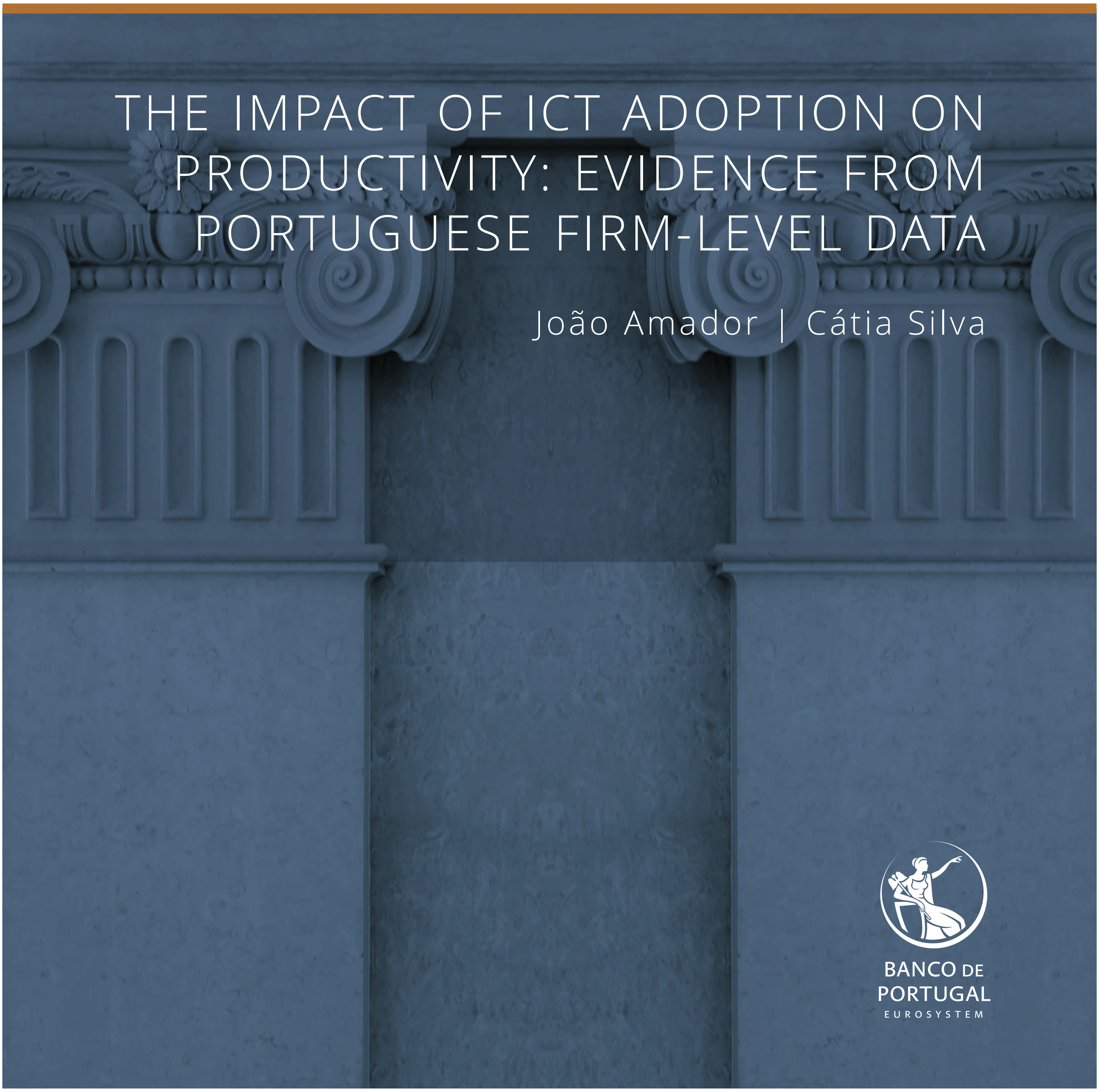
07
WORKING
PAPERS 2023



THE IMPACT OF ICT ADOPTION ON PRODUCTIVITY: EVIDENCE FROM PORTUGUESE FIRM-LEVEL DATA

João Amador | Cátia Silva

BANCO DE PORTUGAL
EUROSYSTEM

07
WORKING
PAPERS 2023

THE IMPACT OF ICT ADOPTION ON PRODUCTIVITY: EVIDENCE FROM PORTUGUESE FIRM-LEVEL DATA

João Amador | Cátia Silva

APRIL 2023
The analyses, opinions and findings of these papers represent the views of the authors, they are not necessarily those of the Banco de Portugal or the Eurosystem.

Please address correspondence to
Banco de Portugal
Rua do Comércio 148, 1100-150 Lisboa, Portugal
Tel.: +351 213 130 000, email: info@bportugal.pt

BANCO DE PORTUGAL
EUROSYSTEM

Lisboa, 2023 • www.bportugal.pt

Working Papers | Lisboa 2023 • Banco de Portugal Rua do Comércio 148 | 1100-150 Lisboa • www.bportugal.pt •
Edition Banco de Portugal • ISBN (online) 978-989-678-864-3 • ISSN (online) 2182-0422

The impact of ICT adoption on productivity: Evidence from Portuguese firm-level data

João Amador
Banco de Portugal
Nova SBE

Cátia Silva
Oxford Economics

April 2023

Abstract
In this paper we study the impact of ICT adoption on the level of labour productivity and TFP of Portuguese firms in the period 2004-2018. For this purpose we combine firm-level annual survey data for different dimensions of ICT adoption and balance sheet variables that allow for the computation of productivity and control for several dimensions of heterogeneity. The paper uses a Bartik (1991) shift-share type instrumental variable and results state that there is a positive and sizeable impact from ICT adoption on TFP and labour productivity. One standard deviation increase in the first principal component that captures overall ICT adoption by the firm leads to an increase of 25 percent in TFP and an increase of 58 percent in labour productivity. When the analysis is made separately, online sales and the creation of a website stand out as the most relevant dimensions for productivity gains.

JEL: O3, O4, J24

Keywords: ICT, digitalization, productivity, Portugal, firm-level data, instrumental variables.

Acknowledgements: The opinions expressed in this paper are those of the authors and do not necessarily coincide with those of Banco de Portugal or the Eurosystem. Authors thank participants in the CAED 2021 Conference in Coimbra and Ana Catarina Pimenta for very useful comments and suggestions. Any remaining errors and omissions are the sole responsibility of the authors. Address: Banco de Portugal, Economics and Research Department, R. Francisco Ribeiro 2, 1150-165 Lisboa, Portugal.

E-mail: jamador@bportugal.pt; csilva@oxfordeconomics.com

1. Introduction

Technological progress has always been one of the strongest forces shaping the world economy, driving productivity and economic growth in the long run. The economic growth literature has been studying the link between the adoption of new technologies by firms and its impact on productivity for a long time. Recent decades witnessed intense technological progress. The ICT revolution, which gained traction in the 80s, made it possible for firms to compute and communicate at a much lower cost, also impacting on their access to information both in the internal market and across borders. More recently, and closely related to ICT, which is often seen as a general purpose technology, the digitalization process, which involves the utilization of robots, 3D printing, big data and cloud computing in the production process, has been expanding.

The quantification of impacts from ICT adoption took time to emerge in the literature. In a 1987 famous quote Nobel Laureate Robert Solow said "we could see computers everywhere but in the productivity statistics", initiating the so-called the "Solow paradox". Since then, there has been significant progress in the analysis of ICT and productivity. Initial contributions focused on incorporating these technologies in growth models and growth accounting exercises. An important contribution is that of Draca *et al.* (2009), which not only includes a survey of the micro and macro literature on the topic, but also finds an important role for ICT on productivity, coming both from growth accounting and econometric evidence. A more recent survey is that of Cardona *et al.* (2013), which states that more theoretical and empirical research is needed, notably for Europe.

The empirical branch of the literature splits into growth accounting exercises, case-studies, sectoral analysis, often with multiple countries, and firm-level studies based on panel data. Some papers advance explanations for the impact of ICT on productivity, including the popular notion of complementary organizational capital, while others focus on the quantification of its impacts.

One recent important contribution is Gal *et al.* (2019), which combines cross-country firm-level data on productivity and industry-level data on digital technologies to assess how their adoption associates with firms' performance, while accounting for heterogeneity. Although not trying to establish a causal relationship, the results state that digital adoption in an industry is associated to productivity gains at the firm level and effects are stronger in manufacturing and routine-intensive activities and for more productive firms. In this context, authors argue that, digital technologies may have contributed to the growing dispersion in productivity performance across firms, which couples with the broader discussion on the causes for the productivity slowdown (Syverson (2017)).

Assessing the impact of ICT on productivity is quite important. Indeed, there are still firms whose access to ICT is not complete, thus further productivity gains may be expected, not to mention that ICT is a prerequisite for digitalization. In addition, public policies have set digitalization as an investment priority. This trend is visible around the world, notably in the European Union (EU), where digitalization was put forward as a priority by the European Commission and it stands as one pillar of the Next Generation EU funds, put in place in the context of the recovery from the COVID-19 pandemic crisis.

It is acknowledged that the literature on the causal impacts of ICT adoption and digitalization on the performance of firms is still very limited (Draca *et al.* (2009)). There is scarce suitable firm-level data as this type of study requires information on the timing of adoption of technologies, as well as knowledge about several other firms' characteristics along the time. Contrarily to closely related topics, as for example the impact of introducing computers in schools, tailored natural experiments are non-existent, thus existing papers use other panel data methods to move beyond correlations and try to establish causal relationships between ICT and firms' performance, defined in terms of productivity or engagement in foreign markets. One of such papers is Abramovsky and Griffith (2006), which considers the impact ICT on firms' decisions for the location of activity and whether to produce in-house or outsource and offshore services. The paper takes an instrumental variables approach and explores within industry firm-level variation, using UK census data at the establishment level. Another recent contribution is that of Gilbert *et al.* (2020) that assesses the impact of ICT and digitalization on productivity and labour share for a sample of French manufacturing firms.

Our paper follows closely the work by Gilbert *et al.* (2020). In a similar way, we take an instrumental variables approach based in the spirit of Bartik (1991), thus constructing a leave-one-out mean in the sector, which allows for causal inference. As in Gilbert *et al.* (2020), we use survey data on technological adoption by firms, though only for ICT dimensions. Our survey is annual and more limited as digitalization dimensions are questioned only in the latest years. Although we have access to a large number of variables that characterize the firm, in this paper we consider only labour productivity and TFP as outcome variables.

We conclude that there is a positive and robust relationship between the adoption of ICT technologies and firms' performance in terms of labour productivity and total factor productivity (TFP). One standard deviation increase in the proxy that captures overall ICT adoption by the firm leads to an increase of 25 percent in TFP and an increase of 58 percent in labour productivity. When we analyse ICT dimensions separately, the creation of a website and online sales stand out as the most relevant dimensions for productivity gains.

The paper is organized as follows. Section 2 describes the data and is divided in three subsections. The first subsection describes the databases that were merged for the analysis. The second subsection contains basic descriptive statistics and the third presents the principal components procedure used to proxy the adoption of ICT technologies at the firm level. Section 4 presents the results of instrumental variable regressions using labour productivity and TFP as outcome variables and the principal component as regressor. In addition, we run regressions for each separate ICT dimension. Section 5 presents some concluding remarks.

2. Data

In this section we describe the data used, pointing out the basic sources of information and their content. In addition, we document the firm-level heterogeneity in terms of ICT adoption in the industry and size dimensions. Moreover, we describe and present the results of the principal components analysis that was used to obtain a metric of overall ICT adoption by each firm in our sample.

2.1. Database

Our paper combines two rich Portuguese firm-level databases. The first set of data corresponds to answers given by firms to a survey designated "*Inquérito à Utilizaçao das Tecnologias de Informação e Comunicação nas Empresas*" (IUTICE), conducted by the Portuguese national institute of statistics (Statistics Portugal). This statistical operation is carried out annually within the framework of EU legislation (EC regulation No. 808/2004), which establishes a set of harmonization guidelines, thus ensuring the availability of comparable statistical results across member states. The survey was initiated in 2003 and we use information up until 2018. The set of firms surveyed partially changes and its total number has changed along the years, with a notable increase after 2010. The set of questions posed to firms has changed along the different vintages of the survey. These questions range from availability of computer at the firm, internet connection, website, electronic payments, electronic invoicing, ICT staff and ICT training. In its latest editions, the survey contains questions regarding some dimensions of digitalization such as the existence of robots, 3D printing or the utilization of big data and cloud computing.

Although changes in the survey are important, there is a subset of questions that have remained unaltered. In order to maximize the number of observations we focus on those questions. Contrarily to Gilbert *et al.* (2020), which asks directly firms about the length of ICT adoption and observes its performance in one moment, we identify the existence of ICT in each year, side by side with productivity. Therefore, we are unable to identify the length of ICT adoption. For example, some firms' entering the sample do not report the existence of a given ICT dimension, but this does not mean that these firms did not have these technologies in place before. The option of restricting the sample to firms that adopt technologies only after being surveyed and stay in the sample afterwards strongly reduces the number of observations. Therefore, we take the strategy of identifying ICT existence and not its time length in the firm. Although, it is reasonable to accept that the impact of ICT accumulates with time, its main impact should accrue to its existence in the firm at a given moment. Overall, we have an unbalanced panel containing 33,539 different firms and an overall number of 65,809 observations.

The second database is the "*Sistema de contas integradas das empresas*", also compiled by Statistics Portugal. This database builds on mandatory legal reporting by Portuguese firms to Statistics Portugal, tax administration, Banco de Portugal and Ministry of Justice. In this dataset we have a large number of balance sheet and income statement variables, which allow us to control for firm heterogeneity and to compute the labour productivity (GVA per worker) and TFP.

TFP plays a critical role on economic growth and explaining cross-country per capita income differences. The seminal work by Solow (1956) first defined TFP as the portion of the output not explained by the amounts of labor and capital (total fixed assets) used in production. In our paper, firm-level TFP is obtained using the method developed by Levinsohn and Petrin (2003). An important issue in the estimation of the TFP is the correlation between unobservable productivity shocks and input levels, which leads to biased estimates. In order to account for these unobservable shocks, the Levinsohn and Petrin (2003) method uses a proxy variable in the estimation process. Although Wooldridge (2009) and Ackerberg *et al.* (2006) have later provided improvements to this method and to its estimation, the fundamentals remained unchanged. The procedure was implemented using the STATA command "prodest", which estimates the production functions using a control function approach. By default, the command requires the log gross output variable – in our case, the log of the GVA, at market prices - a set of free variables - typically the log of labor - a set of state variables – the log capital - and lastly, a set of proxy variables – which, in our case was the cost of goods sold. In our paper the capital stock corresponds to total fixed assets of the firm, as reported in the balance sheet.

2.2. Descriptive statistics

In this subsection we present a set of basic descriptive statistics that illustrate the heterogeneity of ICT adoption across Portuguese firms, along the industry, size and age dimensions. This provides relevant background information regarding our sample.

Table 1 presents the share of firms with each specific ICT technology (PC, website, internet, ICT staff, online purchases and online sales) in each of the 17 sectors in 2010 and 2018. As it would be expected, there is a very large share of firms with PC and internet access in the overall sample, which has increased from 2010 to 2018 to close to 100 percent. Nevertheless, the fact that our sample of firms is not uniform along time disturbs the analysis in those sectors where the number of firms is small (e.g. agriculture, extractive industry, education, health and arts). Even so, it is possible to identify a higher prevalence of PC and internet access in manufacturing, information and communication services, consulting and scientific activities, as well as administrative and support services. The existence of website and especially ICT devoted staff are less pervasive in firms, with overall shares of 65 and 31 percent in 2018. These shares decreased from 2010 to 2018 but we attribute the result to changes in the sample and to the possibility that firms may have outsourced some of these services. The shares of firms with online purchases and online sales are even lower, which is helpful in terms of adding variation to the sample. At the sectoral level, the existence of website, ICT staff and online purchases is more common in the information and communication services.

SECTOR	Nb. firms 2010	Nb. firms 2018	PC 2010	PC 2018	Internet 2010	Internet 2018	Website 2010	Website 2018	ICT staff 2010	ICT staff 2018	Online purchases 2010	Online purchases 2018	Online sales 2010	Online sales 2018
Agriculture	2	3	100	67	100	33	0	33	0	33	50	33	50	.
Extractive	54	.	89	.	78	.	39	.	17	.	22	.	13	.
Manufacturing	1025	1693	95	97	93	96	70	63	48	33	33	33	31	9
Electricity & gas	29	47	79	85	69	83	55	55	28	30	21	30	.	15
Water	49	101	100	100	98	100	80	86	45	35	29	40	10	16
Construction	285	279	86	91	83	90	55	47	35	21	23	23	9	5
Wholesale & retail	1035	1269	92	98	88	97	64	64	39	32	43	39	31	22
Transport	188	285	86	87	85	85	69	54	45	28	32	28	20	20
Accommodation	318	850	69	86	60	74	44	37	19	11	21	17	18	16
Information & com.	276	436	98	98	97	98	87	83	65	63	51	53	29	21
Real estate	455	301	76	91	73	88	44	47	13	7	13	21	8	11
Consult. & science	274	238	98	99	97	99	51	61	36	34	30	39	13	13
Administrative act.	322	384	97	99	96	98	80	74	35	27	37	38	29	21
Education	3	.	100	.	100	.	100	.	33	.	33	.	.	.
Health & social	1	.	100	.	100	.	100	.	100	.	.	.	.	.
Arts & sports	.	2	.	100	.	100	.	50	.	0	.	50	.	50
Other services	39	76	97	97	95	97	69	72	72	72	74	72	74	21
Total	4355	5964	90	95	96	97	73	65	43	31	33	33	24	15

Table 1. Share of firms with each specific ICT technology, by sector

The top panel of table 2 presents the share of firms that have adopted each ICT technology according to its size category (micro, small, medium and large), in 2010 and 2018. The result that stands out is the fact that the pervasiveness of all ICT technologies increases monotonically with the size of the firms. Indeed, in 2018 the share of ICT staff in large firms is seven times larger than in micro firms and more than four times larger than that of small firms. As for online purchases and online sales the share of large firms adopting these technologies is three time larger than in micro firms and twice larger than in small firms. The bottom panel of table 2 replicates the previous analysis but taking into consideration firms' age classes (1-5 years, 6-10, 11-20 and more than 20 years). Although size and age are correlated, results do not show a gap between young and old firms as wide as the one between micro and large firms. For example, in 2010 almost a quarter of firms between 1 and 5 years of age reported ICT staff, while the share for firms above 20 years was slightly above 50 percent. This more muted pattern is also observed when we analyse the share of firms with online purchases and online sales by age class.

	Nb. firms		PC		Internet		Website		ICT staff		Online purchases		Online sales	
	2010	2018	2010	2018	2010	2018	2010	2018	2010	2018	2010	2018	2010	2018
SIZE														
Micro	1546	2683	74	90	67	84	31	36	1	10	2	21	1	9
Small	802	1281	97	98	94	97	62	61	3	18	3	29	2	15
Medium	1184	1088	99	100	99	100	84	89	6	54	4	45	3	22
Large	823	912	100	100	100	100	95	96	7	78	5	61	4	27
AGE														
1-5 years	431	2	88	50	92	100	60	100	24	.	26	.	15	.
6-10 years	813	847	85	95	94	96	65	51	32	19	26	28	17	14
11-20 years	1363	2029	90	95	97	97	70	62	39	27	33	32	23	14
>20 years	1748	3086	93	95	98	97	81	71	54	37	38	36	30	17

Table 2. Share of firms with each specific ICT technology, by size and age

2.3. *The principal components analysis*

The existence of multiple dimensions underlying the adoption of ICT technologies and the fact that firms adopt them at different times and in diverse combinations makes it useful to find a proxy that summarizes firm's ICT reality. The principal component analysis (PCA) is a well established method for reducing the dimensionality of datasets, thereby increasing interpretability, while minimizing information loss. The method solves an eigenvalue/eigenvector problem to create new uncorrelated variables (the principal components) that successively maximize variance. The PCA is defined as an adaptive data analysis technique because variables are defined by the dataset at hand and not a priori.

As previously mentioned, there are six ICT variables considered in the PCA: existence of PC; access to internet; website; ICT staff at work; online purchases; and online sales. Table 3 presents the six eigenvalues and the proportion of each principal component in explaining variability in the data. The first principal component is clearly the most important one, explaining 44 per cent of overall variability in the data. Therefore, it is reasonable to take it as our proxy for the adoption of ICT at the firm level. The standard deviation of the first principal component is 1.678.

COMPONENT	Eigenvalue	Proportion	Cumulative
pc1	2.61	0.44	0.44
pc2	1.22	0.20	0.64
pc3	0.79	0.13	0.77
pc4	0.68	0.11	0.88
pc5	0.54	0.09	0.97
pc6	0.15	0.03	1.00

Table 3. Principal components - eigenvalues

Table 4 presents how much of each ICT dimension is explained by each of the six principal components. The first principal component is not the main contributor to explain variability in all ICT dimensions but it ranks as dominant overall. Values in table 5 are the correlations between each ICT dimension and each of the principal components. Since most of these correlations are positive and statistically significant, firms seem to identify benefits from jointly using different ICT technologies.

VARIABLES	pc1	pc2	pc3	pc4	pc5	pc6	Unexplained
PC	0.47	-0.50	0.11	-0.04	0.20	0.69	0
Internet	0.50	-0.46	0.09	-0.03	0.10	-0.72	0
Website	0.45	0.15	-0.13	0.24	-0.83	0.08	0
ICT staff	0.35	0.34	-0.67	0.32	0.46	0.00	0
Online purchases	0.34	0.42	0.01	-0.84	0.03	0.01	0
Online sales	0.27	0.49	0.71	0.37	0.23	-0.01	0

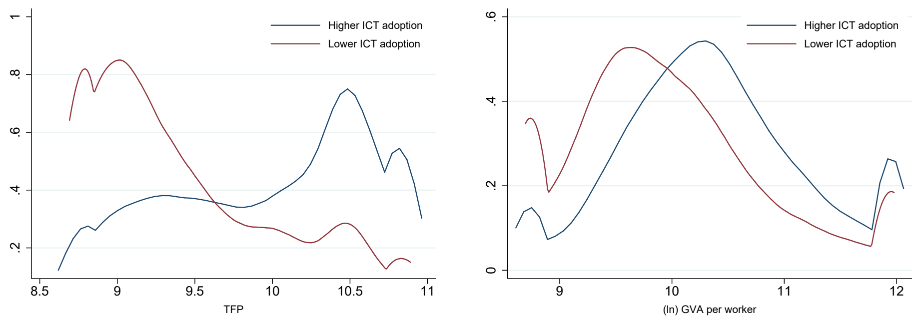
Table 4. Principal components - share on each ICT dimension

VARIABLES	pc1	pc2	PC	Internet	Website	ICT staff	Online Purchases	Online Sales
pc1	1.00							
pc2	0.00	1.00						
PC	0.75	-0.56	1.00					
Internet	0.79	-0.51	0.84	1.00				
Website	0.73	0.17	0.37	0.44	1.00			
ICT staff	0.56	0.37	0.21	0.24	0.40	1.00		
Online purchases	0.55	0.46	0.20	0.23	0.34	0.31	1.00	
Online sales	0.44	0.53	0.13	0.15	0.30	0.20	0.29	1.00

Table 5. Correlation coefficients between principal components and ICT dimensions

3. Empirical strategy

As a preliminary test, we compare the TFP and the labour productivity levels for two segments of the first principal component distribution, corresponding to high and low ICT adopters. More specifically, panel a) of figure 1 plots the distribution of TFP levels (in logs) for firms above and below the median of the first principal component, taken as a proxy for ICT adoption at the firm level. This very simple representation conveys the message that firms above the median in terms of ICT adoption perform clearly better than those below the median. Panel b) replicates the analysis for the labour productivity. In this case the performance advantage of those above the median of ICT adoption is also visible, though not as strong as in the case of the TFP. This early simple evidence, not taking into account confounding



(a) TFP

(b) Labour productivity

Figure 1: ICT adoption and productivity

factors and firms' characteristics, puts us on track to test this relationship taking into account heterogeneity and trying to establish causality.

The identification strategy used to establish the relationship between ICT adoption and firm's productivity levels is based on an instrumental variable approach. We follow Gilbert *et al.* (2020), which uses a Bartik (1991) type instrumental variable for the exact same purpose we do. The Bartik (1991) shift-share instrumental variables became widespread after the work by Blanchard and Katz (1992) that studies the impact of national sectoral employment on US state-level labour markets.

Econometric theory requires an instrumental variable to be both relevant and exogenous. Relevance is associated with the ability to explain the variation in the variable that stands as the regressor of interest. The relevance (strength) of the instrument can be captured by the value of the F-statistic in the first stage regression (Stock and Yogo (2002)). The Staiger and Stock (1997) rule of thumb for the cut off in this statistic is 10, which we also take as a benchmark. As for the exogeneity of the instrument, it is much harder to assess as it implies that it correlates with the dependent variable only through the endogenous one. The validity of the shift-share instrumental variables requires the assumption of the exogeneity of at least one of its components: exogenous shocks or exogenous exposure to share weights. We argue that the latter is likely to be our case in a context where industry fixed effects are included in the specification. Although it is quite possible that unspecified events taking place at the industry level are common to the firm, as for example due to spillover or network effects, the inclusion of industry fixed effects takes account of this problem. Therefore, the only way for the leave-one out instrument to affect productivity is through the individual adoption of ICT, thus turning the instrument valid.

For the purpose of your exercise, the leave-one-out mean in the sector is simply the average of the value of the indicator for all firms in the specific sector except the one being considered, that is:

$$ICT_{it} = \frac{\sum_{\substack{nt \neq it \\ \forall nt \in j}} ICT_{nt}}{N_{jt} - 1} \quad (1)$$

where ICT_{it} is the variable for technology adoption by firm i in year t and N_{jt} is the total number of firms in sector j, to which i also belongs to, in period t.

Equation 1 defines the instrumental variable to be used in the second step of the regression. As explained, since the sector fixed effects capture all other sectoral specificities, we are confident that equation 2 can be consistently estimated.

$$Prod_{it} = \alpha + \beta_1 ICT_{it} + \beta_2 X_{it} + \delta_d + \delta_a + \delta_s + \delta_t + \varepsilon_{it}, \quad (2)$$

where the dependent variable $Prod_{it}$ corresponds either to the logarithm of labour productivity or TFP of firm i in a given year t. The variable for technology adoption by the firm is given by the ICT_{it} and the corresponding β_1 is our parameter of interest. The vector X_{it} includes firm-level financial characteristics such as the leverage ratio and EBITDA. δ_d, δ_a, δ_s and δ_t correspond to size, age category, sector (industry) and time fixed effects. ε_{ijt} is the error term. We use clustered standard errors at the firm level.

4. Results

In this section we present the results of our empirical exercise. We begin with productivity impacts associated to the firm-level proxy for ICT adoption that corresponds to the predicted value of the first principal component, as explained in subsection 2.3. Next, we present results for specific ICT technologies.

4.1. Impact on TFP and labour productivity

Table 6 presents the results of the second stage of our IV regression. Given the empirical strategy previously described, the coefficient for the variable of interest (pc 1) measures the impact on a unitary increase in the first principal components on the performance of the firms, being the outcome variable either the log of TFP or the log of labour productivity. Although the methodology to infer causality is the same as in Gilbert *et al.* (2020), since our data has a different nature, we include additional fixed effects. Beyond, industry fixed effects (17 industries), all regressions include time (years between 2004 and 2018), age and size fixed effects. The variable age classifies firms along four categories (1-5 years; 6-10 years; 11-20 years and more than 20 years) and the size variable classifies firms along four dimensions (micro, small, medium and large firms), in accordance with the definition used by the European Commission, which combines turnover and number of employees.

Specifications in columns 1 to 3 of 6 refer to TFP. Results suggest that the overall adoption of ICT by the firm has a sizeable and significant positive impact on

VARIABLES	(1)	IV-HDFE TFP (2)	(3)	(4)	IV-HDFE LABOUR PROD (5)	(6)
pc 1	0,152***	0,126***	0,125***	0,346***	0,478***	0,421***
	(0,020)	(0,030)	(0,030)	(0,039)	(0,083)	(0,085)
Leverage ratio		1,460***	1,452***		1,851*	1,518
		(0,449)	(0,452)		(0,982)	(1,009)
EBITDA			0,007			0,314**
			(0,018)			(0,152)
F	54,359	15,303	10,783	77,705	19,458	17,166
N	57 128	46 313	46 313	57 128	46 31	46 313
Size FE	YES	YES	YES	YES	YES	YES
Age FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6. Impact of ICT adoption on TFP and labour productivity - IV-HDFE regression

Notes: The standard deviation of first principal component that captures overall ICT adoption by the firm is 1.678.

TFP. All else constant and taking into account the fixed effects implemented, one standard deviation increase in the first principal component that captures overall ICT adoption by the firm leads to an increase of 25 percent in TFP. If further firm-level controls are added, results are maintained. In column 2 we add the leverage ratio, defined as total debt as a percentage of assets, and in column 3 we further add a profitability measure: the EBITDA as a percentage of assets. In both specifications our coefficient of interest slightly decreases its magnitude but remains strongly significant. The coefficient for the indebtedness measure is significant but the profitability one is not.

Specifications in columns 4 to 6 replicate the analysis using the log of labour productivity as the variable that defines firms' performance. Conclusions stay qualitatively unaltered. One standard deviation increase in the first principal component generates a 58 percent rise in labour productivity in the firm. When indebtedness and profitability controls are added, we observe that the magnitude of the coefficient increases.

4.2. Impact by ICT dimension

In order to further understand the impact of ICT adoption on firms' performance we run high dimensional fixed effect regressions with the leave-one-out IV strategy described before, but based on each individual ICT dimensions separately. Tables 7 and 8 present these results for TFP and labour productivity.

Coefficients that capture the impact of having each individual ICT component at the firm on TFP can be found on table 7. All estimated coefficients have the expected positive sign: the use of each of the six technologies improves productivity. Engaging in e-commerce activities and having a website substantially improves productivity. The remaining ICT dimensions also improve productivity, but to a smaller extant. We also observe that coefficients associated with having computers display a smaller degree. This is not a surprising result because many firms in the sample have a PC, meaning that the explanatory impact of such ICT dimension on productivity should be smaller.

VARIABLES	IV-HDFE PC (1)	IV-HDFE Website (2)	IV-HDFE Internet (3)	IV-HDFE ICT staff (4)	IV-HDFE Online purchases (5)	IV-HDFE Online sales (6)
PC	0,416***					
	(0,091)					
Website		0,614***				
		(0,116)				
Internet			0,453***			
			(0,105)			
ICT staff				0,438***		
				(0,071)		
Online purchases					1,952***	
					(0,601)	
Online sales						0,645***
						(0,109)
F	20,847	18,501	27,955	37,857	10,557	35,271
N	57 128	57 128	57 128	57 128	57 128	57 128
Size FE	YES	YES	YES	YES	YES	YES
Age FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7. Impact of individual ICT dimensions on TFP

Table 8 replicates the previous analysis for the labour productivity and results regarding the relative importance of each individual ICT dimension are quite consistent. However, with this alternative performance variable, estimated coefficients have a larger magnitude.

VARIABLES	IV-HDFE PC (1)	IV-HDFE Website (2)	IV-HDFE Internet (3)	IV-HDFE ICT staff (4)	IV-HDFE Online purchases (5)	IV-HDFE Online sales (6)
PC	1,945***					
	(0,266)					
Website		2,010***				
		(0,254)				
Internet			1,945***			
			(0,281)			
ICT staff				0,609***		
				(0,188)		
Online purchases					4,707***	
					(1,381)	
Online sales						1,018***
						(0,256)
F	20,847	18,501	27,955	37,857	10,557	35,271
N	57 128	57 128	57 128	57 128	57 128	57 128
Size FE	YES	YES	YES	YES	YES	YES
Age FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8. Impact of individual ICT dimensions on labour productivity

5. Concluding remarks

The wider adoption of ICT by firms, alongside with the diffusion of digitalization technologies, will certainly accelerate in the next years. This process will bring important changes in the way firms operate and will impact productivity. Current public policies are also actively engaged in promoting this transformation.

In this paper we make use of firm-level data and try to infer the impact of ICT adoption on TFP and labour productivity. We take both a composite measure of ICT adoption and analyse several ICT dimensions separately. A wide set of fixed effects is included and also some firm-level controls, notably for indebtedness and profitability.

Results obtained confirm those from previous research, pointing towards sizeable and significant productivity gains for firms due to the adoption of ICT technologies. One standard deviation increase in the first principal component that captures overall ICT adoption by the firm leads to an increase of 25 percent in TFP and an increase of 58 percent in labour productivity. When this analysis is separately made, e-commerce and the creation of a website stand out as relevant dimensions for productivity gains.

Investigation about the impacts of ICT adoption on firms will surely build up in the next years. Given the myriad of variables that condition productivity at the firm level, the main challenge is to setup exercises that try to capture causality. Further availability of data, ideally comparable across countries, will allow for robust conclusions. Data for other digitalization dimensions such as robots, 3D printing, big data and cloud computing is still limited to a small number of years. Moreover, further consequences of ICT adoption at the firm level are worthwhile exploring. One natural topic of research relates to the impact on employment, wages and skills. Another important dimension concerns the impact of ICT on innovation. Finally, it is also very interesting to know how ICT adoption impacts the participation of firms in external markets and their sourcing decisions, also in connection with the incorporation of services in their export portfolio.

References

Abramovsky, Laura and Rachel Griffith (2006). "Outsourcing and Offshoring of Business Services: How Important is ICT?" *Journal of the European Economic Association*, 4(2-3), 594–601.

Ackerberg, Daniel, Kevin Caves, and Garth Frazer (2006). "Structural identification of production functions." MPRA Paper 38349, University Library of Munich, Germany.

Bartik, Timothy J. (1991). *Who Benefits from State and Local Economic Development Policies?* No. wbsle in Books from Upjohn Press, W.E. Upjohn Institute for Employment Research.

Blanchard, Olivier and Lawrence Katz (1992). "Regional Evolutions." *Brookings Papers on Economic Activity*, 23(1), 1–76.

Cardona, M., T. Kretschmer, and T. Strobel (2013). "ICT and productivity: conclusions from the empirical literature." *Information Economics and Policy*, 25(3), 109–125. ICT and Innovation.

Draca, M, R Sadun, and J Van Reenen (2009). chap. Productivity and ICTs: A review of the evidence. Oxford university press.

Gal, Peter, Giuseppe Nicoletti, Theodore Renault, Stéphane Sorbe, and Christina Timiliotis (2019). "Digitalisation and productivity: In search of the holy grail, firm-level empirical evidence from EU countries." OECD Economics Department Working Papers 1533, OECD Publishing.

Gilbert, Cette, Nevoux Sandra, and Py Loriane (2020). "The Impact of ICTs and Digitalization on Productivity and Labor Share: Evidence from French firms." Working papers 785, Banque de France.

Levinsohn, James and Amil Petrin (2003). "Estimating Production Functions Using Inputs to Control for Unobservables." *Review of Economic Studies*, 70(2), 317–341.

Solow, Robert M. (1956). "A Contribution to the Theory of Economic Growth." *The Quarterly Journal of Economics*, 70(1), 65–94.

Staiger, Douglas and James H. Stock (1997). "Instrumental Variables Regression with Weak Instruments." *Econometrica*, 65(3), 557–586.

Stock, James H. and Motohiro Yogo (2002). "Testing for Weak Instruments in Linear IV Regression." NBER Technical Working Papers 0284, National Bureau of Economic Research, Inc.

Syverson, Chad (2017). "Challenges to Mismeasurement Explanations for the US Productivity Slowdown." *Journal of Economic Perspectives*, 31(2), 165–186.

Wooldridge, Jeffrey M. (2009). "On estimating firm-level production functions using proxy variables to control for unobservables." *Economics Letters*, 104(3), 112–114.

Working Papers

2021

1|21 Optimal Social Insurance: Insights from a Continuous-Time Stochastic Setup
João Amador | Pedro G. Rodrigues

2|21 Multivariate Fractional Integration Tests allowing for Conditional Heteroskedasticity withan Application to Return Volatility and Trading
Marina Balboa | Paulo M. M. Rodrigues | Antonio Rubia | A. M. Robert Taylor

3|21 The Role of Macroprudential Policy in Times of Trouble
Jagjit S. Chadha | Germana Corrado | Luisa Corrado | Ivan De Lorenzo Buratta

4|21 Extensions to IVX Methodsnof Inference for Return Predictability
Matei Demetrescu | Iliyan Georgiev | Paulo M. M. Rodrigues | A.M. Robert Taylor

5|21 Spectral decomposition of the information about latent variables in dynamic macroeconomic models
Nikolay Iskrev

6|21 Institutional Arrangements and Inflation Bias: A Dynamic Heterogeneous Panel Approach
Vasco Gabriel | Ioannis Lazopoulos | Diana Lima

7|21 Assessment of the effectiveness of the macroprudential measures implemented in the context of the Covid-19 pandemic
Lucas Avezum | Vítor Oliveiral | Diogo Serra

8|21 Risk shocks, due loans, and policy options: When less is more!
Paulo Júlio | José R. Maria | Sílvia Santos

9|21 Sovereign-Bank Diabolic Loop: The Government Procurement Channel!
Diana Bonfim | Miguel A. Ferreira | Francisco Queiró | Sujiao Zhao

10|21 Assessing the effectiveness of the Portuguese borrower-based measure in the Covid-19 context
Katja Neugebauer | Vítor Oliveira | Ângelo Ramos

11|21 Scrapping, Renewable Technology Adoption, and Growth
Bernardino Adão | Borghan Narajabad | Ted Temzelides

12|21 The Persistence of Wages
Anabela Carneiro | Pedro Portugal | Pedro Raposo | Paulo M.M. Rodrigues

13|21 Serial Entrepreneurs, the Macroeconomy and top income inequality
Sónia Félix | Sudipto Karmakar | Petr Sedláček

14|21 COVID-19, Lockdowns and International Trade: Evidence from Firm-Level Data
João Amador | Carlos Melo Gouveia | Ana Catarina Pimenta

15|21 The sensitivity of SME's investment and employment to the cost of debt financing
Diana Bonfim | Cláudia Custódio | Clara Raposo

16|21 The impact of a macroprudential borrower based measure on households' leverage and housing choices
Daniel Abreu | Sónia Félix | Vítor Oliveira | Fátima Silva

17|21 Permanent and temporary monetary policy shocks and the dynamics of exchange rates
Alexandre Carvalho | João Valle e Azevedo | Pedro Pires Ribeiro

18|21 On the Cleansing Effect of Recessions and Government Policy: Evidence from Covid-19
Nicholas Kozeniauskas | Pedro Moreira | Cezar Santos

19|21 Trade, Misallocation, and Capital Market Integration
Laszlo Tetenyi

20|21 Not All Shocks Are Created Equal: Assessing Heterogeneity in the Bank Lending Channel
Laura Blattner | Luísa Farinha | Gil Nogueira

21|21 Coworker Networks and the Labor Market Outcomes of Displaced Workers: Evidence from Portugal
Jose Garcia-Louzao | Marta Silva

22|21 Markups and Financial Shocks
Philipp Meinen | Ana Cristina Soares

2022

1|22 Business cycle clocks: Time to get circular
Nuno Lourenço | António Rua

2|22 The Augmented Bank Balance-Sheet Channel of Monetary Policy
Christian Bittner | Diana Bonfim | Florian Heider | Farzad Saidi | Glenn Schepens | Carla Soares

3|22 Optimal cooperative taxation in the global economy
V. V. Chari | Juan Pablo Nicolini | Pedro Teles

4|22 How Bad Can Financial Crises Be? A GDP Tail Risk Assessment for Portugal
Ivan De Lorenzo Buratta | Marina Feliciano | Duarte Maia

5|22 Comparing estimated structural models of different complexities: What do we learn?
Paulo Júlio | José R. Maria

6|22 Survival of the fittest: Tourism Exposure and Firm Survival
Filipe B. Caires | Hugo Reis | Paulo M. M. Rodrigues

7|22 Mind the Build-up: Quantifying Tail Risks for Credit Growth in Portugal
Ivan de Lorenzo Buratta | Marina Feliciano | Duarte Maia

8|22 Forgetting Approaches to Improve Forecasting
Robert Hill | Paulo M. M. Rodrigues

9|22 Determinants of Cost of Equity for listed euro area banks
Gabriel Zsurkis

10|22 Real effects of imperfect bank-firm matching
Luísa Farinha | Sotirios Kokas | Enrico Sette | Serafeim Tsoukas

11|22 The solvency and funding cost nexus – the role of market stigma for buffer usability
Helena Carvalho | Lucas Avezum | Fátima Silva

12|22 Stayin' alive? Government support measures in Portugal during the Covid-19 pandemic
Márcio Mateus | Katja Neugebauer

13|22 Cross-Sectional Error Dependence in Panel Quantile Regressions
Matei Demetrescu | Mehdi Hosseinkouchack | Paulo M. M. Rodrigues

14|22 Multinationals and services imports from havens: when policies stand in the way of tax planning
Joana Garcia

15|22 Identification and Estimation of Continuous-Time Job Search Models with Preference Shocks
Peter Arcidiacono | Attila Gyetvai | Arnaud Maurel | Ekaterina Jardim

16|22 Coworker Networks and the Role of Occupations in Job Finding
Attila Gyetvai | Maria Zhu

17|22 What's Driving the Decline in Entrepreneurship?
Nicholas Kozeniauskas

18|22 The Labor Share and the Monetary Transmission
André Silva | João Gama | Bernardino Adão

19|22 Human capital spillovers and returns to education
Pedro Portugal | Hugo Reis | Paulo Guimarães | Ana Rute Cardoso

20|22 Learning Through Repetition? A Dynamic Evaluation of Grade Retention in Portugal
Emilio Borghesan | Hugo Reis | Petra E. Todd

21|22 Retrieving the Returns to Experience, Tenure, and Job Mobility from Work Histories
John T. Addison | Pedro Portugal | Pedro Raposo

2023

1|23 A single monetary policy for heterogeneous labour markets: the case of the euro area
Sandra Gomes | Pascal Jacquinot | Matija Lozej

2|23 Price elasticity of demand and risk-bearing capacity in sovereign bond auctions
Rui Albuquerque | José Miguel Cardoso-Costa | José Afonso Faias

3|23 A macroprudential look into the risk-return framework of banks' profitability
Joana Passinhas | Ana Pereira

4|23 Mortgage Borrowing Caps: Leverage, Default, and Welfare
João G. Oliveira | Leonor Queiró;

5|23 Does Green Transition promote Green Innovation and Technological Acquisitions?
Udichibarna Bose | Wildmer Daniel Gregori | Maria Martinez Cillero

6|23 Tail Index Estimation in the Presence of Covariates: Stock returns' tail risk dynamics
João Nicolau | Paulo M.M. Rodrigues | Marian Z. Stoykov

7|23 The impact of ICT adoption on productivity: Evidence from Portuguese firm-level data
João Amador | Cátia Silva