Gabinete de Estratégia e Estudos

REPÚBLICA PORTUGUESA
ECONOMIA E MAR

GEE Paper

163

julho de 2022

Job Creation and Destruction in the Digital Age: What about Portugal?

Anabela M. Santos | Javier Barbero Jimenez | Simone Salotti | Andrea Conte

Gabinete de Estratégia e Estudos da Economia e do Mar
Office for Strategy and Studies of Economy and Maritime Affairs
Avenida da República, n.º 79 - 1069-218 Lisboa, Portugal
www.gee.gov.pt
ISSN (online): 1647-6212

Job Creation and Destruction in the Digital Age: What about Portugal?[1]

Anabela M. Santos[2], Javier Barbero Jimenez[3], Simone Salotti[4] and Andrea Conte[5]

Abstract

We assess the effect of digitalisation on employment for the European Union countries, and Portugal in particular, using data for the 1995-2019 period. We estimate an augmented labour demand function derived from a Constant Elasticity of Substitution (CES) cost function to test for a capital-labour substitution effect, distinguishing between digital and traditional capital. The results point towards a positive impact of digital investments on total employment, but the effects are heterogeneous depending on the different employment categories. In particular, high-skilled jobs benefit from digitalisation at the expense of medium- and low-skilled ones. Results for Portugal also show evidence of an overall positive effect of digital investments on employment, showing that an increase of €100.000 in the stock of digital technologies is associated with an increase of 4.6 jobs.

Keywords: Digitalisation; Employment; Skills; Europe; Portugal

JEL Classification: O33; J24; O52

[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Award-winning work by the Call for Papers on The Economic Impact of Digitalisation in Portugal, a partnership between the Office for Strategy and Studies of the Ministry of Economy and Maritime Affairs (GEE), Google and the Association for the Information Society Development (APDSI).

[2] European Commission, Joint Research Centre, anabela.MARQUES-SANTOS@ec.europa.eu

[3] European Commission, Joint Research Centre, javier.BARBERO-JIMENEZ@ec.europa.eu

[4] European Commission, Joint Research Centre, simone.SALOTTI@ec.europa.eu

[5] European Commission, Joint Research Centre, andrea.CONTE@ec.europa.eu

1. Introduction

Over the last decade, the adoption of digital technologies such as smartphones, tablets, e-money, e-commerce, and e-government services has rapidly increased for businesses, people and governments alike. Most of the world's developed economies are moving from an industrial-based economy to an information (knowledge)-based economy. This digital age is intrinsically associated with computer technology and the translation of data and information into a digital form to be stored, shared, processed, and used by computers or other electronic equipment (Cambridge, 2011). Existing evidence suggests that digitalisation has proven beneficial for business sectors by enhancing firm-productivity (Gal et al., 2019; Cincera et al., 2020), increasing the efficiency and effectiveness of business processes (Rossato and Castellani, 2020), and stimulating sales and exports (Eduardsen, 2018). In light of these findings, it is not surprising to observe that most companies have significantly increased their investment in digitalisation in the last years (UNCTAD, 2017; EIB, 2020).

This digital transition was significantly accelerated by the Covid-19 health crisis (EIB, 2021). Worldwide measures to stop the spread of the disease, such as mobility and travel restrictions, physical distancing, and mandatory teleworking (when possible), have pushed both governments and businesses to accelerate their digital plans and invest more in digital technologies than previously expected. These actions aimed at adapting products and services to new short-term market and societal needs as well as at increasing the resilience of companies facing the consequence of the economic crisis related to the pandemic (Equinix, 2021).

In line with previous waves of pervasive new industrial processes and technologies, there is a strong interest among both policy makers and scholars in assessing the macroeconomic and distributional effects of the generation and diffusion of digitalisation in the labour market. Besides the potentially positive effects of digitalisation on business competitiveness (Rossato and Castellani, 2020), it has been put forward by many authors that this type of technological changes may have a harmful effect on the labour market (see, for instance, Leontief, 1952, and Keynes, 1937, who used the term 'technological unemployment'). According to, among others, Ford (2015) and Acemoglu and Restrepo (2020), automation and robotisation may replace workers and lead to job destruction. On the other hand, digitalisation may also create new job opportunities related to new technologies (Degryse, 2016).

The effect of digitalisation is expected to be heterogeneous across economic activities (Gaggl and Wright, 2017; Mann and Püttmann, 2018) and some jobs are at a higher risk to be affected by automation and robotisation than others. For example, automation is more likely to have an impact on office work and clerical tasks, sales and commerce, transport, logistics, manufacturing, and construction (Degryse, 2016). Consequently, some regions and countries with specific sectorial patterns and labor force profiles are likely to be also more affected by the transition than others.

Several recent studies have quantified the net effect of digital technologies on employment, resulting in some mixed evidence that we review in the next section. A promising avenue of research seems to be constituted by the analysis of the heterogeneous effect that digitalisation may have on jobs depending either on the industry or on the occupational tasks of the workers. For instance, Akerman et al. (2015), Bessen (2016), Balsmeier and Woerter (2019), and Reljic et al. (2019) all report heterogeneous impacts of digitalisation on employment depending on skills and qualifications, while Gaggl and Wright (2017) and Mann and Püttmann (2018) concentrate on different industries.

The present paper complements the existing literature in several ways. Firstly, it quantities the net effect of investment in digital technologies on employment in the European Union (EU) over the 1995-2019 period. To the best of our knowledge, the existing studies in the literature concentrate on single European countries (Dauth et al., 2017; Biagi and Falk, 2017; Graetz and Michaels, 2018; Koch et al., 2019; Reljic et al., 2019), while we use data for all the EU member states. Secondly, the paper tests the non-linear relationship between digitalisation and employment, contrary to the existing studies which only tested a linear relationship. Thirdly, and in the framework of the "Call for papers on the Portuguese Economy on the Economic Impact of Digitalisation in Portugal"[6], the present research also shows the positioning of Portugal in the process of job destruction and creation due to digitalisation. So far, no study has assessed and quantified the net effect of technological progress in the country.

In our analysis, we investigate the effect of investments in digital technologies using an augmented labour demand function derived from a Constant Elasticity of Substitution (CES) cost function. We control for endogeneity bias of digitalisation using a Two-Stage Residual Inclusion Estimation. Thanks to the use of interaction terms, we estimate the capital-labour elasticities for the EU27 and Portugal, and then we estimate the marginal effect of digitalisation on employment. We show that investments in digital technologies have a positive effect on total employment. This aggregate result masks the following heterogeneous effects: jobs constituted by routine tasks are negatively affected by digitalisation, while more complex jobs are found to be complementary to digital capital.

From an academic perspective, our study offers novel findings produced with a robust methodology to estimate the net effect of digitalisation on employment. The results are relevant from a policy perspective, as they could be used as evidence informing effective and targeted labour market interventions to facilitate the digital transition, especially for the most vulnerable workers of the economy.

The rest of the paper is structured as follows. Section 2 provides a brief review of the literature on the impact of digitalisation on employment. Section 3 describes the evolution and positioning of Portugal in the EU27 regarding investment in digitalisation and employment

[6] The call was launched in the end of the second-half of 2021 by the Office for Strategy and Studies (GEE), Google, and the Association for the Information Society Development (APDSI).

skills. Section 4 presents the method and the data used in the analysis. Section 5 reports the empirical results, and section 6 concludes.

2. Background theory and related literature

As a disruptive novel technology, digitalisation is nowadays considered as a key driver of technological progress with potential effects on economic growth and even the capacity to contribute to solve major societal challenges. As such, it is at the core of major policy initiatives around the word.[7] The economic literature offers many contributions on the potential consequences of digitalisation on labour market outcomes and dynamics. Some authors have highlighted potential negative effects on employment, as a result of substitution between capital and labour, for instance due to automation replacing certain types of jobs (OECD, 2019). However, according to the classical compensation theory (Marx, 1961; 1969), the labour-displacing effect of new (process-oriented) technologies – such as the digital ones (Freddi, 2018) - would be more than "compensated" by other market dynamics induced by the same technology. Besides the job directly created by the new investments associated with digital technologies and infrastructure, there may be additional effects such as the substitution and displacement of jobs from declining firms and industries to growing ones. The latter may be driven by the creation of new markets and business opportunities, as well as by changing demand patterns related to digitalisation. Finally, new economic actors and activities may emerge in the market and help compensate for the direct labour-substitution effects of innovation (Vivarelli, 1995 and 2007).

Moreover, recent empirical studies (Reljic et al., 2019; Balsmeier and Woerter, 2019; Avom et al., 2021) have confirmed that the impact of digitalisation on employment is complex and depends on the skills of workers and the nature of tasks performed by them. For instance, employees with routine tasks can be replaced relatively easily by new technologies, while those with non-routine activities are expected to benefit in terms of employment shares (Autor et al., 2003; Goos et al., 2014). At the same time, technology transfer and adoption are also associated with the acquisition of new skills (Degryse, 2016), and there are a number of contributions devoted to the study of the so-called skill biased technological change (Katz and Autor, 1999) and the concept of job polarisation (Autor et al., 2006; Goos and Manning, 2007).

Changes in the labor market structure due to digital technologies have been empirically tested both at the microeconomic and at the macroeconomic level, as summarised in Table 1. Findings are not unanimous regarding the net effect of digitalisation in employment. However, on average, digital technologies seems to impact positively high-skilled employment (complementary effect) and negatively lower-skilled workers (substitution effect). The total net effect seems to depend on the specific economic structure of each country in terms of its

[7] For instance, see the US government's digital strategy (https://digital.gov), and, in the EU, both the Digital Single Market (Christensen et al., 2018), and the Next Generation EU programme in the EU, where at least 20% of available funding has to be earmarked to the objective of the digital transition (https://ec.europa.eu/info/strategy/recovery-plan-europe_en).

knowledge capacity, its sectorial composition, and the capacity of up-skilling or re-skilling the labour force in order to support workers moving from one activity to another. For instance, Dauth et al. (2017) for Germany, and Mann and Püttmann (2018) for the US, show that employment in the manufacturing industry was negatively affected by automation, whereas, the service sectors strongly benefitted from it, creating new job opportunities and absorbing job losses from manufacturing.

Table 1. Main empirical findings on digitalisation effect on employment

Authors	Coverage	Main findings
Akerman et al. (2015)	· Firm-level analysis · Norway · 2001-2007	· Internet technology had a positive effect on employment of skilled workers, and no effect on low-skilled workers · Broadband internet adoption complements skilled workers in executing non-routine tasks, but substitutes for unskilled workers in performing routine tasks
Bessen (2016)	· Firm-level analysis · US · 1980-2013	· Computer usage improves employment overall but has heterogeneous effects on specific occupations groups · Computer automation is associated with job losses for low-wage jobs and job gains for high-wage occupations
Biagi and Falk (2017)	· Country-industry-firm size class-level analysis · 12 EU countries (Austria, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Sweden, Slovenia, and the United Kingdom) · 2002-2010	· Enterprise Resource Planning systems have positive effects on employment in manufacturing, and websites have positive effects for the employment in services sectors. The remaining ICT and e-commerce indicators seem not to have any effect on employment · On average, ICT activities seem to be relatively neutral to employment, suggesting that its utilization is not leading to labour substitution
Dauth et al. (2017)	· Germany · 1994-2014	· Robots exposure does not cause job losses, but it affects employment sectorial composition · Every robot destroyed two manufacturing jobs (= 275,000 jobs losses in manufacturing in Germany), and the loss was fully offset by additional jobs in the service sector
Gaggl and Wright (2017)	· Firm-level analysis · UK · 2000-2004	· ICT investment has a positive effect on employment associated with non-routine tasks. And a negative one on routine tasks. Manual work is unaffected
Graetz and Michaels (2018)	· Industry-country-level analysis · 17 countries (US, South Korea, Australia and 14 European countries) · 1993-2007	· No significant effect of industrial robots usage on overall employment · Robots may replace or reduce employment of low-skilled workers
Mann and Püttmann (2018)	· Industry-level analysis · US · 1976-2014	· Automation technology leads to employment growth overall (all industries), but replace workers in routine tasks · Negative effect of automation on employment in manufacturing industry and a positive effect on services
Balsmeier and Woerter (2019)	· Firm-level analysis · Switzerland · 2014-2015	· Investment in digitization has an average positive effect on total employment, with a positive effect on highly skilled employment and a negative one on medium- and low-skill jobs This is driven by machine-based investment, as there is no significant relationship between employment and non-machine-based investment
Cirera and Sabetti (2019)	· Firm-level analysis · 53 developing countries · 2013-2015	· Process automation has no significant effects on total employment growth. A negative effect on employment in services sectors is found
Koch et al., (2019)	· Firm-level analysis · Spain · 1990-2016	· Robot technology adoption has a positive effect on employment, leading to net job creation

Table 1. Main empirical findings on digitalisation effect on employment (continuation)

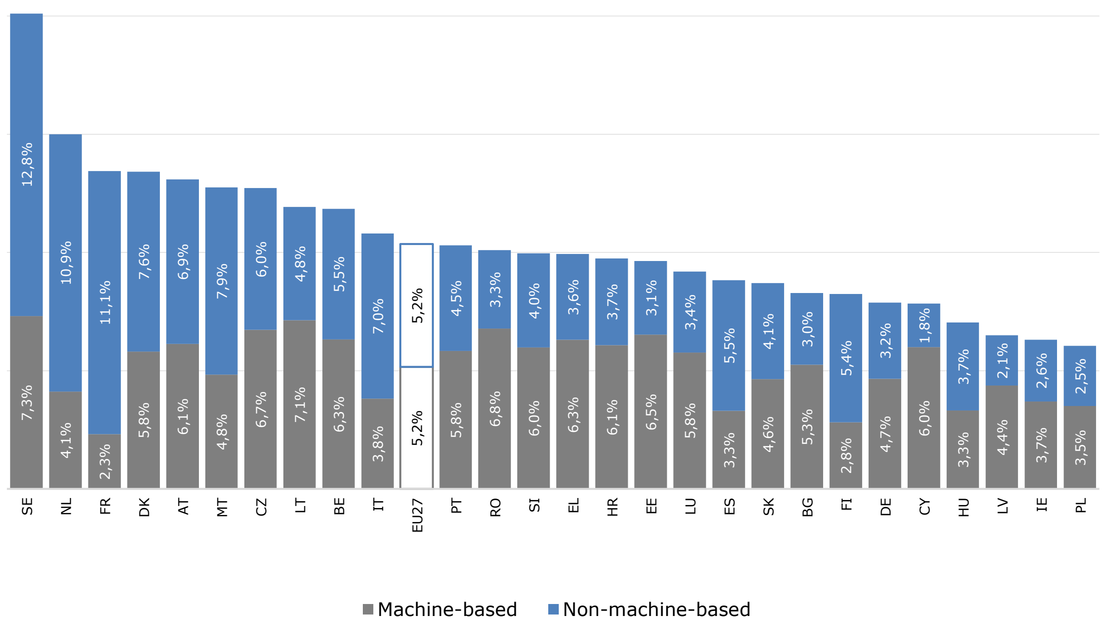
Reljic et al. (2019)	· Country-industry-level analysis · 6 EU countries (Germany, France, Spain, Italy, the Netherlands and the United Kingdom) · 2009-2014	· Digital investment is negatively correlated with total employment growth, whereas, digital inputs show a positive relationship with job creation · ICT investment is positively associated with employment growth of managers, and negatively with that of clerks · ICT consumption is positively correlated with growth employment of clerks. No significant relationship between digitalisation and lower skilled employment was found
Acemoglu and Restrepo (2020)	· Industry-county level analysis · US · 1993-2014	· Negative effect of industrial robots on labour market · One more robot per thousand workers reduces the employment to-population ratio by 0.2 percentage points
Avom et al. (2021)	· Country-level analysis · West Africa Economic and Monetary Union countries · 2000 – 2017	· ICT has a positive effect on total employment. There is evidence of a negative effect on low and medium-skilled jobs, and a positive one on high-skilled jobs

Source: Own elaborations based on the cited studies.

3. Digitalisation and employment skills: evolution and positioning of Portugal

Over the period 1995-2019, investment in digitalisation has represented more than 10% of the total Gross Fixed Capital Formation (GFCF) in the EU, with Portugal recording a value which is just below the EU average (Figure 1). Sweden is the country with the higher average share in digital investment (20%), and Poland and Ireland are the countries with the lowest values (around 6%).

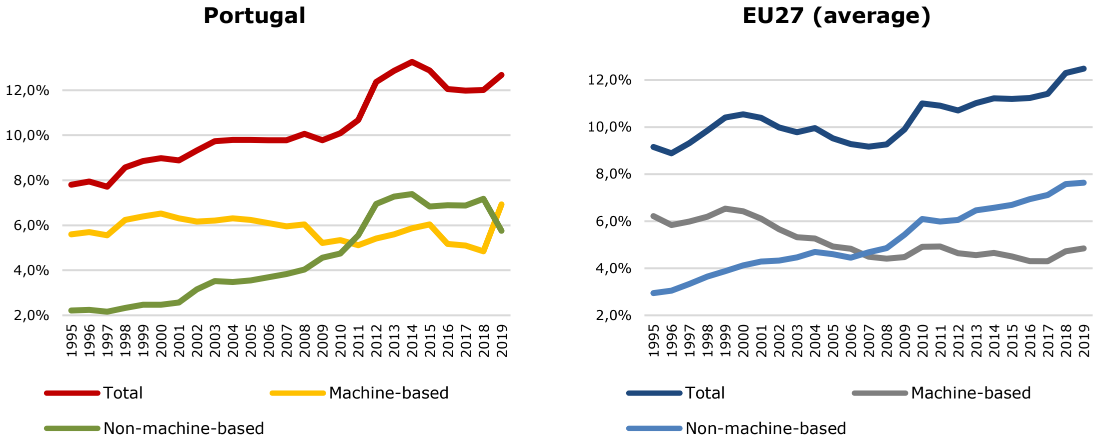
Figure 1. Digitalisation investment as a share of GFCF by EU Member State, 1995-2019 average



Source: Own elaborations based on Eurostat data [nama_10_nfa_fl]. Machine-based GFCF includes investments in computer hardware and telecommunications equipment (machine-based); non-machine based GFCF stands for investments in computer software and databases.

Investment in digitalisation has grown from 9.2% in 1995 to 12.5% in 2019 in the EU. This growth trend is driven by non-machine-based digital investment, which has exceeded machine-based investment starting from 2007 (Figure 2). Portugal has followed a similar trend, moving from a share of digital investment of 7.8% in 1995 to 12.7% in 2019. However, non-machine-based digital investment has been larger than machine-based investments only from 2011 to 2018, as the former decreased substantially in 2019 when it became less than 6% of total GFCF versus about 7% of machine-based investments.

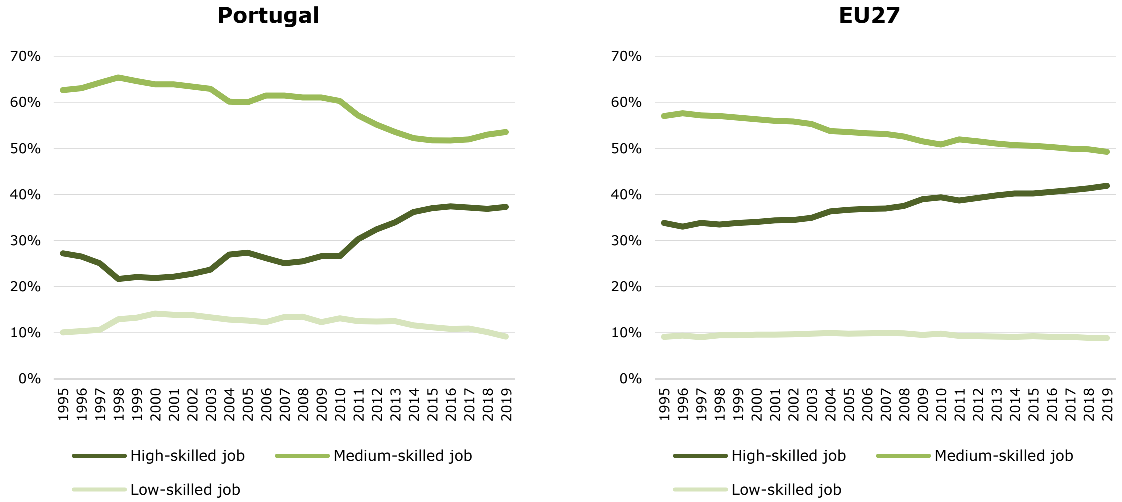
Figure 2. Evolution of investment in digitalisation (machine and non-machine-based), Portugal and EU27, 1995-2019



Source: Own elaborations based on Eurostat data [nama_10_nfa_fl]. Machine-based GFCF includes investments in computer hardware and telecommunications equipment (machine-based); non-machine based GFCF stands for investments in computer software and databases.

Figure 3 shows that the labour market has undergone significant changes during the 1995-2019 period both in Portugal and in Europe in general. In particular, it appears that high-skilled jobs have been replacing medium-skilled jobs over time, with low-skilled jobs remaining relatively constant. The skill categorisation is made according to the professional status of the workers.

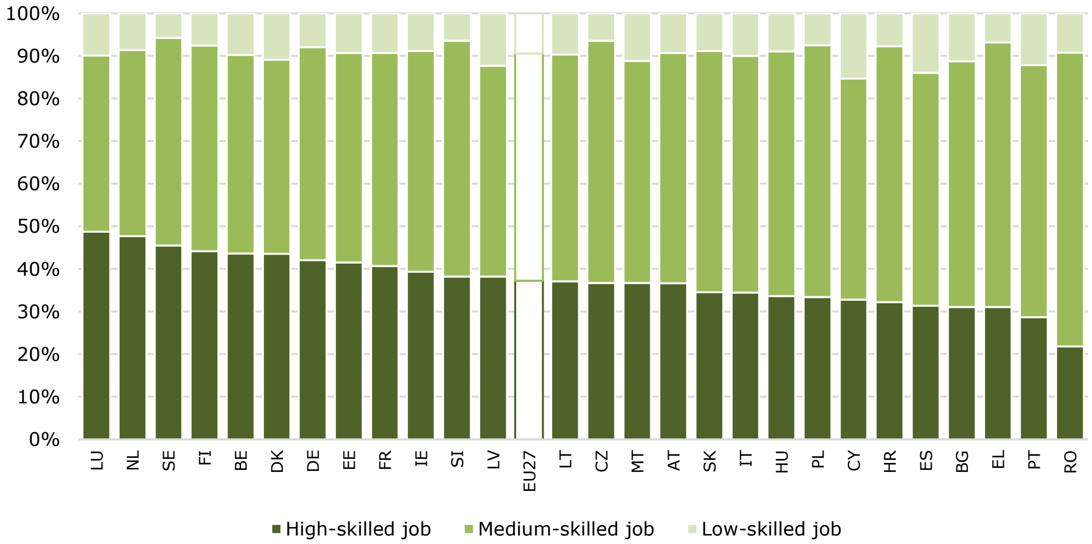
Figure 3. Evolution of employment by skill - professional status (% Total Employment): Portugal *versus* EU27, 1995-2019



Source: Own elaborations based on Eurostat data [lfsa_egais; lfsa_egaed].

Finally, Figure 4 shows that Portugal is close to the bottom of the EU ranking in terms of the proportion of high-skilled jobs over total employment during the 1995-2019 period. We turn to the next sections of the paper in order to investigate the relationship between digital investments and employment in the EU, with a particular focus on the Portuguese situation.

Figure 4. Employment by skill - professional status (% total employment), all EU Member States, average 1995-2019



Source: Own elaborations based on Eurostat data [lfsa_egais; lfsa_egaed].

4. Data and methodology

4.1. Measuring digitalisation

In the scientific literature, digitalisation is usually measured using three types of indicators:

- Acquisition of new digital technologies via tangible and intangible investments. The former are related to machines and equipment (Acemoglu and Restrepo, 2020); the latter investments include software and data access (Balsmeier and Woerter, 2019);
- Enabler of digital technologies. This is normally proxied using data on broadband internet access and mobile internet access (see e.g. Biagi and Falk, 2017);
- Technology as a marketing innovation and a new way of selling: e-sales, websites, and e-commerce (Biagi and Falk, 2017).

In the present study, we use investment in machine- and non-machine-based digital technologies to account for digitalisation, because investment decisions constitute a broader measure capable of considering all the types of indicators highlighted above. For instance, on-line sales or e-commerce implies a previous investment in either tangible or intangible assets, or both. Moreover, and since we study the impact of digitalisation on the labour market, it would be limiting to consider narrower definitions such as those relying on Internet access data.[8]

Time series data on digital investment in the EU countries are taken from Eurostat tables on the cross-classification of gross fixed capital formation by asset (flows).[9] From the list of assets available in Eurostat (see Table A1 in the Appendix), we consider investments in digitalisation those referring to computer hardware (N11321), telecommunications equipment (N11322) and computer software and databases (N1173).

4.2. Measuring employment skills in the labour market

We categorise employment by skills by using the International Standard Classification of Occupations 2008 (ISCO-08) and the ILO (2012) classification as reported in the Table 2 (following, among others, Reljic et al., 2019). We believe this choice to be appropriate given the focus of our analysis, as the possible labour-capital substitution effect would be related to the nature of tasks performed by the workers. Time series data on employment by professional occupation in the EU countries come from Eurostat.

To assess the labour market effect of digitalisation by occupational status we build an indicator assuming value 1 if there is an increase in the ratio between the total employment of high skilled-jobs over the total of medium-low skilled jobs, between two periods. Most of the existing studies (e.g. Balsmeier and Woerter, 2019; Reljic et al., 2019; Avom et al., 2021) have assessed the effect of digitalisation by skills estimating separately three regressions where the dependent variables refer to the level of employment by skills (high, medium and

[8] Internet access is only one of the determinant factors of ICT adoption (Bayo-Moriones and Lera-López 2007; Consoli, 2012).
[9] Data extracted on 20 July 2021.

low). With our approach, we propose an alternative way to capture movement from one category to another.

Table 2. Skill level by professional occupation (ISCO-08)

Broad skill level	ISCO-08
Skill levels 3 and 4 (High)	OC1: Managers
	OC2: Professionals
	OC3: Technicians and associate professionals
Skill level 2 (Medium)	OC4: Clerical support workers
	OC5: Service and sales workers
	OC6: Skilled agricultural, forestry and fishery workers
	OC7: Craft and related trades workers
	OC8: Plant and machine operators, and assemblers
Skill level 1 (Low)	OC9: Elementary occupations

Source: Own elaborations based on ILO (2012).

Figure shows the average ratio between the total employment in high skilled jobs over medium-low skilled jobs by EU27 Member States, as well as the average likelihood of its improvement over time. As we can see, Northern and Western European countries have an average higher ratio whereas Eastern and Southern European countries report lower ratios. Portugal and Romania are the last in the ranking, which shows that the share of medium-low skilled jobs over the high skilled-ones is extremely higher in these countries. On the opposite side, Luxembourg displays a ratio greater than 1 which means that the average number of high-skilled jobs outperforms the number of medium-low skilled-ones.

Figure 5. Total employment in high skilled-jobs over the total employment in medium-low skilled-jobs (1995-2019) and the likelihood of its improvement over time, by EU27

Source: Own elaboration based on Eurostat.

The average likelihood of the ratio improvement indicates how fast transformation in the labour market composition by occupational skills is occurring across EU Member States (the EU27 average is 70%). On average, countries located in the Northern and Western Europe display a higher value, in comparison with Eastern countries. Sweden and Finland are the countries with the higher likelihood of improvement, whereas Bulgaria and Slovakia those with the lowest value.

4.3. Methodological approach

The empirical model adopted in this study is an augmented version of an optimal labour demand function derived from the first order conditions of a Constant Elasticity of Substitution (CES) cost function, where the demand for labour L is a function of its factor price w and production output Y (Hamermesh, 1996; Biagi and Falk, 2017), as expressed in equation (1).

$$L = \alpha^{\sigma} w^{-\sigma} Y \quad (1)$$

Following Van Reenen (1997) and Biagi and Falk (2017), the stock of capital K is used as a proxy for output. The labour price w refers to the wages and salaries per employee. Taking the logarithms of (1), replacing Y for K, adding the country and time dimensions, and an error term (ε), the labour demand equation becomes a log-log linear static function as follows:

$$\log(L_{i,t}) = \beta_{\alpha} - \beta_{\sigma w} \log(w_{i,t}) + \beta_k \log(K_{i,t}) + \varepsilon_{i,t}, \quad (2)$$

where i refers to countries (EU Member States), t is time period (1995-2019), and β are the parameters to be estimated using panel data.

A further modification is needed in order to study the relationship between employment (the demand for labour) and digitalisation. In equation (2), we divide the capital stock between the stock of digital assets ($K_{i,t}^{digit}$) and the stock of non-digital ones ($K_{i,t}^{non\_digit}$). Both stocks are estimated using the Perpetual Inventory Method (PIM) and a depreciation rate of 33% for digital assets, 20% for research and development assets, and 8% for the non-digital ones (see Table A2 in the Appendix). Monetary values expressed in current prices are transformed in constant using GDP deflator (base 2005). Variables are transformed in first-differences (Δ) to express them in growth rates. The model includes country dummies (μ_i) and a dummy to control for periods of economic downturns (φ). A dummy variable to make a distinction between the Member States that have joined the EU since 2004 is included in the equation ($\mathrm{EU13}_i$). Equation (3) also controls for the number of people with higher education in each country via the *educ* variable, something which may affect the relationship between digitalisation and employment. Thus, the short-run labour demand equation can be estimated using the following:

$$\Delta\log(L_{i,t}) = \beta_{\alpha} - \beta_{\sigma w}\Delta\log(w_{i,t}) + \beta_{kd}\Delta\log(K_{i,t}^{digit}) + \beta_{knd}\Delta\log(K_{i,t}^{non\_digit}) + \beta_{educ}educ_{i,t} + \beta_{eu13}EU13_i + \beta_{\tau}\varphi_{i,t} + \beta_{\mu}\mu_i + \varepsilon_{i,t} \quad (3)$$

Furthermore, since the focus of the present analysis is to estimate the digitalisation-employment relationship for Portugal as well as for the rest of the EU, we include in equation (3) an interaction term between the digital technologies variable ($\Delta\log(K_{i,t}^{digit})$) and a dummy variable equal to 1 if the country-id is Portugal and 0 otherwise. This result in an estimated elasticity for Portugal which may potentially differ from the one estimated for the whole EU. For more details about the variables see Table 3.

Table 3. Description of the variables

Variables	**Variable description**
$\log(L_{i,t})$	Logarithm of the total employment (thousand persons)
$\log(w_{i,t})$	Logarithm of the wages and salaries expressed at constant price (base 2005) over the total employment
$\log\left(K_{i,t}^{digit}\right)$	Logarithm of stock of investment in digital technologies expressed at constant price (base 2005), estimated using the PIM
$\log\left(K_{i,t}^{non_{digit}}\right)$	Logarithm of stock of assets not categorised as investment in digital technologies expressed at constant price (base 2005), estimated using the PIM
$educ_{i,t}$	Share of employment with a tertiary education (levels 5-8)
$EU13_i$	Dummy variable = 1 if BG, CY, CZ, EE, HR, HU, LV, LT, MT, PL, RO, SI or SK; 0 otherwise.
$\varphi_{i,t}$	Dummy variable =1 if the difference between the real GDP in T and T-1 is negative (economic downturn); 0 otherwise.

Source: Own elaborations based on Eurostat data. Missing values were replaced by means of linear interpolation.

In the next section, we also present estimates of alternative specifications of equation (3) where the dependent variable is a binary value equals to 1 if changes in employment leads to an increased share of high-skilled employment over total employment with medium-low skills jobs, thus allowing to assess the heterogeneous effects of digitalisation on different professional occupations. Finally, we also test the hypothesis of a non-linear relationship between digitalisation and employment, adding the square term of the digital technology variable to equation (3).

To control for potential endogeneity bias of digitalisation we used a Two-Stage Residual Inclusion Estimation (2SRI), also called the Control Function approach. The conceptual framework of the 2SRI is similar to standard IV methods, such as two stage least squares

(2SLS), however, with some advantages (Wooldridge 2015). For instance, Terza et al. (2008) showed that the results of 2SRI could have a smaller bias than the 2SLS.

Similarly to the 2SLS, the 2SRI is a two-step procedure, where in the first step the endogenous variable (stock of digitalisation) is estimated using a vector of exogenous variables, which includes an exclusion restriction, or excluded instrument(s), only able to influence employment through digitalisation. This means that this(these) variable(s) cannot be correlated with our outcome variable. In addition to the excluded instrument(s), the first equation should also include the same exogeneous co-variants of the second equation.

If the estimated coefficients of the first stage equation are statistically significant, the reduced form of its residuals are estimated. The second step implies including the residuals as an additional explanatory variable in the outcome equation, in addition to the endogenous variable. The residuals coefficient (ρ) shows the direction and size of bias due to endogeneity and the *t* statistic test of this variable tests the null hypothesis of the existence of endogeneity (i.e., if the coefficient is statistically significant the variable is not exogenous). Therefore, the main difference with the 2SLS lies in the second step. Instead of including the predicted value of the endogenous regressor in the outcome equation, as 2SLS does, 2SRI includes the endogenous variable together with the reduced form of the residuals of the first equation. Our system of equations can only be estimated independently using OLS regressions if the error terms of both equations are not correlated with each other.

As exclusion restriction to explain the growth rate of the stock of investment in digital technologies we selected the initial value of the stock in T (which also corresponds to the final stock in T-1), and the growth rate of the stock within two periods. Both variables reveal to be strongly correlated at 1% significance level with our endogenous variable (Table C1 in Appendix C) and un-correlated with the growth rate of employment (Table C2 in Appendix C).

5. Results and discussion

5.1. Baseline model: digitalisation effect on employment in the EU

Table 4 reports the results of equation (3) with total employment as the dependent variable, using the following estimators: Pooled OLS in column (1); Random Effects in column (2); two-step difference-GMM in column (3) and the Two-Stage Residual Inclusion Estimation (2SRI) in column (4).[10] In the first two cases, the stock of digital capital is treated as exogenous, while we deal with its potential endogeneity both with the 2SRI estimates and with those obtained with the difference GMM estimator.

[10] The Wald test for joint significance of coefficients also shows that all model fits the data well. No evidence of multicollinearity is observed based on the VIF and correlation matrix (Table B3 in Appendix B).

Table 4. Results baseline model, dependent variable ΔLog(Employment)

Variables	OLS (1)	RE (2)	Diff. GMM (3)	2SRI (4)
△Log(Stock digital capital)	0.0472**	0.0316***	0.119**	0.106***
	(0.0224)	(0.00895)	(0.0603)	(0.0359)
△Log(Stock non-digital capital)	0.414***	0.258***	0.656***	0.393***
	(0.0576)	(0.0415)	(0.243)	(0.0600)
△Log(real cost per employee)	-0.171***	-0.0922***	-0.117	-0.196***
	(0.0602)	(0.0342)	(0.108)	(0.0608)
Share Empl. Higher Education T-1	0.0302**	0.0292**	0.108	0.0272*
	(0.0144)	(0.0118)	(0.184)	(0.0148)
Period of downturn (Yes/No)	-0.0193***	-0.0260***	-0.0192*	-0.0176***
	(0.00317)	(0.00370)	(0.0101)	(0.00329)
EU13 (Y/N)	0.00107	-0.00474	-	0.00261
	(0.00360)	(0.00362)	-	(0.00379)
Country fixed effects	Yes	No	No	Yes
Constant	-0.00241	-0.000288	-	-0.00287
	(0.00384)	(0.00353)	-	(0.00373)
Observations (ID-countries)	594 (27)	594 (27)	594 (27)	594 (27)
R-squared	0.508	0.3516	-	0.512
Tests for model specification				
Wald test for joint significance	0.000	0.000	0.000	0.000
Arellano-Bond test: AR(1)	-	-	0.005	-
Arellano-Bond test: AR(2)	-	-	0.147	-
Hansen test	-	-	0.223	-
ρ (residual first equation - 2SRI)	-	-	-	-0.0664*
	-	-	-	(0.0369)

Source: Own elaboration.

Note: Robust standard errors in parentheses. Significance level *** p<0.01, ** p<0.05, * p<0.1. Results of OLS (1) and 2SRI (4) refers to weighted regression using GDP. The variable ΔLog(Stock Digitalisation) is considered endogenous in two-step difference GMM (3) and 2SRI (4).

All model specification reports an average positive effect of investment in digitalisation on employment[11] in the EU27 in the period under analysis, in line with the findings of Balsmeier and Woerter (2019) for Switzerland. As we can see with the result of the 2SRI (column 4) existing bias due to endogeneity lowers the effect of digitalisation on employment, if compare the coefficients with the estimates in column (1). The negative and significant coefficient of ρ (bottom of Table 4) shows the size of the bias (-0.0664) and confirms this directionality. Results of the two-step of difference GMM of Arellano and Bond (1991) (column 3), used as robustness test, also endorse the previous findings, and display a similar elasticity for the stock of digitalisation.

[11] Findings that confirm the evidence observed in the two-way scatterplot reported in Figure B1-A and Figure B1-B in Appendix B.

The results of the first stage of the 2SRI are displayed in Table C1 in Appendix C and show that the instruments are valid and the model is correctly specified. Variables also have the expected sign. For instance, the second-order lag of the growth rate of the capital stock of digital technologies is positively correlated with the growth rate in T and the initial value of stock in T display a negative relationship. The qualification of labor force in a country, measured by its education level, influence positively the growth rate of digitalisation, as well as the growth rate of real cost per employee. Period of downturns and being a new EU Member States influence negatively the stock of digital technologies.

Regarding the size of the net effect of digitalisation on employment our coefficients refers to elasticities, indicating that a 1% increase of the stock of digital technologies is associated with an increase of 0.11% of employment, all the rest remaining constant, based on the results of the 2SRI (column 4) and 0.05% based on Pooled OLS (column 1). To compare the magnitude of the estimated effects with the results of Balsmeier and Woerter (2019), which reports the effects in monetary terms, we need to calculate the marginal effects of a 1 euro increase in digital capital stock.[12] Balsmeier and Woerter (2019), using a Pooled OLS and considering all variables exogenous, found that an increase of CHF 100.000[13] in the investment of digitalisation is associated with a total increase of 1.6 jobs in Switzerland. With the results of Pooled OLS estimation, where the variables are also exogenous (column 1) we obtain that in increase of €100.000 in the stock of investment in digital technologies increases the total employment by 1.3 jobs in EU27, and when considering the result of 2SRI (column 4), by 3.1 jobs. Since an increase in stock represents more than an increase in investment (as a result of the replacement and depreciation of digital technologies), the magnitude our findings are in line previous studies.

The negative estimated coefficient of the real cost per employee change shows that rising labour costs lower employment demand's growth. Besides, the negative effect associated with the period of downturn dummy variable signals that employment creation is hit when the general economic environment is adverse.

5.2. Digitalisation effect on employment in Portugal: Is there any difference?

In the previous section, we have provided novel evidence on our first research question, namely the effect of digitalisation on employment in the EU27. In the present section, we are now investigating whether the effect of digitalisation in Portugal shows a different pattern with respect to the other EU Member States.

[12] Estimated using the product of the elasticity and the ratio of the impacted variable (mean of employment) on the impacting one (mean Stock investment in digital technologies).

[13] CHF corresponds to Swiss Franc and on 29 October 2021 its exchange rate was equivalent to 0.94 euros.

Table 5 reports the results of equation (3) including a non-factorial interaction term in our main variable of interest (digitalisation) to make a distinction between Portugal and the rest of the EU by using the 2SRI and without country fixed effects.[14]

Table 5. Results of 2SRI: Portugal versus EU, dependent variable ΔLog(Employment)

Variables	(1)
ΔLog(Stock digital capital)	
EU26 (EU27 minus PT)	0.108***
	(0.0275)
Portugal	0.0960***
	(0.0282)
Z-test: H0: β_{EU26} = β_{PT} (p-value)	0.761
Control variables	Yes
Country fixed effects	No
Constant	-0.00269
	(0.00374)
Observations	594
R-squared	0.517
Wald test for joint significance	0.000
ρ (residual first equation with # - 2SRI)	
	-
EU26 (EU27 minus PT)	0.0860***
	(0.0311)
Portugal	-0.627***
	(0.122)
Model validation tests: equation 1 with #	
Wald test (p-value): Significance of instruments	0.000
Wald test (p-value): Significance of excluded instruments	0.000
Wald test (p-value): Joint significance of the model	0.000

Source: Own elaboration.

Note: Robust standard errors in parentheses. Significance level *** p<0.01, ** p<0.05, * p<0.1. Results refers to weighted regression using GDP. The variable △Log(Stock digital capital) is considered endogenous in 2SRI.

Results in Table 5 reveal an average positive effect of digitalisation in Portugal, as well as for the rest of the EU. The results of the Z-test[15] shows that the elasticities between PT and the EU26 are not statistically different. However, having the same elasticity, which measures relative change, does not mean having the same marginal effect. Indeed, whereas for the EU26 an increase of €100.000 in the stock of digital technologies is associated with an increase of 3.1 jobs, in Portugal it is associated with an increase of 4.6 jobs.

In addition to the analysis above, since the two-way scatterplot in Figure B1-B in Appendix B reveals the possibility of an non-linear relationship between digitalisation and employment,

[14] Results of the first stage available upon request.

[15] The Z-test of differences between coefficients is estimated by the equation: $Z = \frac{\beta_1 - \beta_2}{\sqrt{(Std.Error\ \beta_1)^2 + (Std.Error\ \beta_2)^2}}$

equation (3), but without country fixed, was re-estimated including the squared of the growth rate of the stock of digital technologies. Moreover, in order to test the difference between Portugal and the rest of the EU, the non-factorial interaction term is also included in the regression estimation. Results reported in Table D1 in Appendix D don't show evidence of an inverted U-shaped relationship, for both Portugal and EU26. Therefore, in line also with previous findings, it seems that on average a linear positive effect of digitalisation on employment seems to prevail.

5.3. Complementarity analysis: digitalisation effect on employment by skills

As a complementarity analysis, we have re-estimated equation (3) replacing the dependent variable by our indicator of the change in the labour market structure. The results of the 2SRI are displayed in Table 6, using the results of first step reported in Table C1 in Appendix C. The positive coefficient of the growth rate of the stock of digital technologies reveals that digitalisation has a positive effect on the likelihood of changing labour market structure regarding the nature of the workers tasks. Low and medium skilled-jobs, associated with the specifications of the tasks, are being replaced by high skills ones.

Table 6. Results of 2SRI: Change in labour market structure, dependent variable: increasing in the ratio High to Medium-Low employment skills (Y/N)

Variables	(1)
△Log(Stock digital capital)	3.887**
	(1.857)
Control variables and country fixed effects	Yes
Constant	0.597***
	(0.182)
Observations	594
R-squared	0.058
Wald test for joint significance	0.000
ρ (residual first equation - 2SRI)	-3.800*
	(1.968)

Source: Own elaboration. Note: Robust standard errors in parentheses. Significance level *** p<0.01, ** p<0.05, * p<0.1. Results refers to weighted regression using GDP. The variable △Log(Stock digital capital) is considered endogenous in 2SRI.

6. Conclusion

We assessed the effect of digitalisation on employment for the EU countries, and Portugal in particular, during the 1995-2019 period. We estimate an augmented labour demand function derived from a CES cost function to test for a capital-labour substitution effect, distinguishing between digital and non-digital capital. The results point towards a positive impact of digital investments on total employment. Our findings also suggests a change in the labour market composition induced by digitalisation. In particular, high-skilled jobs benefit from digitalisation investments at the expenses of jobs in medium- and low-skilled professions.

In Portugal, there is also evidence of a positive and linear relationship between digital investments and employment, and its rate of return is even higher than the EU average. Such findings could be explained by the country-specific labour market characteristics as well as by the potential catching up in terms of overall gross fixed capital formation and, specifically, digital investments with respect to the other EU27 Member States.

From an academic perspective, our study offers novel findings produced with a robust methodology to estimate the net effect of digitalisation on employment. The results are relevant from a policy perspective, as they could be used as evidence informing effective and targeted labour market interventions to facilitate the digital transition, especially for the most vulnerable workers of the economy.

References

Acemoglu, D., and Restrepo, P. (2020). Robots and jobs: Evidence from US labor markets. *Journal of Political Economy* 128(6): 2188-2244. https://doi.org/10.1086/705716

Akerman, A., Gaarder, I., and Mogstad, M. (2015). The skill complementarity of broadband internet. *The Quarterly Journal of Economics* 130(4) 1781–824.

Arellano, M., and Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies* 58(2), 277-297.

Autor, D. H., Katz, L. F., and Kearney, M. S. (2006). The polarization of the U.S. labor market. *American Economic Review* 96 (2): 189–94.

Autor, D. H., Levy, F., and Murnane, R. J. (2003). The skill content of recent technological change: An empirical exploration. *The Quarterly Journal of Economics 118*(4), 1279-1333.

Avom, D., Kocou Dadegnon, A.K., and Igue, C. B. (2021). Does digitization promote job creation? Empirical evidence from WAEMU countries. *Telecommunications Policy* 45(8), 102215. https://doi.org/10.1016/j.telpol.2021.102215

Balsmeier, B., and Woerter, M. (2019). Is this time different? How digitalization influences job creation and destruction, *Research Policy* 48(8):103765. https://doi.org/10.1016/j.respol.2019.03.010

Bayo-Moriones, A., and Lera-López, F. (2007). A firm-level analysis of determinants of ICT adoption in Spain. *Technovation* 27(6-7), 352-366.

Bessen, J.E. (2016). How computer automation affects occupations: technology, jobs, and skills. Boston University School of Law, Law and Economics Working Paper 15–49.

Biagi, F., and Falk, M. (2017). The impact of ICT and e-commerce on employment in Europe. *Journal of Policy Modeling* 39(1), 1-18.

Cambridge (2011). *Cambridge Business English*, Cambridge University Press: UK.

Corrado, C.; Hulten, C. and Sichel, D. (2009). "Intangible Capital and U.S. Economic Growth", *The review of Income and Wealth*, 55(3): 661-685. https://doi.org/10.1111/j.1475-4991.2009.00343.x

Christensen, M., Conte, A., Di Pietro, F., Lecca, P., Mandras, G., and Salotti, S (2018). The third pillar of the Investment Plan for Europe: an impact assessment using the RHOMOLO model. JRC Working Papers on Territorial Modelling and Analysis No. 02/2018, European Commission, Seville, 2018, JRC113746.

Cincera, M., Delanote, J., Mohen, P., Santos, A., and Weiss, C. (2020). Intangible investments and productivity performance. *GEE Paper 145*. Available at: https://www.gee.gov.pt/RePEc/WorkingPapers/GEE_PAPERS_145.pdf

Cirera, X., L. Sabetti (2019). The effects of innovation on employment in developing countries: evidence from enterprise surveys. *Industrial and Corporate Change* 28(1), 161-176.

Consoli, D. (2012). Literature analysis on determinant factors and the impact of ICT in SMEs. *Procedia-social and behavioral sciences* 62, 93-97.

Dauth, W., Findeisen, S., Südekum, J., and Woessner, N. (2017). German robots-the impact of industrial robots on workers. CEPR Discussion Papers No. 12306.

Degryse, C. (2016). Digitalisation of the economy and its impact on labour markets. Working Paper 2016.02, European Trade Union Institute.

Eduardsen, J. (2018). Internationalisation through digitalisation: the impact of e-commerce usage on internationalisation in small- and medium-sized firms. In: van Tulder, R., Verbeke, A. and Piscitello, L. (Ed.) *International Business in the Information and Digital Age* (Progress in International Business Research, Vol. 13), Emerald Publishing Limited, Bingley, 159-186. https://doi.org/10.1108/S1745-886220180000013008

EIB (2020). *Who is prepared for the new digital age? Evidence from the EIB Investment Survey*, European Investment Bank. DOI: 10.2867/03951

EIB (2021). *Investment report 2020/2021: Building a smart and green Europe in the COVID-19 era*, European Investment Bank. DOI: 10.2867/904099

Equinix (2021). Beyond COVID-19: Digital Transformation Trends in the Wake of the Pandemic - Equinix 2020-21 Global Tech Trends Survey, May 2021.

Ford, M. (2015). *The Rise of the Robots: Technology and the Threat of Mass Unemployment*. London: Oneworld Publications.

Freddi, D. (2018). Digitalisation and employment in manufacturing. *AI & Society* 33:393-403.

Gaggl, P., and Wright, G.C. (2017). A short-run view of what computers do: Evidence from a UK tax incentive. *American Economic Journal: Applied Economics* 9(3): 262–294. https://doi.org/10.1257/app.20150411

Gal, P., Nicoletti, G., Renault, T., Sorbe , S., and Timiliotis, C. (2019). Digitalisation and productivity: In search of the Holy grail – Firm-level empirical evidence from European Countries. OECD Economics Department Working Papers n° 1533.

Goos, M., and Manning, A. (2007). Lousy and lovely jobs: The rising polarization of work in Britain. *The Review of Economics and Statistics* 89(1): 118-133.

Graetz, G., and Michaels, G. (2018). Robots at work. *Review of Economics and Statistics* 100(5): 753-768.

Hamermesh, D. S. (1996). *Labor Demand*. Princeton, NJ: Princeton University Press.

ILO (2012). *International Standard Classification of Occupations: ISCO-08*. International Labour Office, Geneva.

Katz, L. F., and Autor, D. H. (1999). Changes in the wage structure and earnings inequality. In: Ashenfelter and Card (ed.) *Handbook of Labor Economics. Vol. 3A*, 1463–1555. Amsterdam: Elsevier B.V.

Keynes, J. M. (1937). The general theory of employment. *Quarterly Journal of Economics* 51(2): 209–23.

Koch, M., Manuylov, I., and Smolka, M. (2019). Robots and firms. Aarhus University, Department of Economics Working paper 2019–5.

Leontief, W. (1952). Machines and man. *Scientific American* 187(3): 150-164.

Mann, K., & Püttmann, L. (2018). Benign effects of automation: New evidence from patent texts. *Available at SSRN 2959584*.

Marx, K. (1961). *Capital*, Moscow, Foreign Languages Publishing House, first edn 1867

Marx, K. (1969). *Theories of Surplus Value*, London, Lawrence & Wishart, first edn. 1905-10

Montresor, S. and Vezzani, A. (2015). "The production function of top R&D investors: Accounting for size and sector heterogeneity with quantile estimations", *Research Policy*, 44(2), pp. 381–393. https://doi.org/10.1016/j.respol.2014.08.005

OECD (2019). OECD Regional Outlook 2019. Leveraging Megatrends for Cities and Rural Areas. OECD Publishing, Paris.

Reljic, J., Evangelista, R., and Pianta, M. (2019). Digital technologies, employment and skills. LEM Working Paper Series, No. 2019/36, Scuola Superiore Sant'Anna, Laboratory of Economics and Management (LEM), Pisa.

Rossato, C., and Castellani, P. (2020). The contribution of digitalisation to business longevity from a competitiveness perspective. *The TQM Journal* 32(4): 617-645. https://doi.org/10.1108/TQM-02-2020-0032

Terza J.V.; Basu, A.; Rathouz, P.J. (2008). "Two-stage residual inclusion estimation: addressing endogeneity in health econometric modelling", *Journal of Health Economics*, 27(3):531-43. doi: 10.1016/j.jhealeco.2007.09.009

UNCTAD (2017). Information Economy Report 2017. Digitalization, trade and development. United Nations.

Van Reenen, J. (1997). Employment and technological innovation: Evidence from UK manufacturing firms. *Journal of Labor Economics* 15(2), 255–284.

Vivarelli, M. (2007). Innovation and employment: A survey. *IZA Discussion Paper Series* n.º 2621.

Vivarelli, M. 1995. *The Economics of Technology and Employment: Theory and Empirical Evidence*, Aldershot, Elgar.

Wooldridge (2015). Control Function Methods in Applied Econometrics. *Journal of Human Resources*, 50(2), 420-445.

Appendix

Appendix A. Classification of gross fixed capital formation assets and their depreciation rate

Table A1. Classification of gross fixed capital formation assets

Code	Label
N11G	Total fixed assets (gross)
N11KG	Total Construction (gross)
N111G	Dwellings (gross)
N112G	Other buildings and structures (gross)
N11MG	Machinery and equipment and weapons systems (gross)
N1131G	Transport equipment (gross)
N1132G	ICT equipment (gross)
N11321G	Computer hardware (gross)
N11322G	Telecommunications equipment (gross)
N11OG	Other machinery and equipment and weapons systems (gross)
N115G	Cultivated biological resources (gross)
N117G	Intellectual property products (gross)
N1171G	Research and development (gross)
N1173G	Computer software and databases (gross)

Source: EUROSTAT, Cross-classification of gross fixed capital formation by industry and by asset (flows) [nama_10_nfa_fl].

Table A2. Estimation of capital stock, depreciation rate of different assets

Assets	Depreciation rates	
	value	Source
Computer hardware	33%	Corrado et al. (2009)
Telecommunications equipment	33%	Corrado et al. (2009)
Computer software and databases	33%	Corrado et al. (2009)
Research and development	20%	Corrado et al. (2009)
Other tangible assets	8%	Montresor and Vezzani (2015)

Source: Own elaborations based on Corrado et al. (2009) and Montresor and Vezzani (2015).

Appendix B. Descriptive Statistics, correlation matrix and multicollinearity diagnostics

Table B1. Descriptive Statistics

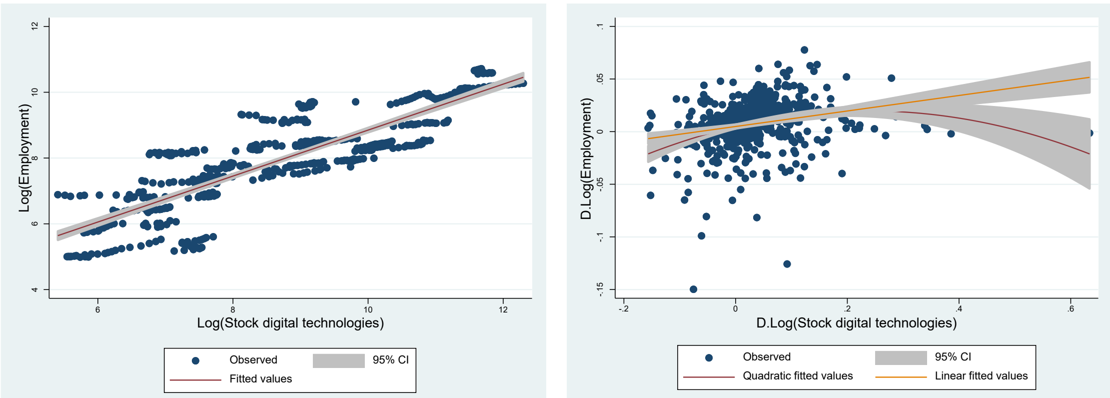
Variables	Mean	Std. Dev.	Min	Max
Employment (thousand persons)	7,229	9,702	146	45,123
Improvement ratio High over MedLow skilled-jobs (Y/N)	0.70	0.46	0	1
Real stock of digital technologies (million euros)	24,595.43	39,118	223.14	219,260
Real stock of non-digital capital (million euros)	737,304	1,227,914	9,358	5,819,858
Real wages and salaries per employee (euros)	17,465	13,252	1,395	69,006
Share of employment with tertiary education	0.28	0.10	0.08	0.51

Source: Own elaboration.

Note: Number of observations: 594.

Figure B1. Two-way scatterplots between the stock of digital technologies and employment (in logs-level and logs-first difference) averaged over 1995-2019, EU27

A. Log-level **B. Logs-first difference**



Source: Own elaboration.

Table B2. Pairwise correlation coefficients between stock of digital technologies and employment (in logs in level and first difference) averaged over 1995-2019, EU27

#	Variables		1	2	3	4
1	Log(Employment)	Coeff.	1			
2	Log(Stock digital technologies)	Coeff.	0.856	1		
		P-value	0.000			
3	△Log(Employment)	Coeff.	-0.107	0.013	1	
		P-value	0.009	0.758		
4	△Log(Stock digital technologies)	Coeff.	-0.109	-0.108	0.242	1
		P-value	0.008	0.009	0.000	

Source: Own elaboration.

Note: Number of observations: 594.

Table B3. Variance inflation factors (VIF) and correlation matrix

#	Variables	VIF	Correlation matrix			
			1	2	3	4
1	△Log(Stock digital capital)	1.10	1			
2	△Log(Stock non-digit capital)	1.19	0.259	1		
3	△Log(real cost per employee)	1.17	0.226	0.34	1.00	
4	Share Empl. Higher Education T-1	1.02	0.044	-0.08	-0.11	1
	Mean VIF	1.12				

Source: Own elaboration.

Note: Number of observations: 594.

Appendix C. Results first stage of the Two-Stage Residual Inclusion Estimation

Table C1. Results of Pooled OLS, dependent variable ΔLog(Stock digit)

Variables	(1)
△Log(Stock digital capital) in T-2	0.348***
	(0.0685)
Log(Stock digital capital) in T-1	-0.108***
	(0.0274)
△Log(Stock non-digital capital)	0.248
	(0.166)
△Log(real cost per employee)	0.336**
	(0.137)
Share Empl. Higher Education T-1	0.365***
	(0.129)
Period of downturn (Yes/No)	-0.0255***
	(0.00603)
EU13 (Y/N)	-0.243***
	(0.0598)
Country fixed effects	Yes
Constant	1.019***
	(0.250)
Observations	594
R-squared	0.305
Wald test (p-value)	
Significance of instruments	0.000
Significance of excluded instruments	0.000
Joint significance of the model	0.000
Ramsey test - Ho: model has no omitted variables (p-value)	0.708
Correlation coefficient between error terms eq. 1 and eq. 2	0.014
Significance level	0.734

Source: Own elaboration.

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table C2. Pairwise correlation coefficients between ΔLog(Employment) and excluded instruments

Variables	**Coeff.**	**P-Value**
△Log(Stock digital capital) in T-2	-0.0385	0.3489
Log(Stock digital capital) in T-1	0.0057	0.8853

Source: Own elaboration.

Appendix D. Testing the non-linear relationship between employment and investment in digital technologies

Table D1. Results of 2SRI: Testing non-linear relationship, dependent variable ΔLog(Employment)

Variables	(1)
△Log(Stock digital capital)	
EU26 (EU27 minus PT)	0.0843*
	(0.0456)
Portugal	0.0499
	(0.0365)
△Log(Stock digital capital) - Squared	
EU26 (EU27 minus PT)	-0.00126
	(0.00365)
Portugal	-0.00182
	(0.00302)
Control variable	Yes
Country fixed effects	No
Constant	0.00603**
	(0.00236)
Observations	567
R-squared	0.481
Wald test for joint significance	0.000
ρ (residual first equation with # level - 2SRI)	
EU26 (EU17 minus PT)	-0.280***
	(0.0802)
Portugal	-0.562***
	(0.119)
ρ (residual first equation with # squared - 2SRI)	
EU26 (EU17 minus PT)	0.0127***
	(0.00478)
Portugal	0.0189***
	(0.00424)

Source: Own elaboration.

Note: Robust standard errors in parentheses. Significance level *** p<0.01, ** p<0.05, * p<0.1. Results refer to weighted regression using GDP. The variable ΔLog(Stock digital capital) is considered endogenous in 2SRI. Results of the first step are available upon request.

REPÚBLICA PORTUGUESA
ECONOMIA E MAR

Gabinete de Estratégia e Estudos

GEE Papers

1: Evolução do Comércio Externo Português de Exportação (1995-2004)
João Ferreira do Amaral

2: Nowcasting an Economic Aggregate with Disaggregate Dynamic Factors: An Application to Portuguese GDP
Antonio Morgado | Luis Nunes | Susana Salvado

3: Are the Dynamics of Knowledge-Based Industries Any Different?
Ricardo Mamede | Daniel Mota | Manuel Godinho

4: Competitiveness and convergence in Portugal
Jorge Braga de Macedo

5: Produtividade, Competitividade e Quotas de Exportação
Jorge Santos

6: Export Diversification and Technological Improvement: Recent Trends in the Portuguese Economy
Manuel Cabral

7: Election Results and Opportunistic Policies: An Integrated Approach
Toke Aidt | Francisco Veiga | Linda Veiga

8: Behavioural Determinants of Foreign Direct Investment
Ricardo Pinheiro-Alves

9: Structural Transformation and the role of Foreign Direct Investment in Portugal: a descriptive analysis for the period 1990-2005
Miguel de Freitas | Ricardo Mamede

10: Productive experience and specialization opportunities for Portugal: an empirical assessment
Miguel de Freitas | Susana Salvado | Luis Nunes | Rui Costa Neves

11: The Portuguese Active Labour Market Policy during the period 1998-2003 - A Comprehensive Conditional Difference-In-Differences Application
Alcina Nunes | Paulino Teixeira

12: Fiscal Policy in a Monetary Union: Gains from Changing Institutions
Susana Salvado

13: Coordination and Stabilization Gains of Fiscal Policy in a Monetary Union
Susana Salvado

14: The Relevance of Productive Experience in the Process of Economic Growth: an Empirical Study
Diana Vieira

15: Employment and Exchange rates: the Role of Openness and Technology
Fernando Alexandre | Pedro Bação | João Cerejeira | Miguel Portela

16: Aggregate and sector-specific exchange rate indexes for the Portuguese economy
Fernando Alexandre | Pedro Bação | João Cerejeira | Miguel Portela

17: The Macroeconomic Determinants of Cross Border Mergers and Acquisitions and Greenfield Investments
Paula Neto | Antonio Brandao | António Cerqueira

18: Does the location of manufacturing determine service sectors' location choices? Evidence from Portugal
Nuno Crespo | Maria Paula Fontoura

19: A hipótese do Investment Development Path: Uma Abordagem por Dados em Painel. Os casos de Portugal e Espanha
Miguel Fonseca | António Mendonça | José Passos

20: Outward FDI Effects on the Portuguese Trade Balance, 1996-2007
Miguel Fonseca | António Mendonça | José Passos

21: Sectoral and regional impacts of the European Carbon Market in Portugal
Margarita Robaina Alves | Miguel Rodriguez | Catarina Roseta-Palma

22: Business Demography Dynamics in Portugal: A Non-Parametric Survival Analysis
Alcina Nunes | Elsa Sarmento

23: Business Demography Dynamics in Portugal: A Semi-parametric Survival Analysis
Alcina Nunes | Elsa Sarmento

24: Digging Out the PPP Hypothesis: an Integrated Empirical Coverage
Miguel de Carvalho | Paulo Júlio

25: Regulação de Mercados por Licenciamento
Patrícia Cerqueira | Ricardo Pinheiro Alves

26: Which Portuguese Manufacturing Firms Learn by Exporting?
Armando Silva | Óscar Afonso | Ana Paula Africano

27: Building Bridges: Heterogeneous Jurisdictions, Endogenous Spillovers, and the Benefits of Decentralization
Paulo Júlio | Susana Peralta

28: Análise comparativa de sobrevivência empresarial: o caso da região Norte de Portugal
Elsa Sarmento | Alcina Nunes

29: Business creation in Portugal: Comparison between the World Bank data and Quadros de Pessoal
Elsa Sarmento | Alcina Nunes

30: The Ease of Doing Business Index as a tool for Investment location decisions
João Zambujal Oliveira | Ricardo Pinheiro Alves

31: The Politics of Growth: Can Lobbying Raise Growth and Welfare?
Paulo Júlio

32: The choice of transport technology in the presence of exports and FDI
José Pedro Ponte | Armando Garcia Pires

33: Tax Competition in an Expanding European Union
Ronald Davies | Johannes Voget

34: The usefulness of State trade missions for the internationalization of firms: an econometric analysis
Ana Paula Africano | Aurora Teixeira | André Caiado

35: The role of subsidies for exports: Evidence from Portuguese manufacturing firms
Armando Silva

36: Criação de empresas em Portugal e Espanha: análise comparativa com base nos dados do Banco Mundial
Elsa Sarmento | Alcina Nunes

37: Economic performance and international trade engagement: the case of Portuguese manufacturing firms
Armando Silva | Oscar Afonso | Ana Paula Africano

38: The importance of Intermediaries organizations in international R&D cooperation: an empirical multivariate study across Europe
Aurora Teixeira | Margarida Catarino

39: Financial constraints, exports and monetary integration - Financial constraints and exports: An analysis of Portuguese firms during the European monetary integration
Filipe Silva | Carlos Carreira

40: FDI and institutional reform in Portugal
Paulo Júlio | Ricardo Pinheiro-Alves | José Tavares

41: Evaluating the forecast quality of GDP components
Paulo Júlio | Pedro Esperança | João C. Fonseca

42: Assessing the Endogeneity of OCA conditions in EMU
Carlos Vieira | Isabel Vieira

43: Labor Adjustment Dynamics: An Application of System GMM
Pedro Esperança

44: Corporate taxes and the location of FDI in Europe using firm-level data
Tomás Silva | Sergio Lagoa

45: Public Debt Stabilization: Redistributive Delays versus Preemptive Anticipations
Paulo Júlio

46: Organizational Characteristics and Performance of Export Promotion Agencies: Portugal and Ireland compared
Inês Ferreira | Aurora Teixeira

47: Evaluating the forecast quality of GDP components: An application to G7
Paulo Júlio | Pedro Esperança

48: The influence of Doing Business' institutional variables in Foreign Direct Investment
Andreia Olival

49: Regional and Sectoral Foreign Direct Investment in Portugal since Joining the EU: A Dynamic Portrait
Irina Melo | Alexandra Lopes

50: Institutions and Firm Formation: an Empirical Analysis of Portuguese Municipalities
Simão Arouca

51: Youth Unemployment in Southern Europe
João Leão | Guida Nogueira

52: Financiamento da Economia Portuguesa: um Obstáculo ao Crescimento?
João Leão | Ana Martins | João Gonçalves

53: O Acordo de Parceria Transatlântica entre a UE e os EUA constitui uma ameaça ou uma oportunidade para a Economia Portuguesa?
João Leão | Guida Nogueira

54: Prescription Patterns of Pharmaceuticals
Ana Gonçalves

55: Economic Growth and the High Skilled: the Role of Scale Eects and of Barriers to Entry into the High Tech
Pedro Gil | Oscar Afonso | Paulo Brito

56: Finanças Públicas Portuguesas Sustentáveis no Estado Novo (1933-1974)?
Ricardo Ferraz

57: What Determines Firm-level Export Capacity? Evidence from Portuguese firms
Ana Gouveia | Ana Luisa Correia

58: The effect of developing countries' competition on regional labour markets in Portugal
Tiago Pereira

59: Fiscal Multipliers in the 21st century
Pedro Brinca | Hans Holter | Per Krusell | Laurence Malafry

60: Reallocation of Resources between Tradable and Non-Tradable Sectors in Portugal: Developing a new Identification Strategy for the Tradable Sector
Ana Fontoura Gouveia | Filipa Canas

61: Is the ECB unconventional monetary policy effective?
Inês Pereira

62: The Determinants of TFP Growth in the Portuguese Manufacturing Sector
Daniel Gonçalves | Ana Martins

63: Practical contribution for the assessment and monitoring of product market competition in the Portuguese Economy – estimation of price cost margins
Luis Folque

64: The impact of structural reforms of the judicial system: a survey
Ana Gouveia | Silvia Santos | Corinna Herber

65: The short-term impact of structural reforms on productivity growth: beyond direct effects
Ana Gouveia | Silvia Santos | Inês Gonçalves

66: Assessing the Competitiveness of the Portuguese Footwear Sector
Fábio Batista | José Matos | Miguel Matos

67: The empirics of agglomeration economies: the link with productivity
Ana Gouveia | Silvia Santos | Marli Fernandes

68: Determinants of the Portuguese GDP stagnation during the 2001-2014 period: an empirical investigation
Carlos Figueira

69: Short-run effects of product markets' deregulation: a more productive, more efficient and more resilient economy?
Ana Gouveia | Silvia Santos | Gustavo Monteiro

70: Portugal: a Paradox in Productivity
Ricardo Pinheiro Alves

71: Infrastructure Investment, Labor Productivity, and International Competitiveness: The Case of Portugal
Alfredo Pereira | Rui Pereira

72: Boom, Slump, Sudden stops, Recovery, and Policy Options. Portugal and the Euro
Olivier Blanchard | Pedro Portugal

73: Case Study: DBRS Sovereign Rating of Portugal. Analysis of Rating Methodology and Rating Decisions
Annika Luisa Hofmann | Miguel Ferreira | João Lampreia

74: For Whom the Bell Tolls: Road Safety Effects of Tolls on Uncongested SCUT Highways in Portugal
Alfredo Pereira | Rui Pereira | João Pereira dos Santos

75: Is All Infrastructure Investment Created Equal? The Case of Portugal
Alfredo Pereira | Rui Pereira

76: Why Virtuous Supply-Side Effects and Irrelevant Keynesian Effects are not Foregone Conclusions: What we Learn from an Industry-Level Analysis of Infrastructure Investments in Portugal
Alfredo Pereira | Rui Pereira

77: The Role of Gravity Models in Estimating the Economic Impact of Brexit
Graham Gudgin | Ken Coutts | Neil Gibson | Jordan Buchanan

78: Infrastructure Investment in Portugal and the Traded/Non-Traded Industry Mix
Alfredo Pereira | Rui Pereira

79: Goods and Factor Market Integration: A Quantitative Assessment of the EU Enlargement
Lorenzo Caliendo | Fernando Parro | Luca David Opromolla | Alessandro Sforza

80: Understanding productivity dynamics:a task taxonomy approach
Tiago Fonseca | Francisco Lima | Sonia C. Pereira

81: On the Effects of Infrastructure Investments on Industrial CO2 Emissions in Portugal
Alfredo Pereira | Rui Pereira

82: Assessing Competition With the Panzar-Rosse Model: An empirical analysis of European Union banking industry
Suzana Cristina Silva Andrade

83: Health Care Investments and Economic Performance in Portugal: An Industry Level Analysis
Alfredo Pereira | Rui Pereira | Pedro G. Rodrigues

84: Is deregulation of product and labour markets promoting employment and productivity? A difference-in-differences approach
Hugo Correia | Ana Fontoura Gouveia

85: Foreign acquisition and internal organization
Paulo Bastos | Natália P. Monteiro | Odd Rune Straume

86: Learning, Prices, and Firm Dynamics
Paulo Bastos | Daniel A. Dias | Olga A. Timoshenko

87: The Diffusion of Knowledge via Managers' Mobility
Giordano Mion | Luca David Opromolla | Alessandro Sforza

88: Empresas Zombie em Portugal - Os sectores não transacionáveis da Construção e dos Serviços
Gabriel Osório de Barros | Filipe Bento Caires | Dora Xarepe Pereira

89: Collective bargaining through the magnifying glass: A comparison between the Netherlands and Portugal
Alexander Hijzen | Pedro Martins | Jante Parlevliet

120: A Look at the main channels of Potential Impact of Brexit on the Portuguese Economy
Guida Nogueira | Paulo Inácio

121: How internationalization and competitiveness contribute to get public support to innovation? The Portuguese case
Anabela Santos, Michele Cincera, Paulo Neto | Maria Manuel Serrano

122: Grande Guerra e Guerra Colonial: Quanto Custaram aos Cofres Portugueses?
Ricardo Ferraz

123: Financing a Renewable Energy Feed-in Tariff with a Tax on Carbon Dioxide Emissions: A Dynamic Multi-Sector General Equilibrium Analysis for Portugal
Rui M. Pereira | Alfredo M. Pereira

124: Brown Sugar, how come you taste so good? The impact of a soda tax on prices and consumption
Judite Gonçalves | João Pereira dos Santos

125: ARFIMA Reference Forecasts for Worldwide CO2 Emissions and the National Dimension of the Policy Efforts to Meet IPCC Targets
José Beirute | Alfredo M. Pereira

126: Reference Forecasts for CO2 Emissions from Fossil-Fuel Combustion and Cement Production in Portugal
José M. Belbute | Alfredo M. Pereira

127: Regulated Early Closures of Coal-Fired Power Plants and Tougher Energy Taxation on Electricity Production: Synergy or Rivalry?
Alfredo Marvão Pereira | Rui Manuel Pereira

128: Picking Our Environmental Battles: Removal of Harmful Subsidies or Carbon Taxation?
Alfredo Marvão Pereira | Rui Marvão Pereira

129: Financing Future Feed-in Tariffs from Currently Installed RES-E Generating Capacity
Alfredo Marvão Pereira | Rui Marvão Pereira

130: Foreign Direct Investment, Income Inequality and Poverty in Portugal, 1973-2014: What does cointegration analysis tell us?
Aurora Teixeira | Ana Sofia Loureiro

131: On the Spillover Effects of CO2 Taxation on the Emissions of other Air Pollutants
Alfredo Marvão Pereira | Rui Marvão Pereira

132: On the Macroeconomic and Distributional Effects of the Regulated Closure of Coal-Operated Power Plants Alfredo Marvão Pereira | Rui Manuel Pereira

133: The China Shock and Employment in Portuguese Firms
Lee Branstetter | Brian Kovak | Jacqueline Mauro | Ana Venâncio

134: Energy Taxation Reform with an Environmental Focus
Alfredo Marvão Pereira | Rui Manuel Pereira

135: ARFIMA Reference Forecasts for Worldwide CO2 Emissions and the Need for Large and Frontloaded Decarbonization Policies
José M. Belbute | Alfredo M. Pereira

136: Exporter Firms Behaviour, Evidence From Portuguese Firms Using Microdata
Luís Pedro Manso Machado

137: Collateral Value and Entrepreneurship: Evidence from a Property Tax Reform
Miguel Ferreira | João Pereira dos Santos | Ana Venâncio

138: The Financial Channels of Labor Rigidities: Evidence from Portugal
Edoardo M. Acabbi | Ettore Panetti | Alessandro Sforza

139: Can a small leak sink a great ship? A comprehensive analysis of the Portuguese household savings
Tiago Domingues | Margarida Castro Rego

140: Corporate taxes and high-quality entrepreneurship: evidence from a tax reform
Ana Venâncio | Victor Barros | Clara Raposo

141: Built Like a House of Cards? - Corporate Indebtedness and Productivity Growth in the Portuguese Construction Sector1
José Santos | Nuno Tavares | Gabriel Osório de Barros

142: Effectiveness of Simplex: The Case of Portuguese Social Security
António Alberto Nifrário de Pinho Tavares

143: Digital innovation in higher education: A questionnaire to Portuguese universities and polytechnic institutes
Paulo Nuno Vicente |Margarida Lucas | Vânia Carlos

144: Portugal in the Global Innovation Index: A panel data analysis
Marcelo P. Duarte | Fernando M. P. O. Carvalho

145: Intangible investments and productivity performance
Michele Cincera | Julie Delanote | Pierre Mohnen | Anabela Santos | Christoph Weiss

146: Digitalization in Two-sided Platform Competition
Filomena Garcia | Muxin Li

147: Collusion between two-sided platforms
Joana Pinho | Yassine Lefouili

148: Da confluência entre Big Data e Direito da Concorrência: As concentrações digitais - O caso Facebook/WhatsApp
Ana Rodrigues Bidarra

149: The Determinants of Total Factor Productivity in the Portuguese Quaternary Sector
Paulo Matos | Pedro Neves

150: Os modelos Input-Output, a estrutura setorial das economias e o impacto da crise da COVID 19
Pedro N. Ramos | João Ferreira | Luís Cruz | Eduardo Barata

151: Public Expenditure and private firm performance: using religious denominations for causal inference
Henrique Alpalhão | Marta Lopes | João Santos| José Tavares

152: Employee Training and Firm Performance: Quasi-experimental evidence from the European Social Fund
Pedro S. Martins

153: Dream Jobs
Luca David Opromolla | Giordano Mion | Gianmarco I.P. Ottaviano

154: Minimum wage and financially distressed firms: another one bites the dust
F. Alexandre | P. Bação | J. Cerejeira | H. Costa | M. Portela

155: Do short-term rentals increase housing prices? Quasi-experimental evidence from Lisbon
Susana Peralta | João Pereira dos Santos | Duarte Gonçalves

156: Economic and social policies under EMU
Ricardo Pinheiro Alves

157: International Sourcing in Portuguese Companies - Evidence from Portuguese Micro Data
Ana Martins | Guida Nogueira | Eva Pereira

158: The Impact of R&D tax incentives in Portugal
Rita Bessone Basto | Ana Martins | Guida Nogueira

159: The Determinants of Competitiveness of the Portuguese Defense Industry
Roxanne Merenda

160: How is the minimum waste shaping the wage distribution; bite, spillovers, and wage inequality
Carlos Oliveira

161: Macroeconomy Impacts of the Covid-19 Pandemic in Some European Union Countries: a Counterfactual Analysis
António Portugal Duarte | Fátima Sol Murta

162: Digital adoption and productivity: understanding micro drivers of the aggregate effect
Natália Barbosa | Ana Paula Faria

163: Job Creation and Destruction in the Digital Age: What about Portugal?
Anabela M. Santos | Javier Barbero Jimenez | Simone Salotti | Andrea Conte

REPÚBLICA PORTUGUESA
ECONOMIA E MAR

Gabinete de Estratégia e Estudos