countries that are in this analysis (EC 2022c). Although it has some strengths, including the number of users of e-government services, there is still a lot of catching up relative to the other economies, mainly in terms of connectivity and SMEs with the basic digital intensity levels.
- Belgium is similar to Portugal in terms of population, having just more one million people than Portugal. Most importantly, there are also similarities in terms of digitalization. Belgium ranked 16th in the 2022 Digital Economy and Society Index, just one position below Portugal. This country presents a bigger integration of digital technology and less connectivity, but both countries present dissimilar results in the components of Digital Public Services and Human Capital (EC 2022g).
- France is one of the largest and most advanced economies in Europe, with a diversified industrial sector, strong investment in research and development and a robust presence in international trade OECD 2023a). The enterprise situation in the country sees a total of more than 4 million enterprises in 2020, most of which are micro-enterprises (OECD 2023b). In terms of technological development applied to the labor sector, France is a technologically advanced country that prioritizes meeting the needs of its large consumer market.

- As the EUs leading economy, Germany will be included since its progress on digital transformation will be vital for the EU to reach its goals for the digital decade. Moreover, the country is, like Portugal, in the middle of the field in the DESI, ranking 13th in 2022. Germany and Portugal display similar rankings in the DESI dimensions of human capital, integration of digital technology, and digital public services. However, a significant deviation can be observed in the connectivity dimension, where Germany markedly outperforms Portugal (WEF 2023; EC 2023d).
- Austria ranked 10th in the 2022 Digital Economy and Society Index ranking, with an above-average score of 54.7. With most dimensions of performance above EU averages, Austria presents quite a different context for the advancement of digitalization. Still, similarly to Portugal, the country scores low on the aspect of connectivity. Furthermore, the value added to GDP by the ICT is quite low (EC 2022i).
- Bulgaria and Estonia differ from Portugal in cultural and economic factors. Language, historical influences, and traditions are very different. Additionally, each country has distinctive economic structures and challenges. Nevertheless, not only both countries belong to the EU and are considered small countries such as Portugal, but they also invest intensively in digital transformation, showing a high value added by the ICT sector at current prices. By adding them to the analysis we are comparing apparent success cases with the Portuguese ones, to observe if and how they are similar.
- Over the last years Poland has been one of the fastest growing economies not only in Europe but also globally, the country's well-diversified economy has proven to be very resilient and recovered quickly from the COVID-19 Pandemic (Marciniak 2023; WBG 2023a). In its 2023 Economic Survey on Poland, the OECD highlights the growth of ICT innovation in Poland, and underscores the urgent need to improve digital skills, especially among older adults, while suggests a more practical and flexible education

system to address skill gaps as well as targeted awareness campaigns and scholarships to increase women's participation in ICT (OECD 2023c). In the 2022 DESI, Portugal consistently outperforms Poland across several key indicators. In terms of the overall ranking, Portugal stands at 15th, substantially higher than Poland's 24th position (EC 2023c).

As previously mentioned, this dataset includes several indicators on the ICT sector and ICT usage in enterprises. It is important to go through the most crucial topics, as this data provides the opportunity to compare the Portuguese case with other European countries.

An important indicator is the number of employed people with ICT education by sex. As the two following tables show (Table 2 and Table 3), there is still a high prevalence of males with ICT education in employment. Throughout the years analyzed (2004-2021), in Portugal, close to 78% of the employed people with this type of education were men. This percentage was more favorable to women in the beginning years of the analysis, given that in 2004 almost 30% of the employed persons with ICT education were women. In 2021, this value was only 19.5%. Comparing Portugal with other countries, it is easy to notice a continued male prevalence in this sector: in France, around 85% of these people are men. The highest value, 89.7% was verified in 2021, where only 10.3% were women. When looking at the EU average, Portugal is below average when it comes to males (80.97%, compared to the Portuguese average of 77.67%). As for employed females, Portugal is above the European average, as the latter is set at 19.03%.

	Mean	Median	Min	Max	IQR	SD
AUT	85.27	86.05	75	90.7	4.8	3.825
BEL	87.21	87.1	83.2	92.6	3.7	2.314
BGR	70.19	71.7	59.3	78.6	9.95	6.37
DEU	86.02	86.3	80.9	88.8	1.2	1.714
ESP	78.38	78.4	74.1	82.6	5.07	2.93
EST	75.09	78.5	45.4	84.5	12.4	11.95
EU27	80.97	82.2	72.5	84.6	5	3.405
FRA	84.9	85.4	77.7	89.7	4.2	3.087

GRC	65.57	63.6	57.2	78.5	10.8	6.762
ITA	76.08	77.8	63.9	84.0	10.2	5.876
POL	85.94	87.1	79.9	90.4	6.2	3.49
PRT	**77.67**	**77.6**	**70.8**	**85.1**	**7.1**	**4.533**

Table 2: Descriptive statistics on employed males with ICT education.

	Mean	Median	Min	Max	IQR	SD
AUT	16.39	15.3	10.7	25.0	5.43	4.07
BEL	12.79	12.9	7.4	16.8	3.7	2.31
BGR	34.54	31.5	24.4	54.1	12.5	9.62
DEU	14.43	13.8	13.3	19.1	1.57	1.61
ESP	21.62	21.6	17.4	25.9	5.08	2.93
EST	25.77	20.55	16.5	54.6	13.3	10.6
EU27	19.03	17.8	15.4	27.5	5	3.41
FRA	14.93	14	10.3	22.3	4.5	3.09
GRC	34.43	36.4	21.5	42.8	10.8	6.76
ITA	23.92	22.2	16	36.1	10.2	5.88
POL	14.06	12.9	9.6	20.1	6.2	3.49
PRT	**22.33**	**22.4**	**14.9**	**29.2**	**7.1**	**4.53**

Table 3: Descriptive statistics on employed females with ICT education.[4]

The scenario is similar in what regards ICT specialists divided by sex. An ICT specialist is a "worker who has the ability to develop, operate and maintain ICT systems, and for whom ICT constitutes the main part of their job"[5]. As seen in Table 4, Portugal's average is close to 83% of male ICT specialists. The country with the least disparity, but still with a high number is Bulgaria, with an average of 70%. The only other country with this average below 80% is Estonia, both Eastern European countries. This can show an investment that these countries might be doing in providing the female population with ICT skills and opportunities.

	Mean	Median	Min	Max	IQR	SD
AUT	83.158	83.050	79.6	86.8	4.9	2.657
BEL	83.417	83.250	80.4	85.9	1.95	1.578
BGR	70.133	70.650	67.1	71.9	2.6	1.651
DEU	83.092	83.400	80.6	84.8	.8	1.229
ESP	81.75	81.650	80.6	83.6	1.4	.925
EST	77.567	77.450	73.8	80.6	3.15	1.967
EU27	82.608	82.950	80.9	83.8	1.4	.967
FRA	81.108	80.650	79.1	84.2	1.8	1.464
GRC	80.15	79.750	73	84.6	4	3.219
ITA	84.725	84.800	83.9	85.8	1.4	.72

[4] Note: Tables 5 and 6 represent, out of the overall employed people with ICT education, the share of males and females, respectively.

[5] **Invalid source specified.**

POL	85.217	85.500	83.3	86.4	1.2	.92
PRT	**82.383**	**82.300**	**78.9**	**86.7**	**2.8**	**2.446**

Table 4: Descriptive statistics on Employed ICT Specialists that are male (% of total ICT Specialists, from 2011-2022)

Regarding the percentage of ICT personnel in total employment, Portugal's average is of around 1.80% in ICT services (Table 5). This value has been increasing since the beginning of the analysis. In 2008, the Portuguese employment was only constituted by around 1.32% of ICT personnel and, twelve years later, it expanded to 2.53% in 2020.

Comparing the Portuguese case with other countries, several European countries have much higher records (2.79% for Estonia, and 2.71% for France, on average, for instance), which shows that Portugal still has room for improvement and catching up in these types of services. By providing the right incentives and investment, the country may find a way to have higher employment, in relative terms, of ICT personnel.

	Mean	Median	Min	Max	IQR	SD
AUT	2.18	2.19	1.92	2.51	.28	.18
BEL	2.58	2.52	2.46	2.82	.07	.12
BGR	2.16	2.04	1.4	3.07	.81	.52
DEU	2.31	2.29	1.9	2.83	.49	.35
ESP	2.19	2.13	1.85	2.70	.32	.24
EST	2.79	2.7	2.05	3.97	.89	.57
FRA	2.71	2.73	2.52	2.97	.19	.13
GRC	1.37	1.39	1.2	1.59	.17	.12
ITA	2.16	2.15	2.06	2.33	.1	.08
POL	1.81	1.73	1.22	2.51	.75	.44
PRT	**1.80**	**1.73**	**1.32**	**2.53**	**.44**	**.36**

Table 5: Descriptive statistics on the percentage of ICT personnel (in services) in total employment[6]

Another important indicator of ICT usage in enterprises is to analyze the differences in the percentage of enterprises employing ICT specialists, depending on the size class. Usually, companies are classified small-sized if they have 10 to 49 employees, medium-sized if it ranges from 50 to 249 and large when they have 250 employees or more.

[6] Note: The EU average is not in this table as there was not enough data in the different countries to provide these descriptive statistics.

As the following tables show (Table 6 and Table 7), as companies grow larger, the number of ICT workers increases. They demonstrate that Greece (28.73% and 55.81%, respectively) and Belgium (27.83% and 54.33%) have the highest percentages of small- and medium -sized enterprises employing ICT specialists, while Poland has the lowest, with only 14.66% and 30.86%.

	Mean	Median	Min	Max	IQR	SD
AUT	23.971	23.8	19.8	31.8	4.7	3.963
BEL	27.829	28.2	25.7	29.4	1.8	1.232
BGR	20.229	21	14.7	22.4	2.1	2.585
DEU	21.057	21.6	19.2	22.6	3.2	1.446
ESP	22.143	22.9	16.9	25.6	7.3	3.535
EST	15.471	15.3	13.5	18.2	.9	1.416
EU27	19.9	19.7	19.3	20.5	1	.493
FRA	16.229	16.3	14.8	17.5	2.2	1.086
GRC	28.729	27	23.1	37.2	8.1	5.048
ITA	16.114	16.4	14.5	17	1.6	.899
POL	14.657	13.2	10.8	24.3	2.2	4.433
PRT	**21.129**	**20**	**18.7**	**29.300**	**2.1**	**3.699**

Table 6: Descriptive statistics on the percentage of small-sized enterprises employing ICT specialists.

	Mean	Median	Min	Max	IQR	SD
AUT	50.214	50.1	44.8	56.6	8.1	4.191
BEL	54.329	54.5	51	57.4	2.9	2.049
BGR	31.157	32.6	20.5	34.7	1.4	4.788
DEU	45.3	45.4	42.1	48.3	3.7	2.137
ESP	45.586	47.5	37.6	51.0	9.4	5.012
EST	32.957	32.6	30.3	37.4	1.7	2.208
EU27	42.286	42.4	41.5	43.3	1.4	.71
FRA	39.186	38	36.6	43.3	4.6	2.649
GRC	55.814	57.5	48.5	62.9	8.4	5.053
ITA	42.371	42.7	39.9	43.8	2.6	1.406
POL	30.857	30	25.7	40.4	3.8	4.652
PRT	**46.7**	**47.3**	**41.1**	**50.2**	**5.1**	**3.604**

Table 7: Descriptive statistics on the percentage of small-sized enterprises employing ICT specialists.

Table 8, which illustrates the same indicator among large enterprises, shows that Austria (86.2%) joins Greece (81.03%) and Belgium (85.69%) with the highest percentages and Bulgaria becomes the lowest with 56.23%. Moreover, in each size class, it is noticeable that the percentage of Portuguese firms employing ICT specialists is close to the EU average and the country with the highest similarity to Portugal is Spain. Additionally, among the three greatest economies in the EU, Germany in every size class is the country with more firms hiring ICT workers, nonetheless, Italy and France have similar values.

	Mean	Median	Min	Max	IQR	SD
AUT	86.2	86.9	82.6	89.3	3.3	2.264
BEL	85.686	85.4	84.6	87.6	2	1.199
BGR	56.229	61.1	23.9	64.7	5.2	14.401
DEU	78.914	77.1	76.1	83.3	5.1	2.844
ESP	71.586	72.3	64.8	74.7	3.7	3.359
EST	68.757	69.7	61.7	74.3	5.6	4.066
EU27	75.214	75.1	74.2	77.4	1.1	1.067
FRA	73.6	72.4	71.2	77.1	4.2	2.373
GRC	81.029	82.8	66.4	88.2	6.1	7.041
ITA	73.214	73.2	71.5	75.6	2.2	1.44
POL	74.8	73.8	73.4	81.3	.3	2.872
PRT	**75.843**	**75.2**	**72.6**	**79.4**	**3**	**2.265**

Table 8: Descriptive statistics on the percentage of large enterprises employing ICT specialists.

A strong component of this research is to analyze the impacts of the ICT specialists on productivity and how the ICT sector can be changing the whole spectrum of the economy. Therefore, it is highly relevant to analyze how the employment of ICT specialists, as a percentage of total employment, has been progressing throughout the years.

In the European Union (27 countries), there has been tremendous progress since 2004, since it started with a level of 3,1 % and in 2022 it increased to 4,6%. This alone shows signals of a transforming economy, with more and more people being employed in this sector.

In the case of Portugal, the transformation has been outstanding, as the country started with a level of 2,3% and almost doubled it with a level of employment of 4,5% in 2022. Even though this evolution has been able to start closing the gap between Portugal and other European countries, Table 9 shows that the countries with the highest ICT specialists' employment averages are Belgium and Estonia. Portugal has shown a steady increase since 2013, although with a slight decrease from 2021 to 2022, from 4.7% to 4.5%. The country has been closing its gap with the European Union, showing an important focus in having ICT specialists on its enterprises.

	Mean	Median	Min	Max	IQR	SD
AUT	3.832	3.600	2.9	5	1.1	.58
BEL	4.395	4.200	3.4	5.6	1	.648
BGR	2.753	2.500	2.2	3.8	.7	.483
DEU	3.826	3.700	3.1	5	.3	.509
ESP	3.368	3.200	2.8	4.3	.5	.4
EST	4.4	4.100	2.5	6.6	2	1.215
EU27	3.616	3.500	3	4.6	.5	.443
FRA	3.789	3.900	2.7	4.5	.8	.551
GRC	2.305	2.200	1.6	2.9	.9	.453
ITA	3.295	3.200	2.9	3.9	.4	.276
POL	2.884	2.800	2.3	3.6	.5	.362
PRT	**2.958**	**2.800**	**1.9**	**4.7**	**.7**	**.74**

Table 9: Descriptive statistics on Employed ICT specialists (% of total employment 2004-2022)

It is also important to analyze whether these employed specialists have an impact of the economy. In theory, it is easy to associate the success of a nation to how well they are doing technologically: the more digitalized and technological a society is, the more advanced and economically prosperous is considered.

To find some correlation, GDP per capita and the employed ICT specialists (ICT Total), in percentage of total employment to the year of 2022, were computed. Figure 5 shows that these two appear to be positively correlated. The regression line in red shows the upward trend: a country with more ICT specialists should have a higher GDP per capita. By looking closer, the countries with less than 5% of ICT specialists, have a lower GDP per capita than the countries with more than 5%, except for Iceland and Estonia. Although it is not a rule, the countries with more ICT specialists seem to present higher values of GDP per capita, showing that, in fact, a more digitalized society, with more specialists in ICT, can be more economically prosperous.

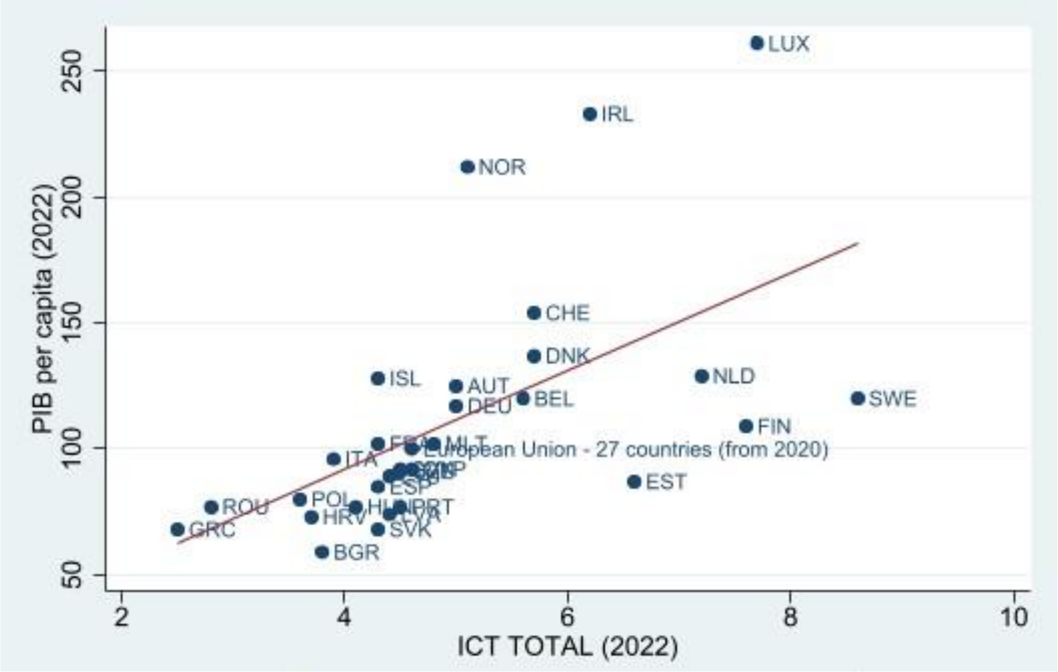

Figure 5: Comparison between GDP Per Capita and percentage of ICT specialists' total employment (2022)

Variables	Mean	Median	Min	Max	IQR	SD
AUT	76.667	76.85	57.6	89.6	16	10.73
BGR	87.012	88.1	71.5	95.0	9	6.397
DEU	62.406	62.55	57.7	66.6	4.7	2.795
EST	69.994	66.2	55.7	92.4	11.8	10.954
ESP	91.469	91.1	87.9	96.0	3.45	2.375
EU27	68.806	69.9	58.6	73.1	4.3	4.205
EU28	68.581	70.05	57.7	73.7	4.55	4.635
EU15	69.5	71.2	57	75.6	5.4	5.347
FRA	98.233	98.5	95.7	99.3	1.2	1.074
GRC	52.228	54.55	30.2	74.7	29.5	15.422
ITA	28.372	30.25	15.1	37.3	11.8	7.388
POL	64.271	64.6	56.1	69.1	2.5	3.09
PRT	**32.006**	**32.15**	**24.5**	**39.6**	**8.5**	**4.483**

Table 10: Descriptive statistics on employed persons with ICT education by educational attainment level

Looking at employed individuals with ICT education, categorized by educational attainment levels, reveals several important insights (Table 10). Firstly, the median and mean percentages of employed persons with ICT education are relatively close in most regions, suggesting a consistent presence of ICT-educated workers in the workforce during the studied period. Notably, France stands out with the highest median and mean percentages, indicating a strong representation of ICT-educated individuals in the French workforce throughout the years. Conversely, Italy and Portugal have lower median and mean percentages, indicating a smaller proportion of the employed population with ICT education in these countries.

Moreover, Greece shows a wide interquartile range, implying significant variability in the percentage of employed persons with ICT education over time. Austria demonstrates the highest maximum value, reaching 89.6%, suggesting a peak in the percentage of employed persons with ICT education in 2016. In contrast, Italy exhibits the lowest maximum value of 37.3% in 2017, indicating a comparatively lower peak in the representation of ICT-educated workforce during the same period.

In addition to this, it is important to analyze the education attainment level of the ICT specialists. In most of the European Countries, from 2004 to 2022, the mean percentage of employed ICT specialists with tertiary education was above 50%, almost in every country. This shows that more and more of these workers have tertiary education, explained by an increasing specialization of this sector. In a further analysis at the countries in comparison (Table 11), Portugal is one of the countries that has less than most of the workers with tertiary education, as Italy, Austria, and Germany. However, it is important to refer that this is a mean for an interval of 18 years. Portugal started with a level of 30,3% of employed ICT specialists with tertiary education in 2004 and more than doubled it until 2022 (63,9%). This is a significant improvement, which shows the investment the country has been doing on specializing and on providing the right education to these workers.

	Mean	Median	Min	Max	IQR	SD
AUT	48.032	40.300	31.8	67.2	28.5	14.209
BEL	71.889	73.000	61.1	81.3	11.1	6.2
BGR	60.126	64.900	43.1	76.2	21.3	12.016
DEU	48.853	48.100	46	54.1	3.3	2.363
ESP	77.558	80.000	68.1	83.1	9.3	5.064
EST	55.784	56.900	47.9	59.6	5.8	3.235
EU27	56.216	56.400	46	65.2	13.8	6.622
FRA	69.642	74.000	51.4	81.4	23.2	11.102
GRC	63.932	66.000	52.9	72.6	12.3	6.843
ITA	31.016	31.600	19.6	41.3	9.6	6.267
POL	63.4	65.800	48.4	73.6	19.5	9.327
PRT	**46.021**	**42.600**	**30.3**	**63.9**	**20.4**	**10.989**

Table 11: Descriptive statistics on Employed ICT Specialists with Tertiary Education (% of total ICT Specialists, from 2004-2022)

In conclusion, not only has the country been increasing its employed ICT specialists as a percentage of total employment, but also that these are more academically educated. Portugal might be catching up with other European countries, although this sudden rise must be sustained, and the country should have an appropriate strategy to cope with that.

Regarding the enterprises that provided training to develop and/or upgrade the ICT skills of their personnel (Table 12), it is noticeable that the activity Information and Communication has the highest mean (51.426) and the highest maximum (88.5), the level of training in the I&C area is expected to be high. Excluding the high value for I&C the means fluctuate between 14.601 for transportation to the 29.782 for Professional and Technical. Compared to I&C and Accommodation that have an highest standard deviation, the numbers for other sectors are lower.

	Mean	Median	Max	Min	IQR	SD
Accommodation	28.349	17.5	82.600	2	42.3	23.133
Administrative	19.631	18.15	57.600	4.7	11.6	8.847
Construction	11.351	10.5	26.500	2	7.1	5.188
Elecricity&Gas	27.478	26.35	66.600	6.1	13.8	11.882
Info & Comm	51.426	53.3	88.500	11.8	22.85	16.428
Manufacturing	19.657	17.7	66.100	0	12.9	10.116
Profess & Tec	29.782	30.3	57.700	8.9	13.1	10.245
Real Estate	21.978	20.65	41.400	5.4	15.5	9.768
Transport	14.601	14.85	26.300	3.7	7.6	5.268
Water	24.375	26.2	38.000	6.7	17.55	10.827
Retail	19.068	18.15	48.200	3.5	10.7	8.1
Others	43.886	47.55	88.900	0	19.2	20.111

Table 12: Enterprises that provided training to develop/upgrade ICT skills of their personnel by NACE Rev.2 activity

The Portuguese Institutional Framework

In an increasingly digital and technological world, governments around the world have had some difficulty in keeping up with the transition. Much effort has been made in this regard, as every country has the ambition of having increasingly digital, efficient, and technological economies and societies. Portugal is no exception, as seen by recent investment plans that aim precisely at digitalizing society, promoting economic growth, and spurring innovation.

The country's economy, which heavily relies on low wages and low value-added, as well as a combination of low qualifications among workers and business owners, are the key hindrances to Portugal's growth and recovery (Cortes, Hoerning, & Trigo Pereira 2022).

Adding to that, there is also a problem regarding the public administration and its connectivity and interconnection with its citizens and businesses. In 2019, only 41% of individuals used the internet to interact with public authorities, much below the OECD average of 57.9%. Portugal ranked slightly under the OECD average in the user-driven index measuring the extent to which policies and public services are delivered based on the needs of citizens and enterprises (OECD 2020a).

To reach its full potential, the public administration should take advantage of the opportunities presented by new technologies. This would help create greater investment venues in the country and place public administration at the service of their citizens.

Aware of that, Portugal has launched two major plans that give emphasis to take advantage of new technologies in public services. However, these plans are much more than that. They aim at transforming the Portuguese society and economy by investing into a green and digital transition through public policies focused on firms and its workers. The first plan is the Action Plan for Digital Transition presented in 2020, which served as a base to the recent Recovery and Resilience Plan, part of the European Recovery Plan, NextGenerationEU.

Action Plan for Digital Transition (Plano de Ação para a Transição Digital, 2020)

The Action Plan for the Digital Transition is, according to its definition, “the country's transformation engine, aiming to accelerate Portugal by leaving no one behind, through capacity building and digital inclusion among people, businesses' digital transformation and public services' digitization” (Ministério da Economia e Transição Digital 2020). This program, presented in 2020, has 56 initiatives that aim to foster the digital transition of the Portuguese economy. This plan focuses on three different areas: digital empowerment of people, businesses' digital transformation and public services' digitization.

The e-Residency Program, intended to create a digital identity concept using the Digital Mobile Key. This would allow the use of the Portuguese public services online by its citizens, nationals, and foreigners not resident in the country.

The Action Plan also includes the Cloud Strategy for Public Administration**,** which creates a strategic framework for the integration of Public Administration in the cloud through the adoption of cloud computing tools.

In the area of business digital transformation, this plan incorporates measures from the program Industry 4.0 (*Indústria 4.0*). This program was launched in 2017 to stimulate the Industry 4.0 in Portugal, contributing to the strengthening of the technical and technological capacities of SMEs in the context of Industry 4.0. With a view to accelerating their digital maturity and contributing to relevant productivity gains and greater competitiveness, this would make Portugal an attractive pole for investment.

One of these measures is the Digital Capacity Building Program for SMEs inland. This program aims at the reskilling of ICT professionals and its establishment in the interior regions of Portugal, by first focusing on intensive training of staff, in a polytechnic institute, followed by an integration in a qualified SME. By converting inland workers into ICT professionals, the competitiveness of the country will get better (Ministério da Economia e Transição Digital 2020).

Recovery and Resilience Plan (Plano de Recuperação e Resiliência, 2021) in Portugal

The COVID-19 pandemic had a devastating effect on the Portuguese economy, similarly to other European economies. It resulted in increased public health and social spending, a slowdown in the economy and the destruction of jobs (Monteiro & Jalali 2022).

Adding to that, according to the European Commission, Portugal needs to invest in the digital transition, particularly in the development of digital skills, in the use of digital technologies to ensure equal access to quality education and training, and to boost firms' competitiveness. There is also a sluggish productivity growth, held back by relatively low levels of investment and R&D intensity, general low skill levels of the population and a business environment hampered by inefficiencies in the justice system and regulatory restrictions (EC 2021d).

To ensure a robust recovery after the COVID-19 crisis and to address these problems the Portuguese government established the Recovery and Resilience Plan (RRP) in compliance with the Recovery and Resilience Facility (RRF) of the European Union.

The RRP is designed to be a powerful instrument that enhances recovery, assuming the goal of relaunching economic activity through capacity building and modernization of the productive structure, in order to make it more competitive, more resilient to face future challenges, and in general, more able to capitalize on the opportunities associated with the dual transition - digital and climate (Ministério do Planeamento 2021).

The Plan is structured around the three elements of resilience, green and digital transitions in an initial investment projected at 16,644 million euros. 22% of the budget will be invested into the digital transition, with similar policies to the previous Action Plan for the Digital Transition, as RPP was based on the planning instruments previously established by the Portuguese government. With this, Portugal satisfies the EU requirement of dedicating at least 20% of total investment to digital objectives.

A considerable amount of this budget is allocated to digital transition in education, fostering educational and pedagogical innovation, the development of skills in digital technologies, and the modernization of the education system. There is also a strong component regarding the Digitalization of the Portuguese workforce with the program "Digital Academy". This project offers specialized training to the Portuguese workforce to increase the number of individuals with digital skills, improve the competitiveness and resiliency of enterprises. This will improve citizens’ digital skills and promote digital inclusion in society. Adding to that, it exists the ambition of strengthening the digitalization of enterprises and catching up with the digital transition process. Companies must be able to reposition their businesses in a digitally advanced ecosystem. In this context, the programs National Network of Test Beds, Digital Commerce, Coaching 4.0 and Entrepreneurship were created.

The National Network of Test Beds establishes a national network of test beds with proper infrastructures conditions for companies to develop and test new products and services. The Digital Commerce Program focuses on the digitalization of SMEs in the commerce area, with the goal of activating their digital trade channels, by the incorporation of technology into business models, as well as dematerializing processes with customers, suppliers and logistics using information and communication technologies. Therefore, this will support internationalization via e-commerce.

Supporting Business Models for Digital Transition (Coaching 4.0) is an initiative framed in the national program Industry 4.0 that fosters the integration of technology in companies, supporting the development of processes and organizational skills that foster the digital transformation of their business models.

The Entrepreneurship program is made by investments that materialize the reinforcement of the strategic commitment to the development of the entrepreneurial ecosystem, which involves directly supporting startups, usually in the seeding phase, with a strong digital and green component, by consolidating the existing structure to support entrepreneurship (Startup Portugal) and by supporting the development of support for the development of incubators and accelerators.

It is expected to support more than 50,000 SMEs, support the creation of 30 Test-Beds and reach 4,000 companies with theoretical training and consultancy focused on Industry 4.0 and issue vouchers to 3,000 startups.

The digitalization of the economy should foster job creation in new branches of potential business areas to explore such as big data analytics, climate change and cybersecurity that are considered the biggest drivers of job growth for the next 5 years (WEF 2023b) and can lead to a further expansion of the economy.

This plan should make a significant contribution to boosting the country’s economic rebound and contribute to a green, digital, inclusive, and resilient future (EC 2021d).

Literature Review

Digital Transformation

Digital transformation, although a term commonly used in academia and industry, still possesses diverse interpretations. According to Westerman et al. (2011), digital transformation refers to the utilization of technology to drastically improve the performance or reach of enterprises. Fitzgerald et al. (2014) and Liere-Netheler et al. (2018) expanded on this concept, positing that digital transformation involves leveraging new digital technologies to enable significant business improvements. Like them, both Nwankpa and Roumani (2016) and Remane et al. (2017) provide intersecting viewpoints on digital transformation, associating it with significant enterprise changes precipitated by the diffusion of digital technologies. They accentuate shifts to analytics, big data, cloud computing, mobile internet, and social media platforms, framing digital transformation as the evolution of organizational processes and operations. Complementing this, Remane et al. (2017), observe digital transformation as fundamental alterations in existing business models, as well as the genesis of new ones, in response to the spread of similar digital technologies. This unified perspective underscores how digital technologies can instigate changes on both an operational and strategic level, spurring the modification and creation of business models in the digital era.

However, Matt et al. (2015) and Tabrizi et al. (2019) view digital transformation strategy as a blueprint to assist companies in managing transformations caused by the integration of digital technologies and post-transformation operations.

These definitions, while offering valuable insights, underscore the complex, multifaceted nature of digital transformation, making its unambiguous conceptualization a challenge. While each definition of digital transformation provides valuable insights, several challenges emerge due to the ambiguity and breadth of the term. For instance, many definitions struggle with unclear terminology, often using "digital technologies" as a catch-all phrase without explicit delineation. Additionally, they often conflate the concept of digital transformation with its impacts, such as enhanced performance or new business models, obscuring the nature of the transformation process itself (Vial 2019).

Based on previous definitions of digital transformation and the research surrounding it, we define digital transformation as the strategic process of integrating and leveraging digital technologies to facilitate drastic improvements in business performance, reach and productivity. This includes the evolution of organizational processes and operations, driven by the adoption and diffusion of technologies such as analytics, big data, cloud computing, CRM, mobile internet, and social media platforms. Digital transformation embodies significant enterprise changes, fundamentally altering existing business models and spawning the genesis of new ones in response to the evolving digital landscape. It's essential to approach digital transformation with a comprehensive understanding of its intricacies and nuances, recognizing it as a strategic, ongoing journey rather than a finite project. As such, the concept and practice of digital transformation represent the continuous adaptation and innovation necessary for businesses to thrive in the digital era.

Productivity

Techno-pessimists Vs Techno-optimists

Techno-pessimists maintain that the observed decline in productivity is simply a reversion to the norm following an extraordinary period of IT-driven growth that lasted about a decade. They argue that this deceleration is primarily observed in sectors that either produce or heavily utilize IT, and they view this slowdown as a lasting trend. They contend that the groundbreaking innovations of the early 20th century, such as electrification, far outweigh any technological advancements made since then or anticipated for the future. They also propose that as technology continues to evolve and ideas accumulate, the cost of innovation for researchers escalates. This perspective is further supported by the noticeable decrease in business dynamism, particularly in leading economies like the United States, as noted by several scholars (Andrews et al. 2016).

In contrast, techno-optimists, such as Brynjolfsson and McAfee (2011), assert that the fundamental pace of technological advancement remains steady and that the IT revolution is poised to significantly reshape advanced economies. They suggest that the growing digitalization of economic activities has sparked four key innovative trends: enhanced real-time tracking of business operations; quicker and more cost-effective business experimentation; broader and simpler idea sharing; and the capacity to duplicate innovations more rapidly and accurately, a process known as scaling-up. Techno-optimists maintain that the advancements in computing power and ICT could stimulate future productivity growth by making scientific breakthroughs more probable and reducing the costs of access, thereby creating a positive feedback loop between technology and science. However, they also caution that poor institutional practices and policies could hinder this positive cycle. Techno-optimists further posit that the full advantages of the "digital economy" may not yet be apparent due to the ongoing transition phase marked by staggered adoption of new technology and associated transition costs. They suggest that the observed productivity slowdown could reflect the dynamics related to these complementary investments (Andrews et al. 2016).

The Productivity paradox

Since the late 1980s, the question of productivity has become a central peace on the agenda of policymakers across the world. Much of the attention came after Robert Solow's famous Phrase: "You can see the computer age everywhere but in the productivity statistics". Productivity growth has, since the 1980s, gradually fallen by 50% in the G7 countries (Erber, Fritsche, & Harms 2017) Additionally, OECD economies' diminishing productivity growth is a new general feature of economic growth (Bergeaud, Cette, & Lecat 2015). It has become a widespread economic phenomenon.

In the context of an economy that is progressively going digital and where intangible assets, rather than tangible ones, are a significant driver of productivity development, many scholars have suggested that national accounts may not be able to assess productivity (Dettori, Marrocu, & Paci 2012). This is due to structural change, the transformation of the economy from an industrial to a services-oriented one, as well as the expansion of the unorganized sector in a number of OECD countries. Others object to the use of total factor productivity, commonly known as the Solow residual, as a gauge of innovation and, consequently, of technological advancement (Crafts 2018). The magnitude of the mismeasurement, however, does not appear to be sufficient to fully explain the consistently dropping rates of productivity in OECD nations (Ahmad, Ribarsky, & Reinsdorf 2017).

The basic idea that guides our understanding of the global productivity slowdown is likewise called into serious question (Crafts 2018). The productivity impact of radical technological innovation is by no means linear and proportional from the perspective of evolutionary (neo-Schumpeterian) growth theory, nor is it possible to achieve significant productivity gains from radical technological innovation in a short period of time (Freeman & Louçã 2001). Adding to that, it is proven that prospective GPTs might not be able to produce significant gains in productivity for several decades (David 1990).

To summarize, the existing literature on the productivity slowdown suggests that the productivity slowdown is more likely to be the outcome of economic factors, rather than solely of methodological issues, and theory matters when it comes to conceptualizing the paradox in question (Fragkandreas 2021).

ICT adoption and productivity

The adoption of digital technologies has been shown to empower companies to innovate, such as by enhancing business processes, and automating specific routine tasks. Additionally, they diminish the expenses associated with engaging with suppliers and customers (Brynjolfsson et al 2008; Gal et al 2019). There has been a wide range of studies at the firm- and industry-level suggesting positive linkage between the investment in digital technologies and productivity (Dedrick et al. 2003, Draca et al 2009). Recently, when analyzing cross-country data related to the implementation of digital technologies by businesses researchers have found significant disparities in the level of adoption of digital technologies among firms, with these differences being especially pronounced across countries (Gal et al. 2019). Relich (2017) determined that selected ICT components have a positive and significant influence on labor productivity in EU countries. Additionally, the impact of ERP, e-commerce, and CRM software on labor productivity is greater in transition economies compared to developed economies of the EU. Furthermore, the impact of ICT hardware investment, ICT specialist skills, and software specialist skills differs significantly between manufacturing and services, with a more substantial effect observed in services (Borowiecki et al. 2021). Similar results were found for Estonia, where firm-level productivity effects from digital technology were stronger in services compared to manufacturing (Mosiashvili and Pareliussen, 2020). Criscuolo and Himbert (2021) found that insufficient investment in intangible assets can lead to lower productivity for firms operating in digital-intensive sectors. Additionally, industries relying more on ICT specialists tend to have weaker catch-up of laggard firms, contributing to productivity divergence (Gal et al. 2019). Gal et al. (2019) found that skill and occupational shortages hinder the productivity benefits of digital adoption, indicating synergies between digitalization and other intangible factors. Multiple studies indicate that digital technologies exhibit strong complementarities with organizational capital and management skills, R&D and intangible investments, human capital and ICT-related skills, and a regulatory environment that enables the efficient reallocation of resources (Gal et al. 2019).

The relationship between the adoption of digital technology and productivity is complex and nuanced, as demonstrated by diverging views from techno-optimists and techno-pessimists, and further complicated by issues in productivity measurement and underlying theoretical considerations. Techno-optimists see potential for future growth, while techno-pessimists view the decline as a lasting trend. Questions regarding productivity measurement, the nonlinear impact of technological innovation, and historical evidence of time-lagged effects all contribute to the multifaceted nature of this subject. This complexity underscores the challenges in empirically identifying the precise links between digital technology adoption and productivity, reflecting the intricate interplay of technological, organizational, and economic factors. Our research is aimed at addressing some of these issues in regard to the Portuguese economy.

Data

In what regards to the development of the digital transition in the European Union, two different sources were considered: a large dataset from Eurostat, related to the Digital Economy and Society database.

The individual parts of this report use two Portuguese databases for its analyses: IUTICE and SCIE. These were provided by INE in collaboration with GPEARI for the evaluation of the impact of digital transition on productivity.

Digital Economy and Society

Since 2002, Eurostat has worked to coordinate the annual collection of information on ICT usage and e-commerce in enterprises (and by households and individuals) by providing standardized questionnaires – for comparison purposes. This effort is taken in collaboration with Members States' national statistical institutes (NSIs) and the OECD, with ongoing adjustments to changing EU regulation. The data is collected annually, except for two-yearly benchmarking indicators. The following sections are written with reference to the 2021 edition of the European business statistics compilers' manual for statistics on ICT usage and e-commerce.

For the 'Survey on ICT usage and e-Commerce in Enterprises', the unit of observation is the enterprise, defined as "the smallest combination of legal units that is an organisational unit producing goods or services, which benefits from a certain degree of autonomy in decision-making, especially for the allocation of its current resources." As they can work in a variety of sectors, enterprises can be classified according to their main economic activity; this is achieved by using NACE (European Classification of Economic Activities) Rev. 2 classification. For the purposes of this Survey, 12 classes (and related subclasses) of activities are considered, among others Manufacturing (Section C), Wholesale and retail trade (Section G), Information and communication (Section J). Additionally, the Survey investigates firms with 10 or more employees and self-employed persons – with the option to include also businesses of less than 10. Finally, all enterprises on the territory of the country shall be accounted for.

The survey questions are categorized as follows:

Questions	Description
A (1-7)	Access and use of the internet
B (1-12)	E-Commerce sales
C	Sharing of information electronically within the enterprise (ERP, CRM, CRM)
D (1-2j)	Use of cloud computing services

E (1-2g)	Internet of Things (IoT)
F (1-5h)	Artificial Intelligence (AI)
X (1-3)	Background information: main economic activity, number of employees, total turnover

Figure 6: Main Topics of the Survey Questions

The data concerning Portuguese enterprises was collected between February and July 2021 by the National Statistical Institute (INE). The survey comprehended web and postal surveys, with mandatory and stand-alone surveys. With a population size of enterprises of more than a hundred thousand entities, the sample drawn was stratified according to economic activity, number of employed persons, and turnover – for a sample of 8,083 (of which 3,952 micro-enterprises). The overall response rate was 94% for enterprises with 10 or more employees and 83% for micro-enterprises (less than 10 employees).

IUTICE

Information on ICT use by enterprises is collected at the national level in Portugal through the "Survey on Information and Communication Technologies Use in Enterprises" (Inquérito à Utilização de Tecnologias da Informação e da Comunicação nas Empresas, hence IUTICE). This process is carried out yearly by the Portuguese National Institute of Statistics, specifically by the Department of Economics Statistics/Service of Business Statistics (DEE/EP). Over the years, the survey has been modified to comply with the European guidelines and criteria, while remaining a firm-level inquiry; the following sections are written with reference to the 2022 Methodological Document.

The information is collected through sample surveys, with the target population being active enterprises located in Portugal (operating in sectors of Annex I). A stratified (probabilistic) sampling method is employed, based on the economic activity, size class, turnover, and region; the overall sample size is approximately 8,000 companies. In addition to basic firm information – such as tax number, contacts, and location – the survey investigates the following categories:

Internet Access and Use, E-Commerce, Human Resources and Skills in ICT, ICT Security, Use of Robotics, and ICT and the Environment. It is important to note that the set of firms surveyed has relatively changed over time; similarly, part of the survey questions have been modified to comply with European legislation or to match technological advancement.

SCIE

The Integrated Business Account System (Sistema de Contas Integradas das Empresas - SCIE), a firm-level database compiled by INE, was created in 1994-1995. The database includes financial and economic information on firms reported in IES (simplified business information), complemented with other sources of information available in INE or provided under protocols established with other Portuguese government agencies. The SCIE system was reformed around 2007 and recent surveys are not compatible for analysis with past data, which is why only data from 2007 onwards are considered in the study.

The annual study focuses on enterprises in mainland Portugal and the Autonomous Regions of Azores and Madeira. The population covered in the dataset consists of all firms that engage in at least one activity producing goods and or services during the period analyzed.

SCIE and IUTICE

The IUTICE database provided covers the years between 2007 and 2022 while the SCIE covers years between 2008 and 2021; a merged dataset was created based on individual firms' IDs for years from 2008 to 2021. The dataset consisted of 47,119 individual firms and 82,750 observations. A cleaning process was then carried out to satisfy the following conditions:

- Keeping only firms with three or more employees; this step was taken to limit sample bias, reducing the number of observations to 66,396 and of firms to 34,409 firms.
- Verifying consistent reporting for the information provided, in terms of positive turnover, positive total assets, positive total liabilities, positive number of employees, and positive payroll. The dataset then consisted of 34,133 firms for 66,001 observations.

A variable to indicate the size of the enterprise was created, following the European Commission classification of small and medium-sized enterprises (European Commission n.d.). Size depends on the headcount and either the turnover or balance sheet total, with the following thresholds (where large companies are those that do not satisfy either of these conditions):

Company category	Staff headcount	Turnover	Balance Sheet Total
Medium	< 250	≤ € 50 m	≤ € 43 m
Small	< 50	≤ € 10 m	≤ € 10 m
Micro	<10	≤ € 2 m	≤ € 2 m

Table 13: Firm Size Matching

Descriptive statistics

To further characterize the used dataset, descriptive statistics for two years, 2010 and 2020, have been produced, according to the sector of activity of the enterprises (using NACE Rev. 3) and the size of the firm (using the previously mentioned definition by the European Commission) (excluded sectors due to very low number of observations: Agriculture, Education, Health and Social Activities, Extractive).

Table 14 shows rates of adoption of ICT technology among the sample firms by sector of activity, in two years – 2010 and 2019. For computer and internet use, the data supports the idea of increasing relevance of ICT for enterprises benefit across all sectors. The ICT sector, administrative activities, and manufacturing generally show above-average rates for the variables considered. Even if the rates of ICT staff and online sales seem to be decreasing over time, this may not be true in practice, as the enterprises surveyed change year by year.

	Computer use		**Internet use**		**Website use**		**ICT Staff**		**Online Sales**	
Sector of Activity	2010	2019	2010	2019	2010	2019	2010	2019	2010	2019
Accommodation	79	93	87	98	75	42	30	12	27	20
Administrative Activities	99	99	100	100	88	80	40	29	31	22

Construction	90	98	97	100	68	51	42	27	13	4
Consulting & Science	100	100	100	100	61	68	43	35	12	10
Electricity & Gas	92	95	100	97	100	74	45	42	0	22
Information & Communication	99	100	99	100	93	89	69	65	28	20
Manufacturing	95	99	98	100	76	67	51	36	32	9
Other Services	100	98	95	100	90	79	73	83	50	26
Real Estate	88	99	98	100	72	67	27	12	10	12
Transport	96	98	100	100	83	49	54	29	23	15
Water	100	100	98	100	85	90	47	48	13	14
Wholesale & Retail	97	100	97	100	76	71	46	40	36	24
Total	95	98	98	100	77	67	47	35	28	16

Table 14: Percentage of sampled firms that use computers and the internet, have a website, employ ICT Staff, and make online sales, by sector of activity (NACE Rev.3)

	Computer use		**Internet use**		**Website use**		**ICT Staff**		**Online Sales**	
Size	2010	2019	2010	2019	2010	2019	2010	2019	2010	2019
Large	100	100	100	100	95	96	71	79	37	26
Medium	100	100	100	100	86	89	56	57	31	23
Small	98	99	98	100	67	61	31	20	24	13
Micro	79	97	90	99	48	43	18	12	15	10
Total	95	98	98	100	77	67	47	35	28	16

Table 15: Percentage of sampled firms that use computers and the internet, have a website, employ ICT Staff, and make online sales, by size of activity (NACE Rev.3)

Table 15 shows rates of adoption of ICT technology among the sample firms by size, in two years – 2010 and 2019. The above-mentioned divide is clear in the data: large firms display significantly higher rates in all categories, although middle-sized enterprises have been approaching the rates of larger ones – particularly in terms of computer, internet, and website use. As in the previous case, declining rates for ICT staff and online sales may be misleading (particularly for small and micro firms), as the sample composition varies every year.

These tables show an increasing adoption of ICT over the last years. Online presence and activity have become ever more relevant. Large firms have contributed greatly to this positive trend, although improvements can be seen also in SMEs.

INDIVIDUAL PART

Introduction

Since the mid-2000s, productivity growth has been declining in the majority of advanced economies, and Portugal has not been exempted from this phenomenon. Sluggish aggregate productivity has largely been considered a reason for the low average growth rates of the economy (National Productivity Board, 2019; Bação, Lopes, & Simões, 2022). The issue has been intensified over time by the already existing gap relative to other European and OECD countries (OECD, 2019). In Portugal, the long-term growth rate of labor productivity has been declining, especially since the Euro crisis of 2012. Similarly, total factor productivity has grown at a non-increasing rate, and below EU rates (National Productivity Board 2019). Since productivity affects a country's standard of living by partly determining per capita income (Atkinson, 2018), it is crucial to examine possible solutions to declining growth.

This paper aims to investigate whether the adoption of cloud computing, big data analytics, and artificial intelligence by large Portuguese enterprises is correlated with increased productivity rates The following sections provide an overview of these three advanced digital technologies; revise existing literature on how these technologies are connected to firm productivity; present an overview of the Portuguese context in terms of technological adoption; and use Portuguese firm-level data to quantify the impact of adopting cloud computing, big data analytics, and artificial intelligence on enterprises' productivity, as measured by total factor productivity.

Literature review

Productivity and ICT

Productivity is an indicator of economic efficiency, calculated as the ratio of output produced – in terms of goods or services, or value added – to input used – labor and physical capital. One measure of this is labor productivity, derived by using hours of work or the number of workers as inputs and expressed as output per labor input. A second measure of productivity is total factor (or multifactor) productivity (TFP), which is the residual output variation unexplained by input changes. Starting from Solow's growth model, which considers labor and physical capital plus a technological change factor, TFP coincides with Solow's residuals; in these calculations, the more precisely and extensively inputs are specified in the production function, the more TFP will be truly represented by the residual. Still, some inputs in the production function, including R&D, software, and changes in production processes, are harder to quantify. At the firm level, productivity is determined by both internal and external factors. In the presence of large productivity variance within the same industry (as in Portugal), internal processes and internal characteristics of firms – such as investment in R&D and innovation – gain even more relevance in determining productivity (National Productivity Board, 2019). Indeed, innovation and the adoption of new technologies can fundamentally change the way goods and services are produced and delivered in a certain industry, leading to growing output per certain input (Atkinson, 2018). In this context, digitalization has been widely seen as a possible solution to stagnant productivity growth rates.

As the benefits of digital technologies are taking more than expected to be materialized, many have questioned the promises of innovation. The answer may lie in the very nature and development of advanced digital technologies. General-purpose technologies (GPTs) are radically new technologies that may systematically change production modes, including the skills required for production as well as the connected legal requirements. Within this class fall ICT, such as artificial intelligence, the Internet of Things (IoT), and cloud computing.

Generally, the development and adoption of GPTs – more broadly, innovation – follow an S curve. Starting as single-purpose and limited-use technologies (bottom of the curve), over time GPTs develop full maturity, becoming cheaper and widely adopted (center of the curve), leading to stagnation pending a new wave (top of the curve or maturity). The current slowdown in productivity may originate from current ICT maturity, where there is no significant innovation capable of spurring productivity growth; a new wave is not yet possible as new technologies are either at early development stages (artificial general intelligence or strong AI) or just additions to existing technologies (such as cloud computing seen an increase in already-present Internet services) (Atkinson, 2018) – hence the productivity growth stagnation.

Most literature on advanced digital technology is focused on its effects on SMEs, but large companies may have different motives and consequences from these tools. While the vast majority of Portuguese enterprises fall within the category of SMEs (SMEs constitute 99.7% of the universe of Portuguese firms), large enterprises tend to have higher productivity, being more exposed to international competition and being able to benefit from economies of scale. In the last decade, they produced around 40% of Portuguese gross value added (Portdata, 2023). The productivity differential also varies by sector of activity, with large firms performing on average better in manufacturing and worse in the business service sector, compared to small and medium enterprises (OECD, 2021). This analysis is restricted to large enterprises to complement existing findings on SMEs.

Cloud computing

Cloud computing is a general-purpose "internet-based technology through which information is stored in servers and provided as a service and on-demand to clients" (Etro, 2009, p. 182). It mainly consists of four main services: Software as a Service (SaaS), Platform as a Service (PaaS), Infrastructure as a Service (IaaS), and Expert as a Service (EaaS) (Khayer, Bao, & Nguyen, 2020). Overall, cloud computing provides a remote environment to store and access computing resources (e.g., servers, storage, applications) through "pay as you go" subscriptions.

By reducing the fixed costs associated with the purchase of hardware and software, cloud computing lowers the barriers to entry, furthering competition and job creation. The scalability allowed by this technology makes the effects stronger for new market entrants and/or small and medium-sized enterprises (SMEs), which may lack the necessary capital to invest in ICT assets or labor. For SMEs, cloud computing could give way to an increase in employment, business creation, sales, and average and total production (Etro, 2009; DeStefano, Kneller, & Timmis, 2020). The effect may be different for incumbent firms: cloud computing seems to have a distinct effect on the spatial organization of production by these companies, allowing for greater decentralization thanks to the remote availability of data and software (DeStefano, Kneller, & Timmis, 2020).

Artificial intelligence

Artificial Intelligence (AI) is a "machine-based system that is capable of influencing the environment by producing an output (…) for a given set of objectives" (OECD AI Policy Observatory, 2019). Artificial intelligence is not a new technology, but its capacities have drastically improved in the last decade or so (Corrado, Haskel, & Jona-Lasinio, 2021). A key characteristic of modern AI systems is their use of large databases as input and autonomous use of advanced algorithms, providing a high degree of predictability and a capacity for more complex activities (Bação, Lopes, & Simões, 2022; Bäck, Hajikhani, Jäger, Schubert, & Suominen, 2022). Theoretically, firms' adoption of an AI system should increase their productivity by decreasing the required input – such as labor – for a given product or service or increasing output – for instance, by allowing for price differentiation or expansion to new markets – for a given input (Bäck, Hajikhani, Jäger, Schubert, & Suominen, 2022).

So far, the absence of large amounts of firm-level data has rather hindered research on the topic; however, some studies have worked around this issue by employing proxies to measure AI adoption, such as AI patenting (Damioli, Van Roy, & Vertesy, 2021) or by using data on advertisements for jobs with AI-related skills (Bäck, Hajikhani, Jäger, Schubert, & Suominen, 2022). Such studies generally find positive – although at times contrasting – effects of AI on productivity, dependent on firm size, cohort, and sector of activity (Bäck, Hajikhani, Jäger, Schubert, & Suominen, 2022; Damioli, Van Roy, & Vertesy, 2021).

Importantly, the initial lack of evidence on the success of AI has brought many to rethink the Solow productivity paradox, claiming that "AI is everywhere except in productivity statistics" (Rock, Syverson, & Brynjolfsson, 2017; Damioli, Van Roy, & Vertesy, 2021). While the absence of empirical evidence ("AI in productivity statistics") may be attributed to the lack of any effect, it is more likely that the cause of this phenomenon is a time lag. Early adopters may not experience the hoped-for productivity growth enterprise due to technological immaturity and investment delay effects (Bäck, Hajikhani, Jäger, Schubert, & Suominen, 2022). The gains will be realized only once the AI is sufficiently developed and properly implemented, meaning that late adopters may reap higher benefits. The implementation phase especially may require time- and resource-consuming changes to the internal working of enterprises. Similarly, it may take years for productivity gains to be accrued by adopting firms – giving rise to an investment delay effect – and these benefits may rise over time – learning by doing (Bäck, Hajikhani, Jäger, Schubert, & Suominen, 2022).

Big data

The concept of "Big Data" is rather intuitive: it refers to large amounts of data; more specifically, Big Data is characterized by volume, velocity, and variety. The first V, volume, is connected to the significantly larger pools of data now collected by businesses over time; the second, velocity, refers to the increased speed at which this data is generated by users and processed and analyzed by firms; finally, variety points to the various sources and types of data (Shahid & Sheikh, 2021).

Big Data Analytics (or BDA) is the "process of examining large volumes of data to discover hidden patterns, insights, and correlations" (Shahid & Sheikh, 2021, p. 596). Through BDA, enterprises can recognize new and changing consumer needs and respond most appropriately, hereby gaining a significant advantage over their competitors. There is evidence that big data has a positive impact on productivity: firms can improve their performances, by increasing their efficiency in or innovating productive processes, or by delivering more customer-centric goods and services with greater value added (McKinsey Global Institute, 2011; Hallman, Rakhimov, Plaisent, & Bernard, 2014; Shahid & Sheikh, 2021). In addition, being able to aggregate and analyze data at a higher level (compared to individual firms), firms at the intersection of demand and supply enjoy renewed opportunities for growth (McKinsey Global Institute, 2011).

The Interaction of Advanced Digit*al Technologies*

Cloud computing, big data analytics, and artificial intelligence are deeply connected. Firstly, consider the relationship between cloud computing and big data: cloud computing provides the storage space, analytical resources, and computing applications necessary for big data, that, by definition, exceed the processing capabilities of traditional computers and database systems (Hashem, et al., 2015). Big data is also extremely useful to artificial intelligence; thanks to the availability of large amounts of diverse information, AI systems can learn to make automated decisions in a more and more accurate manner (Pencheva, Esteve, & Mikhaylov, 2018). Finally, AI can complement cloud computing; indeed, cloud services may become, over time, self-managed and more efficient in collecting, storing, and processing data thanks to artificial intelligence (Belgaum, Alansari, Musa, Alam, & Mazliham, 2021).

Context

According to research by the European Investment Bank (2022), 62% of Portuguese enterprises use at least one advanced digital technology (namely, the Internet of Things, Big data/AI, 3-D printing, Augmented or virtual reality, Digital platform technologies, Automation via robotics, Drones), 7 percentage points below the European average. The share of enterprises adopting one or more of these tools varies greatly across sectors of activity and the size of the company.

More precise estimates for the technologies of interest are provided by the European Commission Digital Economy and Society Index (2022): in 2021, the share of Portuguese enterprises using cloud computing, big data, and artificial intelligence were respectively 29%, 11%, and 17%. While the first two values are below European averages (34% for cloud services and 14% for big data), AI seems to be adopted in Portugal at double the EU average rate (8%). Although the digital transition cannot just revolve around the adoption of advanced digital technologies, these products may significantly boost enterprises' productivity and contribute to greater societal wealth.

In the last few years, the Portuguese government has taken various measures to strengthen businesses' digitalization. In 2020, Portugal issued the "Action Plan for Digital Transition" to accelerate the digital transition of individuals, enterprises, and the government. The second pillar of the plan, on Businesses' Digital Transformation, is focused on supporting investment and digitization, especially for SMEs. Measure 8 prescribes the creation and development of Digital Innovation Hubs, which will promote the adoption of advanced digital technologies (República Portuguesa, 2020). The next year, the Recovery and Resilience Plan was implemented; the plan supports the development of digital skills and the use of digital technologies to enhance the country's competitiveness (European Commission, 2021). Portugal has also designed technology-specific plans, such as "AI Portugal 2030". The strategy aims to spur research, innovation, and the development of new goods and services through AI (Kasavina, 2023). Finally, under the PRR, Portugal offers incentives for enterprises' digital transition, in the form of non-refundable and reimbursable financial aid (Portugal Digital, 2022).

Data

The database used for this analysis has already been introduced in the Resource chapter. To briefly summarize the main features, the data here used is obtained by merging two datasets, IUTICE and SCIE, which collect information at the firm level respectively on the use of ICT and the financial and economic status. The initial merged dataset ranged from 2008 to 2021 and included 47,119 firms, for a total of 82,750 observations. The database was then cleaned: only firms with three or more employees were kept (this step was taken to minimize possible bias in the sample as in Branco, Domingues, and Martins (2018) and Correia and Gouveia (2016)) – the number of firms dropped to 34,409 firms and of observations to 66,396; and, lastly, consistent reporting was verified by analyzing turnover, assets, liabilities, payroll, and number of employees (leaving 34,133 firms for 66,001 observations).

As mentioned in the literature review, only large enterprises are considered in this analysis. While acknowledging that most Portuguese firms are SMEs, large enterprises provide higher value-added per firm (with great variance depending on the sector of activity). A size variable was created for this purpose, based on the European Commission's categorization of firms. A company is considered micro, small, or medium-sized if its staff headcount is respectively lower than 10, 50, and 250, and either its turnover is less than or equal to €2 million, €10 million, and €50 million, or their balance sheet total is less or equal to €2 million, €10 million and €43 million. Firms that do not respect these conditions are classified as large; they may hence have more than 250 employees, or turnover or balance sheet total above €50 m. The sample used for the following analyses comprises 1,702 firms for a total of 12,153 observations.

Based on the sector of activity, enterprises are categorized into one of 21 sections of the CAE Rev. 3 (Classificação Portuguesa das Actividades Económicas). The following 11 sectors are not mentioned in the analysis as there are no corresponding observations in the sample: Agriculture, Extractive Industry, Arts and sports, Education, Health and social activities, Financial and insurance activities, Activities of families employing domestic staff and family production activities for their own use, Activities of international bodies and other extra-territorial institutions, Public Administration and Defense. Two other sectors were excluded due to the extremely low number of observations: Other services (1 observation) and Real estate (10 observations).

Finally, answers on the adoption of cloud computing were collected only for 2014, 2016 to 2018, and 2020 to 2021; on the usage of big data analytics for 2016, 2018, and 2020; and on artificial intelligence only for 2021. Because the earlier answers on these topics were recorded in 2014, the analysis was restricted to years from 2014 onwards. The final dataset is composed of 1,366 firms and 7,218 observations.

Table 16 presents summary statistics for firms' features, such as the number of employees, the number and share of personnel employed in Research and Development (R&D), and investment in R&D and software. Among enterprises classified as large, there is great variation in terms of the number of employees; although the mean is 779, half of the firms employ less than 400 persons. This implies the presence of a few firms with an extremely high number of workers. Secondly, as seen by the median, 50% of enterprises do not have R&D personnel and make no investment in R&D or software development. On average, firms in the sample use 1% of their personnel in R&D, and 99% of enterprises have around 1 in 4 people employed in R&D. The mean investment in R&D and software development is increased by huge investments by a very small number of enterprises.

	Mean	**Std. dev.**	**Median**	**90th percentile**	**99th percentile**	**Min**	**Max**
N. employees	779	1,638	400	1,494	7,356	3	26,857
R&D personnel	7	36	0	12	160	0	1,097
% R&D personnel	0.01	0.05	0.00	0.03	0.24	0.00	0.94
R&D investment	77,043	795,196	0	0	1,459,311	0	22,867,298
Software investment	256,722	2,292,529	0	149,883	4,800,290	0	71,878,152

Table 16: Enterprises' characteristics 1

Dummy variables for the adoption of cloud computing, big data analytics, and AI, and the use of a combination of them (cloud computing and AI; big data and cloud computing) were created based on the collected answers. The generation of an interaction variable for the adoption of artificial intelligence and big data was not possible, as data for these technologies was never collected in the same year.

Considering all the years of data collection for the different variables, it is possible to derive descriptive statistics according to the CAE Rev. 3 classification. As can be seen in Table 17, cloud computing is by far the most adopted technology, relative to AI and big data, with over 1 firm out of 2 using it. Artificial intelligence and big data show similar rates of adoption, with around 1 in 3 firms adopting either one of them or both. The ICT sector shows above-average values for all three technologies, so do the Wholesale and retail, and Electricity and Gas sectors.

Sector of Activity	Cloud computing		Big data		Artificial Intelligence	
	%	N	%	N	%	N
Accommodation	58	132	46	65	19	21
Administrative Activities	49	279	26	139	27	55
Construction	68	165	27	82	9	35
Consulting & Science	70	101	26	47	31	26
Electricity & Gas	71	42	61	23	60	5
Information & Communication	73	189	41	92	48	40
Manufacturing	54	1,317	27	648	36	263
Transport	58	246	38	120	34	41
Water	59	105	56	52	29	21
Wholesale & Retail	59	628	35	310	38	119
Total	**57**	3,204	**32**	1,578	**34**	626

Table 17: Share of firms that use cloud computing, artificial intelligence, and big data analysis, and the total number of large enterprises by sector of activity (CAE Rev.3) 2

Because questions on cloud computing and big data appear more frequently in the survey than AI ones, it is possible to see the evolution over time. The proportion of firms using cloud computing has been steadily increasing over the years, with 3 out of 4 firms using it in 2021. The share of enterprises using big data has increased as well compared to 2016 – from 1 in 4 to 1 in 3, although with no statistically significant difference between 2018 and 2020.

Firms report all information in nominal value at the time of compiling the survey; therefore, a deflator has been introduced to generate real values of reported information. The values have been obtained from the National Institute of Statistics (INE) website. When the deflator specific to the sector of activity was not available, the general deflator was used. This process allows to compare real gross value added over time and obtain more reliable estimates of the effect on productivity.

Methodology

To estimate the impact of cloud computing, big data, and artificial intelligence on productivity, it is first necessary to estimate total factor productivity (TFP). TFP is the residual output variation unexplained by input changes – labor and physical capital. The estimate for TFP will be closer to its real value when inputs are more precisely defined in the production function. Yet, some inputs – for instance, R&D and software – are by nature harder to quantify. A standard Cobb-Douglas production function is adopted. A simplified form where productivity y_{it} for firm i at time t, is

$$y_{it} = \alpha + \gamma_1 l_{it} + \gamma_2 k_{it} + \varepsilon_{it} \tag{1}$$

where the labor input l is the labor input and k capital input. In the presence of panel data, total factor productivity is calculated through a control function approach with the Stata prodest command as presented in Mollisi and Rovigatti (2018). The Levinsohn–Petrin method of estimation is adopted, using the purchase of raw materials, subsidiaries, and consumer goods (including biological assets) as intermediate input, total capital as the state variable, and the number of employees as the free variable. Output is measured as gross value added at market prices. Once total factor productivity is estimated, it is time to turn to the general models for the effect of the technologies on TFP.

The general model to estimate the relationship between cloud computing, big data, and AI, and TFP is

$$\begin{aligned}\ln(TFP) = \beta_0 + \ & \beta_1\, Cloud\ Computing + \beta_2\, Big\ Data + \ \beta_3\, AI + \beta_4\, Cloud\ computing \\ & * Big\ Data + \beta_5\, Cloud\ computing * AI + \beta_6\, AI * Big\ Data \\ & + \ \beta_7\, Cloud\ Computing * AI * Big\ Data + \beta_8\, N.employees \\ & + \ \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT \\ & + \beta_{12}\, Share\ of\ Personnel\ in\ R\&D \ + \ \beta_{13}\, Personnel\ Expense + \delta_1\, Sector \\ & + \delta_2\, Region + \ \delta_3 Year + \varepsilon_{it}\end{aligned} \tag{16}$$

measures the mean efficiency across firms over time, region, and sector while ε_{it} measures random and unaccounted variation from the mean. The main coefficients of interest are β_1, β_2, …, to β_7. The first three represent respectively the impact of cloud computing, big data, and artificial intelligence, on total factor productivity; β_4, β_5 and β_6 capture the interaction between two of these technologies; β_7 represents the effect of adopting cloud computing, big data, and AI, on total factor productivity. Control variables include time (year), region, and sector, to correct for fixed effects; they also include firm-specific features such as tangible and intangible assets, personnel – overall and in R&D – and total personnel expenses.

Three models are initially set up, where each model is specific to one technology. Then, the interaction between cloud computing and AI, between cloud computing and big data, and between AI and big data are tested. Finally, a model with the interaction between all three technologies is formulated. However, because the use of different technologies was not recorded in the same year, it is not possible to directly test the last two models (interaction between AI and big data, and interaction between all three technologies). Two different strategies are presented to deal with this issue. The full seven models are listed in the appendix in the order in which they have been presented.

The second strategy consists of collapsing the relevant information – such as TFP, total tangible and intangible assets, number of employees, personnel expenses, etc. – into their average between 2020 and 2021, and testing models 6 and 7 on a cross-sectional dataset. Firstly, this technique allows to estimate a model for which data is not readily available. Secondly, as advanced digital technologies are generally expected to have a lagged effect over time, taking the average of the dependent and control variables may capture the real effect on TFP.

The third strategy makes one key assumption to calculate the models. Remember that the central issue is that information on artificial intelligence usage is collected only in 2021, while on big data only in 2020, 2018, and 2016 (while cloud computing for every year from 2014 to 2021, except for 2015 and 2019). The assumption behind this strategy is that once a technology is adopted, it is most likely to be maintained in the following year. Intuitively, given the costs incurred, it may be unlikely that a company easily and rapidly dismisses the use of the technology. To test whether this is true in the data, the sample is restricted to enterprises that have consistently reported over the years their usage of 4 technologies and products (when questions were present in the questionnaire) – internet, website, cloud computing products, and big data (AI data excluded as it is collected only in one year).

For older innovations, such as using the internet or having a website, (almost) all companies that adopted it have kept using it (respectively, 100% and 97%). To test the assumption for advanced digital technologies, firms that have never adopted either cloud computing or AI are excluded; this leaves firms that have, at some time, adopted the technologies and either kept them ever since or only used them inconsistently for one or few years. Out of 467 enterprises, 82% of companies that have at some point used cloud computing have maintained it over time. 61% of the 358 enterprises that have ever employed big data analytics have kept it over time. Therefore, the assumption is supported by the data, and it is possible to test the effect of having all advanced digital technologies on TFP assuming that firms are likely to maintain the technology in years where information reporting is missing.

The complete models are in the appendix. Summarizing them:

1. The first model estimates the impact of cloud computing on total factor productivity,
2. The second model estimates the impact of big data on TFP,
3. The third model estimates the impact of artificial intelligence on TFP,
4. The fourth model estimates the impact of cloud computing and big data on TFP,
5. The fifth model estimates the impact of cloud computing and artificial intelligence on TFP,
6. The sixth model estimates the impact of big data and artificial intelligence on TFP,
7. The seventh model estimates the impact of cloud computing, big data, and AI on TFP.

Given the existing literature findings, cloud computing, big data, and artificial intelligence are expected to have a positive impact on total factor productivity, and hence have a positive estimate. Nonetheless, it is important to remember that a time lag has already been identified for the effect of advanced digital technologies, meaning that their impact on productivity may take multiple years to be recorded and not be detectable within this analysis alone.

Results

Table 18 and Table 19 report the regression output when controlling for year, sector, location, tangible and intangible assets, EBIT, number of employees, share of personnel in R&D, and personnel expenses (full tables with coefficients of controls can be found in the appendix). Results for the first and second strategies are not statistically significant; the third strategy presents significant estimates for the seventh model, estimating the effect of the interaction between cloud computing, big data, and AI on TFP. Controlling for all other covariates, the simultaneous adoption of the three technologies is associated, on average, with 36% higher total factor productivity – at a 10% confidence level. The increase is, on average, equal to 14% when considering only cloud and big data and controlling for other factors – at 5% confidence level.

	First strategy					Second strategy	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cloud computing	-0.01			(0.04)	(0.08)		-0.01
	(0.03)			-0.06			(0.07)
Big data		0.01		(0.06)		-0.03	-0.03
		(0.04)			-0.12	(0.09)	(0.08)
Artificial Intelligence			0.04		(0.11)	-0.10	-0.11
			(0.08)	0.11		(0.07)	(0.07)
Cloud computing & Big data				(0.08)			
					0.21		
Cloud computing & AI					(0.14)		
Big data & AI						0.02	
						(0.13)	
Cloud computing, Big data & AI							0.04
				1578	626		(0.13)
Number of observations	3204	1578	626	0.33	0.33	418	418
R-squared	0.32	0.33	0.33	(0.04)	(0.08)	0.37	0.37

*** p < 0.01, ** p < 0.05, * p < 0.10
Note: Coeff., SE in parentheses; controls: tangible fixed assets, intangible assets, number of employees, EBIT, share of personnel in RD, personnel expenses, sector of activity, year, region.

Table 18: Main regression results of advanced digital technologies (single and combined) on total factor productivity, by strategy 3

	Third strategy						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cloud computing	-0.00			-0.04	-0.05		-0.04
	(0.02)			(0.03)	(0.08)		(0.10)
Big data		0.02		-0.07		-0.11	-0.11
		(0.03)		(0.05)		(0.10)	(0.11)
Artificial Intelligence			0.04		-0.12	-0.10	-0.10
			(0.08)		(0.11)	(0.08)	(0.11)
Cloud computing & Big data				0.13**			
				(0.06)			
Cloud computing & AI					0.21		
					(0.14)		
Big data & AI						0.27	
						(0.19)	
Cloud computing, Big data & AI							0.31*
							(0.17)

Number of observations	4194	3126	626	3126	626	508	508
R-squared	0.32	0.32	0.33	0.32	0.33	0.34	0.34

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$
Note: Coeff., SE in parentheses; controls: tangible fixed assets, intangible assets, number of employees, EBIT, share of personnel in RD, personnel expenses, sector of activity, year, region.

Table 19: Main regression results of advanced digital technologies (single and combined) on total factor productivity, by strategy

Limitations

The limitations of this study are connected to the very nature of this research question and to the data availability. The non-significance of the estimates may be attributed to various reasons, and causality is rather hard to establish in the relationship going from advanced digital technologies to TFP. First, previous literature has found significant time lags between adopting advanced digital technologies and increasing total factor productivity. This may be magnified in larger firms, where managerial practices and company culture may be more entrenched and hence harder to modify in order to reap the benefits of new technologies. Second, the analysis may suffer from reverse causality or omitted variable bias. The first would be true if firms with higher TFP (for instance due to higher investment in R&D and software development) are the ones that are more likely to adopt, e.g., AI systems. Omitted variable bias may be present in the model for two reasons: first, inputs affecting TFP (such as managerial practices, or certain investments) can be hard to quantify; second, even when quantified, the information is available only for a very minority of enterprises, significantly restricting the possibilities for analysis. A larger volume of information – especially on the investment in software development and R&D – is needed to provide better estimates of the impact of advanced digital technologies. Third, 2020 recorded lower response rates compared to other years, which may have led to selection bias.

While the second and third strategies described above are meant to satisfy data needs, they present clear limitations. The second strategy has an implied time limitation; the cross-section is obtained by averaging values for 2020 and 2021 when COVID-19 shocks greatly affected the economic capacities of countries all around the world. In Portugal, COVID was accompanied by a sharp contraction of gross domestic product in 2020 especially (European Commission, 2021). While output decreased, this does not necessarily imply that TFP shrunk as well. Indeed, COVID-related conditions, such as frequent lockdowns and increasing remote work, may have incentivized the adoption of cloud computing – as services and information had to be accessed remotely – or AI systems – which may substitute missing workers.

The third strategy assumes that once firms have adopted cloud computing and big data, they will keep using them over time. This is evidently the case for using the internet and having a website, with all enterprises consistently using them over time once adopted. This seems to be the case also for cloud computing and big data – 82% and 61% of firms use them in the years following adoption. However, being more likely to continue using a certain technology cannot ensure with certainty its future usage after implementation. This may hence undermine the validity of the results.

Conclusion

This study aimed to assess the relationship between the adoption of advanced digital technologies – namely, cloud computing, AI, and big data analytics –and total factor productivity of large enterprises in Portugal. Stagnant productivity growth rates have been common in advanced economies for the last decade, and innovation of the digital front may be an effective way to improve the economic scenario.

The analysis has depicted various effects, with mainly non-significant estimates across the models. Although the initial models did not yield statistically significant results, the third strategy, for the simultaneous adoption of cloud computing, big data, and artificial intelligence, provided compelling that these technologies may indeed spur TFP growth. Enterprises embracing all three technologies experienced, on average, an increase of 36% in total factor productivity, controlling for various factors. Additionally, the non-significant results do not necessarily imply a complete lack of impact but point to the complexity of creating a causal link between technology adoption and TFP.

This study presents limitations, primarily related to data availability, time lags, and potential for omitted variable bias and reverse causality. Future research should consider the possibility of time lags and try to quantify, through other means of analysis, other factors such as managerial practices that may hinder or strengthen the effect of adopting digital technologies on TFP, investment in software development and R&D. Moreover, results may have been influenced by COVID-19, which clearly impacted economic activity in the analyzed years.

This research contributed to existing literature on large enterprises, providing preliminary evidence that advanced digital technologies benefit total factor productivity. Despite being an absolute minority in the business landscape, large enterprises greatly contribute to overall value added in the Portuguese economy, hence deserve particular attention. Further research, grounded in broader and longer-term datasets, will be fundamental to informed policy action promoting digitalization to incentivize productivity growth in Portugal.

GROUP PART

Limitations

The first caveat of this work project that needs to be considered is that this is not a causational study. There is no cause-and-effect relationship between the different variables, which means that this study cannot have causal claims - no experimental manipulation is involved in the data. Hence, this can only be considered a correlational study, as its goal was to analyze the possible relationship between the dependent and independent variables without making causal conclusions. Correlation does not imply causation.

In addition, there is the possibility of omitted variable bias. The questions on the IUTICE survey were not exhaustive about the different technologies and their adoption, which means that other factors impact productivity. As TFP is a very complex measurement, it is crucial to address this as a limitation of our results.

Moreover, there is no information on the way enterprises use ICT in their daily activities. The group's different questions of interest go through very different topics, such as ICT specialists, Websites, Cloud Computing, and AI, among others. However, even though there is information on the survey concerning the adoption of technological tools, the group is not aware of how well and in what ways companies are implementing them. To minimize this, the survey questions would have to be more exhaustive in each topic, including, for instance, the time and effort firms take to be involved in their adoption.

Finally, most of the data was not available for every year. This potentially created gaps in the different datasets, and significantly decreased the number of observations for some of the questions of interest.

Conclusions

This work project aimed to find significant relationships between adopting different technological tools and productivity, in particular Total Factor Productivity. As there are five different questions of interest, it is crucial to briefly go over them all, and then provide a more general conclusion.

Firstly, we found a positive and significant association between website existence and productivity. Focusing on website functionalities, having an online recruitment system appears to have a significant association with TFP. As for Social Media, only Wiki-related tools were found insignificant in the analysis. For enterprises with at least one social media type, having the goal to recruit through these channels has a significant effect on productivity.

Secondly, when it comes to Cloud Computing and Big Data on SMEs, the group found that adopting the first individually had a positive and significant correlation with TFP; the latter technology and both tools together showed insignificant effects in these types of enterprises. Possibly, there might not exist enough statistical variation to identify combined effects that are witnessed for single technologies.

The third research question focused on the association between the adoption of advanced digital technologies (AI, Cloud Computing, and Big Data) and TFP in large enterprises. Companies using all three technologies experienced, on average, an increase of 36% in TFP. Other strategies used in this analysis did not yield significant results, although this may not imply a complete lack of association between TFP and advanced technologies.

The fourth study within this paper investigates the impact of Enterprise Resource Planning (ERP) systems, finding a positive correlation between them and productivity. This result was particularly significant for large firms located in Lisbon’s Metropolitan Area.

The final research question is related to the association between ICT and productivity, focusing on the provision of ICT education to firms’ employees. A positive and significant correlation was found between having specialized personnel and productivity. Although there was no significant association between providing training to already-specialized employees, there seem to exist high gains in focusing this training on those that do not possess the highest skills on a topic.

Overall, all research questions show the importance of ICT adoption by Portuguese firms. When it comes to the adoption of advanced digital technologies, mainly related to Big Data and Cloud Computing, results found that for smaller firms, it appears to be more significant to focus on only one of these technologies, while larger firms appear to be more productive when using all at the same time. This may be related to the fact that larger firms may have more specialized personnel, increasing productivity gains.

The remaining research questions show that other digital tools, such as websites, social media, and internal systems might be important additions to firms with the goal of increasing their online presence. All the above were found to have significant associations with productivity.

Policy Implications

Considering all the conclusions described above, and considering the different limitations this research paper has, policymakers should continue and propose new plans that give the opportunity for SMEs and large enterprises to invest in their digital adoption. Incentivizing this may translate into new productivity gains, giving the opportunity for firms to be recognized abroad and increase their target audiences. In addition, policymakers should keep on providing or investing in training for employees who do not possess specialized digital skills, given that this may increase their work productivity and, consequently, the firms'.

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Group Appendix

The NACE Rev. 2 activities considered in the "'Survey on ICT usage and e-Commerce in Enterprises" are:

- Section C: Manufacturing
- Section D: Electricity, gas, steam, and air conditioning supply
- Section E: Water supply, sewerage, waste management and remediation activities
- Section F: Construction
- Section G: Wholesale and retail trade; repair of motor vehicles and motorcycles
- Section H: Transportation and storage
- Section I: Accommodation and food service activities
- Section J: Information and communication
- Section L: Real estate activities
- Section M: Professional, scientific, and technical activities
- Section N: Administrative and support service activities
- Group 95.1 (Section S): Repair of computers and communication equipment (Other service activities).

Individual appendix

$$\ln(TFP) = \beta_0 + \beta_1\, Cloud\ Computing + \beta_8\, N.employees + \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT + \beta_{12}\, Share\ of\ Personnel\ in\ R\&D + \beta_{13}\, Personnel\ Expenses + \delta_1\, Sector + \delta_2\, Region + \delta_3\, Year + \varepsilon \quad (2)$$

$$\ln(TFP) = \beta_0 + \beta_2\, Big\ Data + \beta_8\, N.employees + \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT + \beta_{12} Share\ of\ Personnel\ in\ R\&D + \beta_{13}\, Personnel\ Expenses + \delta_1\, Sector + \delta_2\, Region + \delta_3\, Year + \varepsilon \quad (3)$$

$$\ln(TFP) = \beta_0 + \beta_3\, AI + \beta_8\, N.employees + \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT + \beta_{12}\, Share\ of\ Personnel\ in\ R\&D + \beta_{13}\, Personnel\ Expenses + \delta_1\, Sector + \delta_2\, Region + \delta_3\, Year + \varepsilon \quad (4)$$

$$\ln(TFP) = \beta_0 + \beta_1\, Cloud\ Computing + \beta_2\, Big\ Data + \beta_4\, Cloud\ computing * Big\ Data + \beta_8\, N.employees + \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT + \beta_{12}\, Share\ of\ Personnel\ in\ R\&D + \beta_{13}\, Personnel\ Expenses + \delta_1\, Sector + \delta_2\, Region + \delta_3\, Year + \varepsilon \quad (5)$$

$$\ln(TFP) = \beta_0 + \beta_1\, Cloud\ Computing + \beta_3\, AI + \beta_5\, Cloud\ computing * AI + \beta_8\, N.employees + \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT + \beta_{12}\, Share\ of\ Personnel\ in\ R\&D + \beta_{13}\, Personnel\ Expenses + \delta_1\, Sector + \delta_2\, Region + \delta_3\, Year + \varepsilon \quad (6)$$

$$\ln(TFP) = \beta_0 + \beta_2\, Big\ Data + \beta_3\, AI + \beta_6\, AI * Big\ Data + \beta_8\, N.employees + \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT + \beta_{12} Share\ of\ Personnel\ in\ R\&D + \beta_{13}\, Personnel\ Expenses + \delta_1\, Sector + \delta_2\, Region + \delta_3\, Year + \varepsilon \quad (7)$$

$$\ln(TFP) = \beta_0 + \beta_1\, Cloud\ Computing + \beta_2\, Big\ Data + \beta_3\, AI + \beta_7\, Cloud\ Computing * AI * Big\ Data + \beta_8\, N.employees + \beta_9 \ln(Tangible\ assets) + \beta_{10} \ln(Intangible\ assets) + \beta_{11}\, EBIT + \beta_{12}\, Share\ of\ Personnel\ in\ R\&D + \beta_{13}\, Personnel\ Expenses + \delta_1\, Sector + \delta_2\, Region + \delta_3\, Year + \varepsilon \quad (8)$$

	First strategy					Second strategy	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cloud computing	-0.01			-0.05	-0.05		-0.01
	(0.03)			(0.04)	(0.08)		(0.07)
Big data		0.01		-0.06		-0.03	-0.03
		(0.04)		(0.06)		(0.09)	(0.08)
Artificial Intelligence			0.04		-0.12	-0.10	-0.11
			(0.08)		(0.11)	(0.07)	(0.07)
Cloud computing & Big data				0.11			
				(0.08)			
Cloud computing & AI					0.21		
					(0.14)		
AI & Big data						0.02	
						(0.13)	
Cloud computing, Big data & AI							0.04
							(0.13)
Ln of tangible fixed assets	-0.10***	-0.10***	-0.10***	-0.10***	-0.10***	-0.05**	-0.05**
	(0.01)	(0.01)	(0.03)	(0.01)	(0.03)	(0.02)	(0.02)
Ln of intangible assets	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)
Ln of EBIT	-0.01	-0.01	0.00	-0.01	0.00	-0.01	-0.01
	(0.02)	(0.02)	(0.04)	(0.02)	(0.04)	(0.03)	(0.03)
Ln of personnel expenses	0.03	0.02	-0.02	0.02	-0.02	-0.05	-0.05
	(0.03)	(0.04)	(0.05)	(0.04)	(0.05)	(0.07)	(0.07)
Number of employees	-0.00***	-0.00***	-0.00	-0.00***	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Share of personnel working in R&D	0.96	0.21	2.73	0.21	2.73	0.42	0.42
	(0.69)	(0.24)	(2.21)	(0.24)	(2.21)	(0.33)	(0.33)
Year							
2016	-0.37***						
	(0.05)						
2017	-0.15***						
	(0.05)						
2018	0.00	0.39***		0.39***			
	(0.05)	(0.05)		(0.05)			
2020	-0.28***	0.10**		0.10**			
	(0.05)	(0.04)		(0.04)			
2021	0.32***		0.00		0.00		
	(0.05)		(0.00)		(0.00)		
Sector							
Wholesale & Retail	0.16**	0.09	0.63***	0.09	0.62***	0.36	0.37
	(0.07)	(0.09)	(0.23)	(0.09)	(0.23)	(0.29)	(0.29)
Administrative Activities	0.89***	0.78***	1.34***	0.78***	1.33***	1.04***	1.05***
	(0.09)	(0.12)	(0.26)	(0.12)	(0.26)	(0.31)	(0.32)
Construction	0.01	-0.09	0.52**	-0.08	0.52**	0.20	0.21

	(0.09)	(0.12)	(0.25)	(0.12)	(0.25)	(0.31)	(0.31)
Consulting & Science	0.59***	0.49***	0.85***	0.50***	0.83***	0.53	0.53
	(0.13)	(0.17)	(0.32)	(0.17)	(0.32)	(0.39)	(0.39)
Electricity & Gas	0.72***	0.37*	1.96***	0.38*	1.93***	0.95**	0.95**
	(0.16)	(0.22)	(0.57)	(0.22)	(0.57)	(0.43)	(0.43)
Information & Communication	0.72***	0.67***	1.35***	0.68***	1.32***	1.01***	1.02***
	(0.09)	(0.12)	(0.28)	(0.12)	(0.28)	(0.31)	(0.31)
Manufacturing	0.07	0.04	0.36	0.05	0.34	0.23	0.24
	(0.07)	(0.09)	(0.23)	(0.09)	(0.22)	(0.28)	(0.29)
Transport	0.65***	0.60***	1.17***	0.60***	1.15***	0.92***	0.92***
	(0.09)	(0.11)	(0.28)	(0.11)	(0.28)	(0.32)	(0.33)
Water	-0.15*	-0.05	0.03	-0.04	0.04	0.11	0.12
	(0.09)	(0.12)	(0.26)	(0.12)	(0.26)	(0.33)	(0.33)
Region							
Algarve	0.05	-0.03	0.40	-0.03	0.39	0.62*	0.62*
	(0.15)	(0.21)	(0.32)	(0.21)	(0.31)	(0.35)	(0.35)
Area Metropolitana de Lisboa	-0.03	-0.09	0.06	-0.09	0.07	0.40***	0.40***
	(0.09)	(0.13)	(0.19)	(0.13)	(0.19)	(0.15)	(0.15)
Centro	-0.21**	-0.30**	-0.25	-0.29**	-0.25	0.06	0.06
	(0.09)	(0.13)	(0.18)	(0.13)	(0.19)	(0.13)	(0.14)
Norte	-0.22**	-0.29**	-0.19	-0.29**	-0.19	0.12	0.12
	(0.09)	(0.13)	(0.19)	(0.13)	(0.19)	(0.14)	(0.14)
Região Autónoma da Madeira	-0.36**	-0.43**	-0.13	-0.42**	-0.13	0.11	0.11
	(0.15)	(0.20)	(0.34)	(0.20)	(0.34)	(0.33)	(0.33)
Região Autónoma dos Açores	-0.62***	-0.64***	-0.60**	-0.64***	-0.59**	-0.26	-0.27
	(0.14)	(0.18)	(0.28)	(0.18)	(0.28)	(0.17)	(0.17)
Intercept	2.50***	2.52***	3.13***	2.53***	3.17***	2.68***	2.70***
	(0.35)	(0.47)	(0.82)	(0.47)	(0.82)	(0.90)	(0.91)
Number of observations	3204	1578	626	1578	626	418	418
R-squared	0.32	0.33	0.33	0.33	0.33	0.37	0.37

*** p < 0.01, ** p < 0.05, * p < 0.10
Note: Coeff., SE in parentheses

Table 20: Full regression results of advanced digital technologies (single and combined) on total factor productivity

	Third strategy						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cloud computing	-0.00			-0.04	-0.05		-0.04
	(0.02)			(0.03)	(0.08)		(0.10)
Big data		0.02		-0.07		-0.11	-0.11
		(0.03)		(0.05)		(0.10)	(0.11)
Artificial Intelligence			0.04		-0.12	-0.10	-0.10
			(0.08)		(0.11)	(0.08)	(0.11)
Cloud computing & Big data				0.13**			
				(0.06)			
Cloud computing & AI					0.21		
					(0.14)		
Big data & AI						0.27	
						(0.19)	
Cloud computing & Big data & AI							0.31*
							(0.17)
Ln of tangible fixed assets	-0.10***	-0.10***	-0.10***	-0.10***	-0.10***	-0.08***	-0.08***
	(0.01)	(0.01)	(0.03)	(0.01)	(0.03)	(0.03)	(0.03)
Ln of intangible assets	-0.00	-0.00	0.00	-0.00	0.00	0.01	0.01
	(0.00)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)
Ln of EBIT	0.00	0.01	0.00	0.01	0.00	0.02	0.02
	(0.01)	(0.02)	(0.04)	(0.02)	(0.04)	(0.04)	(0.03)
Ln of personnel expenses	0.03	0.03	-0.02	0.03	-0.02	-0.03	-0.03
	(0.02)	(0.03)	(0.05)	(0.03)	(0.05)	(0.06)	(0.06)
Number of employees	-0.00***	-0.00***	-0.00	-0.00***	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Share of personnel working in R&D	0.84	0.91	2.73	0.91	2.73	3.26	3.27***
	(0.58)	(0.69)	(2.21)	(0.69)	(2.21)	(2.51)	(0.51)
Year							
2015	-0.22***						
	(0.05)						
2016	-0.36***						
	(0.05)						
2017	-0.15***	0.20***		0.20***			
	(0.05)	(0.04)		(0.04)			
2018	-0.00	0.36***		0.36***			
	(0.05)	(0.05)		(0.05)			
2019	0.02	0.37***		0.38***			
	(0.05)	(0.05)		(0.05)			
2020	-0.28***	0.08**		0.08**			
	(0.05)	(0.04)		(0.04)			
2021	0.31***	0.62***	0.00	0.62***	0.00	0.00	
	(0.05)	(0.06)	(0.00)	(0.06)	(0.00)	(0.00)	
Sector							
Wholesale & Retail	0.15**	0.16**	0.63***	0.16**	0.62***	0.78***	0.76***

	(0.06)	(0.07)	(0.23)	(0.07)	(0.23)	(0.24)	(0.24)
Administrative	0.89***	0.88***	1.34***	0.89***	1.33***	1.49***	1.47***
Activities	(0.07)	(0.08)	(0.26)	(0.08)	(0.26)	(0.28)	(0.27)
Construction	-0.02	-0.01	0.52**	-0.01	0.52**	0.59**	0.58**
	(0.08)	(0.09)	(0.25)	(0.09)	(0.25)	(0.27)	(0.28)
Consulting &	0.59***	0.57***	0.85***	0.58***	0.83***	0.82**	0.80***
Science	(0.11)	(0.13)	(0.32)	(0.13)	(0.32)	(0.37)	(0.30)
Electricity & Gas	0.67***	0.63***	1.96***	0.64***	1.93***	1.95***	1.93***
	(0.13)	(0.15)	(0.57)	(0.15)	(0.57)	(0.59)	(0.52)
Information &	0.71***	0.78***	1.35***	0.79***	1.32***	1.59***	1.56***
Communication	(0.08)	(0.09)	(0.28)	(0.09)	(0.28)	(0.33)	(0.28)
Manufacturing	0.07	0.08	0.36	0.08	0.34	0.47*	0.46*
	(0.06)	(0.07)	(0.23)	(0.07)	(0.22)	(0.24)	(0.23)
Transport	0.66***	0.67***	1.17***	0.67***	1.15***	1.15***	1.13***
	(0.07)	(0.08)	(0.28)	(0.08)	(0.28)	(0.28)	(0.26)
Water	-0.15**	-0.06	0.03	-0.05	0.04	0.15	0.19
	(0.08)	(0.09)	(0.26)	(0.09)	(0.26)	(0.30)	(0.33)
Region							
Algarve	0.05	0.01	0.40	0.02	0.39	0.33	0.30
	(0.13)	(0.14)	(0.32)	(0.14)	(0.31)	(0.27)	(0.52)
Area Metropolitana	-0.00	-0.00	0.06	0.00	0.07	0.23	0.23
de Lisboa	(0.08)	(0.09)	(0.19)	(0.09)	(0.19)	(0.17)	(0.24)
Centro	-0.19**	-0.23***	-0.25	-0.22***	-0.25	-0.09	-0.10
	(0.08)	(0.08)	(0.18)	(0.09)	(0.19)	(0.17)	(0.24)
Norte	-0.20***	-0.22**	-0.19	-0.21**	-0.19	-0.11	-0.11
	(0.08)	(0.09)	(0.19)	(0.09)	(0.19)	(0.17)	(0.24)
Região Autónoma	-0.38***	-0.39***	-0.13	-0.38***	-0.13	-0.19	-0.21
da Madeira	(0.13)	(0.14)	(0.34)	(0.14)	(0.34)	(0.32)	(0.36)
Região Autónoma	-0.60***	-0.59***	-0.60**	-0.58***	-0.59**	-0.57**	-0.58
dos Açores	(0.12)	(0.13)	(0.28)	(0.13)	(0.28)	(0.28)	(0.38)
Intercept	2.37***	1.94***	3.13***	1.97***	3.17***	2.39**	2.47**
	(0.32)	(0.34)	(0.82)	(0.34)	(0.82)	(0.95)	(0.96)
Number of observations	4194	3126	626	3126	626	508	508
R-squared	0.32	0.32	0.33	0.32	0.33	0.34	0.34

*** p < 0.01, ** p < 0.05, * p < 0.10
Note: Coeff., SE in parentheses

Table 21: Full regression results of advanced digital technologies (single and combined) on total factor productivity