Nuno Gonçalves
Univ Coimbra, Faculty of Economics
npocinhogoncalves@outlook.pt
Carlos Carreira
Univ Coimbra, CeBER, Faculty of Economics
ccarreir@fe.uc.pt
orcid.org/0000-0002-4786-5605

DOI: https://doi.org/10.14195/2183-203X_56_5

Intangible Capital and Productivity of Portuguese Firms in the Last Decade (2010-2019)

Capital Intangível e Produtividade das Empresas Portuguesas na Última Década (2010-2019)

Nuno Gonçalves
Carlos Carreira

Received for publication: April 15, 2023
Revision accepted for publication: June 25, 2023

ABSTRACT
This article analyzes the effects of intangible capital on the productivity of Portuguese firms in the last decade. Intangible assets can increase the productivity of labor and productive factors. Although no consensus has been reached on standard principles and uniform methods for measuring intangible assets, the attempts of various investigators, such as those proposed in this research, pave the way for the development of a framework. To achieve this objective, a Cobb-Douglas production function was estimated at the firm level, where intangible capital is assumed as a productive factor. To perform a sectoral analysis, the model was estimated by activity sector. We also estimated the evolution of the contribution of intangible capital in two distinct periods 2010-14 (recession) and 2015-19 (recovery). The results obtained were to some extent expected, confirming the evidence of the positive effect of intangible assets on productivity. The intangible effect is greater in the sectors of Manufacturing and Construction, and inside the Manufacturing sector, the Textile industry is where the effect is larger. For the Trade and Business Services sector the effect is negative or null. Although intangible capital has a strong influence at the aggregate level, it has gradually lost its relevance. This result is understandable, given the low and decreasing levels of intangible investment and the continuous decrease in intangible capital during the decade.
Keywords: intangible capital; intangible investment; productivity; Cobb-Douglas production function; Portugal.

JEL Classification: C33; D24; L60; L80; O34.

Acknowledgment: We would like to thank Inês Milheiras for her contribution to the literature review section as a scholarship of the "Summer with Science 2022" program, funded by the Foundation for Science and Technology (FCT). Funding for this work was provided by the FCT, R&D unit CeBER (UIDB/05037/2020).

1. Introduction

In today's economies, intangible assets play a central role in improving the competitiveness and growth of firms and, consequently, tangible assets are no longer as determinant as they once were. Thus, intangible investment became an essential prerequisite for technological progress (Yallwe and Buscemi, 2014).

By nature, an intangible asset is a non-physical asset, examples being licenses, designs, patents, copyrights, software, marketing, branding, organizational or human capital, as well as R&D. Measuring such assets, however, is a challenge, even today. Because there is a lack of physical substance, firms typically do not properly report intangible assets on their balance sheets, so that quantifying their impact on productivity is difficult or inaccurate. Intangible investments are financially constrained, especially R&D investment, seeing that the results are unpredictable and drawn out. The funding of projects is also accompanied by adverse selection, moral hazard, and information asymmetry, and due to their nature, such assets are rarely used as collateral (Silva and Carreira, 2012).

This study analyzes the importance of intangible assets, especially in relation to the way they may have affected the productivity of Portuguese firms in the last decade. This work is important for entrepreneurs to better understand the potential benefits of intangible assets for output growth and to identify differences between intangible assets and performance in different sectors.

2. Related Literature

The role as a principal driver of economic growth was assigned by Solow (1957) to productivity, along with capital and labor force accumulation. Later, neoclassical growth models tried to explain how productivity grows endogenously, including R&D investment and other intangibles as a main source (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992). The importance of intangible assets as a fundamental component for productivity growth is underlined in many macroeconomic studies (Corrado et al., 2009; Corrado et al., 2013; Corrado et al., 2016), as well as in many microeconomic studies (Marrocu et al., 2012; Niebel et al., 2017; Piekkola, 2018; Criscuolo et al., 2021).

Corrado et al. (2009) estimated the effect of intangible assets at the macro level and their importance for economic growth, finding that intangible investment nurtured labor productivity by 0.84 percentage points (p.p.) in the United States of America. In European countries the effect was smaller but still significant: in the UK by 0.58 p.p., in Germany by 0.53 p.p., in Italy by 0.34 p.p., and in Spain by 0.19 p.p. From the mid-1990s to the period of the 2008 financial crisis, the USA's stronger labor productivity growth over that of the European countries is explained by Europe's low levels of investment in intangible assets (Corrado et al., 2013). Despite the low levels of intangible investment in these countries, the elasticities of intangible investment productivity for 10 countries (Austria, Czech Republic, Denmark, Spain, Finland, France, Germany, Italy, Netherlands, and UK) were greater than their respective share factor (Niebel et al., 2017). The work of Niebel et al., (2017) in conjunction with the study conducted by Corrado et al. (2016)

pointed to the fact that the elasticities found at the aggregate level are greater than those found by sector and differ markedly between the manufacturing industries and service sectors. Naturally, there is a heterogeneous effect of intangibles across firms. On average, there is a gap of one-third in labor productivity between firms in the top 10% of more productive firms and those in the 40-60 percentile. This could be explained by the frontier firms' greater use of a highly skilled workforce that is more creative and innovative, while the remaining firms engage in more routine work and employ a less-qualified labor force (Criscuolo et al., 2021).

Marrocu et al., (2012) investigated the impact of intangible capital on the productivity level of firms in a 6-country European panel (France, Italy, Netherlands, Spain, Sweden, and the United Kingdom), between 2002 and 2006, relying on the companies' balance sheets. They estimated a Cobb-Douglas production function, finding a highly significant effect of intangible capital on productivity. The intangible capital effect on productivity is still less than the physical capital effect, roughly half of the latter; nevertheless, the impact intangible capital has on a firm's performance is still relevant. During the post-crisis period of 2008 to 2013, for EU-28, Piekkola (2018) did not find a strong effect of intangible capital on labor productivity at the sectoral level. More noteworthy was the conclusion that intangible capital negatively affected the labor productivity growth during the period.

Using the Community Innovation Survey database from 2006 to 2018, Roth et al., (2022) estimated a production function for German firms. For the first time, intangible investment equaled the tangible investment in Germany. The positive impact of intangibles on the firm-level productivity is mainly driven by non-R&D intangibles, such as software and databases, training, advertising, and marketing. The study highlighted the fact that the impact of non-R&D intangibles on firm-level productivity was stronger in the services sector than in that of production, but on other hand, R&D is a strong driver of productivity, specifically in high-tech industries. Also, using a panel of data for the German industry during the period between 2006-2010, Crass and Peters (2014) drew several conclusions about the relation between intangible assets and productivity. They found that R&D, Brand, and Human Capital had significant positive effects on productivity. The most interesting findings were: (i) short-run productivity is increased with training expenditure, which is stronger than an increase in R&D or marketing expenditure; (ii) however, a firm's stock of patents granted, and trademarks slightly increases long-run productivity; (iii) lastly, it was found that the patent stock and skilled labor force, like patent stock and marketing, are complements. Companies belonging to the high-tech industry exhibit a certain degree of complementarity between different types of intangible assets and stable knowledge accumulation, which has a greater effect on technical efficiency (Turovets, 2021).

A few studies were conducted on the Portuguese reality, specifically exploring the regional spillover effects (Carreira & Lopes, 2018). Nunes and Almeida (2009) allude to a quadratic relationship between intangible assets and growth in Portuguese SMEs. The level of intangible assets is only a catalyst factor for growth in Portuguese firms at high levels of intangible assets, being limited for low levels of intangible assets. Other studies point out that intangible assets, in conjunction with net income, goodwill and other intangible assets, are highly important to the value of stock prices. Intellectual property and R&D investment,

however, are not value-relevant factors for shareholders (Oliveira et al., 2010). The profitability of Portuguese SMEs neither increased nor diminished with an increased investment on intangible assets between 2001 and 2009 (de Carvalho et al., 2013).

3. Model Specification, Estimation Technique and Data

3.1. Model specification

We estimate the following Cobb-Douglas production function of firm i at time t:

$$Y_{i,t} = A_{i,t} M_{i,t}^{\alpha} K_{i,t}^{\beta} L_{i,t}^{\gamma} I_{i,t}^{\delta} \quad (1)$$

where $Y_{i,t}$ represents the gross output, $A_{i,t}$ denotes the total factor productivity (TFP), $M_{i,t}$ the inputs or intermediate consumptions, $K_{i,t}$ the physical capital, $L_{i,t}$ the labor and $I_{i,t}$ intangible capital. We do not impose any restriction on the elasticity parameters (i.e., we do not consider $\alpha + \beta + \gamma + \delta = 1$). When we log-normalize equation (1), we get the following equation:

$$Y_{i,t} = a_{i,t} + \alpha m_{i,y} + \beta k_{i,t} + \gamma l_{i,t} + \delta i_{i,t} \quad (2)$$

We consider the productivity term $a_{i,t}$ to be composed of a common factor z, and by an unobservable productivity term $p_{i,t}$ known by the company. We add a time dummy d_t designed to capture the macroeconomic effects, which vary over time but not across firms; productivity is composed of a vector of control variables $x_{i,t}$, and by an error term $\epsilon_{i,t}$. This gives us the following final equation:

$$y_{i,t} = z + p_{i,t} + d_t + \alpha m_{i,y} + \beta k_{i,t} + \gamma l_{i,t} + \delta i_{i,t} + \theta x_{i,t} + \epsilon_{i,t} \quad (3)$$

3.2. Estimation technique

The estimation of equation (3) is likely to suffer from endogeneity. The endogeneity problem arises from the fact that consumption demand functions are determined by the firm's knowledge of its own productivity level. When choosing inputs, firms try to identify the last impact of inputs on productivity, thus adjusting inputs for each new production. So, inputs will be correlated with productivity and hence the error term in the productivity equation. Another issue to consider when deciding which estimator to use is to consider that firms do not adjust their investment policy every year, which translates into several zeros in the investment. To circumvent this problem, Levinsohn and Petrin (hereafter LP) (2003) proposed a two-stage semi-parametric method, using intermediate consumptions as a proxy for productivity; it is less costly to adjust intermediate inputs to the productivity shocks than to redefine investment policy. This is the main approach used in many studies (Marrocu et al., 2014; Crass & Peters, 2014; Roth et al., 2022). Other methodologies, like that of

Olley & Pakes (1992), are commonly used, although Eberhardt and Helmers (2010) alert to the fact that these estimators are conceptually quite similar for estimating Cobb-Douglas production functions, but the choice of the estimation method might influence the empirical results. The STATA command *prodest* was used for LP estimations (Rovigatti & Mollisi, 2018).

3.3. Data

The database used in this study was prepared by the researchers of the ENtRY project (funded by FCT-Fundação para a Ciência e Tecnologia, PTDC/EGEECO/31117/2017), and was extracted from the Sistema de Contas Integradas das Empresas (SCIE), administered by the Instituto Nacional de Estatística (INE). The final sample consists of an unbalanced panel of 511 687 active companies operating in Portugal, taken from the manufacturing and service industries, excluding public services, the financial sector, and social services, for the period 2010-2019. The *tobacco industry*, *manufacturing of petroleum products*, *pharmaceuticals*, and *other transport equipment*, as well as *air transport* and *water collection, treatment and distribution* were later excluded, due to the small number of observations in these categories of economic activity.

Gross output is measured as the value of sales of goods and services, less the value of purchases of goods for resale, so it is adjusted for the change in stocks of final goods and other operating income. This variable was deflated by the two-digit industry-level producer price index obtained from INE. Labor is the 12-month average of employment. Intermediate consumption includes the cost of materials and services purchased and was deflated by the GDP deflator index. The stock of tangible and intangible capital was obtained by applying the perpetual inventory method, considering the respective values of the annual investment. For the first year of a firm's time series, the book value of tangible and intangible assets was deflated by the GFCF deflator and the GDP deflator, respectively, to derive the capital stock. For subsequent years, investments are added, and depreciation rates are subtracted yearly (10% for tangible capital and 33.33% for intangible capital). As Crass and Peters (2014) have shown that productivity estimation results based on intangible capital stocks and intangible investment expenditures are almost identical[1], we use the firms' investment expenditures in training, R&D, software, industrial property, and other intangible assets, as their intangible investments. For control variables, we use dummies for exporting firms, business cycle variation (change in real GDP) to capture the effects of the Great Depression, the age of the firm, the dimension class of the firm and industry dummies (see Table A.1 in annex). All monetary variables are measured in constant euros from 2016. For the dimension class of firms, the number of employees was considered, a firm being classified as micro if it has fewer than 10 employees, as small if it has more than 10 employees, as medium if it has more than 50 employees and as large if it has more than 250 employees. In line with those parameters, we have 435 774 (85.16%) micro firms, 65 066 (12.72%) small firms, 9 444 (1.85%) medium-sized, and 1 403 (0.27%) large firms.

[1] This suggests that the amount of investment for a specific intangible is a very good proxy for the firm's capital stock of this intangible.

Table 1 presents the descriptive statistics of the main variables presented previously. On average, the output of Portuguese firms is 660 thousand euros, with almost 9 workers per firm. On average, Portuguese firms spend 423 thousand euros on intermediate consumptions. The mean value for tangible capital is 294 thousand euros, which is higher than intangible capital, with 37.5 thousand. For investments, the mean is higher for tangible assets, 45.9 thousand euros, compared to intangible investments of 6.7 thousand. On average, the firms report lower expenses in training, and more on other types of intangible capital. In our sample, and, as was evidenced by Kaus et al., (2020) for the German reality, in Portugal many firms invest nothing or very little, but a few invest large amounts in intangibles, so the variable of investment in intangible capital is highly right skewed.

Table 1: Descriptive statistics of the main variables

Variables	Mean	Standard-Deviation	Minimun	Maximum (in th)	Skewness	Kurtosis
Output	660 000	10 300 000	1	3 784 000	121.850	25 116
Labour	8.84	98	1	26.857	133.326	26 619
Intermediate consumptions	423 000	7 340 000	1	3 211 000	132.032	33 644
Tangible capital	294 000	8 070 000	1	3 263 000	248.267	87 714
Intangible capital	37 560	3 900 000	1	3 285 000	406.245	255 5148
Investment in Tangible Capital	45 900	1 370 000	0	707 008	201.816	60 405
Investment in Intangible Capital	6 697	595 000	0	432 300	299.544	471
Training	378.87	11 028	0	7 800	223.364	064
R&D	676.53	80 103	0	67 317	458.994	621
Software	1 272.26	156 000	0	96 076	344.473	431
Industrial Property	1 386.65	242 000	0	161 000	383.054	185 062
Other Intangible Capital	2 640.97	434 000	0	432 300	510.289	397 795

Notes: The number of observations is 2 795 705; the values correspond to raw state.

4. Data Analysis, Results, and Discussion

4.1. Preliminary analysis

This section presents a first analysis of the data carried out with the aim of presenting some stylized facts about intangible investment at the firm level. We start by analyzing the

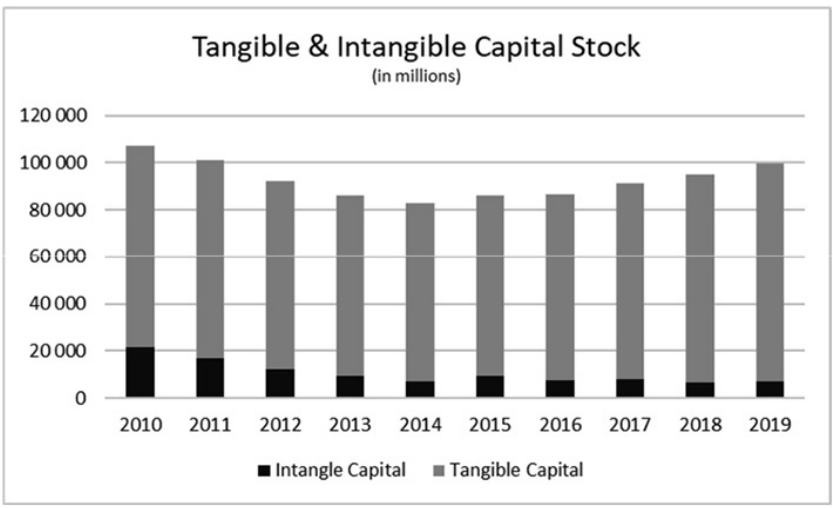
number of firms that invested in intangibles during the period between 2010 and 2019 (see Table 2). Only 91 972 firms, corresponding to 17.97% of the sample, invested in intangibles during the last decade; 16.45% of firms invested in employee training, which is the most common type of investment, and in second place was software investment, with 14.50% of the firms involved. The type of investment least utilized was in industrial property, with only 5.65% of the firms employing it, and there were similar results in R&D investment (5.96% of firms) and other types of intangible investments (6.74%). The values presented in Table 2 tell us that a minority of Portuguese firms invested in intangible assets during the last years.

Table 2: Number of firms that invested in intangibles, or in a certain type, between 2010 and 2019

The firm invested?	Intangible Investment	Training	R&D	Software	Industrial Property	Other Intangible
Yes	91 972 (17.97%)	84 159 (16.45%)	30 508 (5.96%)	74 186 (14.50%)	28 899 (5.65%)	34 512 (6.74%)
No	419 715 (83.02%)	427 528 (83.55%)	487 719 (94.04%)	437 501 (85.50%)	482 788 (94.35%)	477 175 (93.26%)

Next, we analyze the tangible and intangible capital stock for Portuguese companies by year (in Graph 1). We find that tangible and intangible stock between 2010-2014 was in a downward trend, and in the following years there was a recovery, but not enough to reach the levels of 2010 and 2011. The levels of intangible capital stock decreased during the period, as the intangible stock in 2019 was less than half the value in 2010. Here we have a clear downward trend, with the tangible capital stock increasing in the second half of the period.

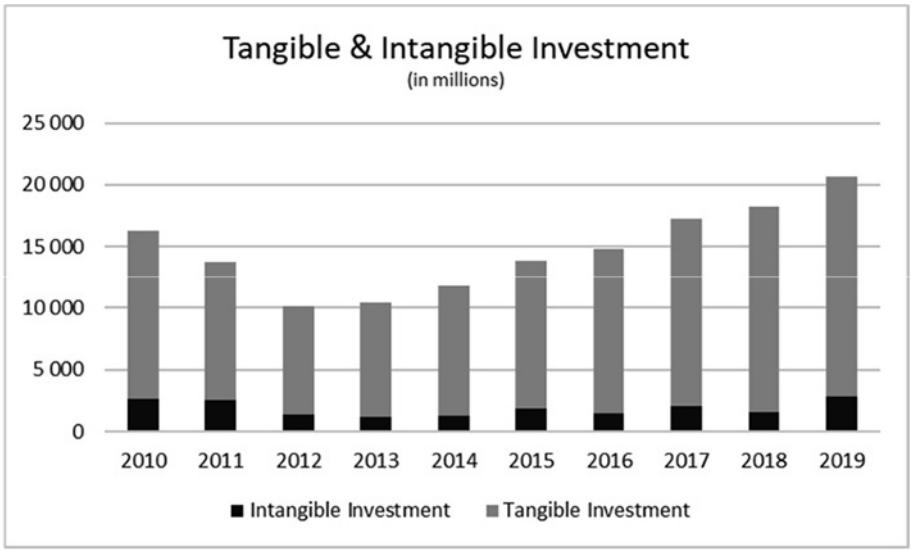
Graph 1: Tangible and intangible capital stock per year



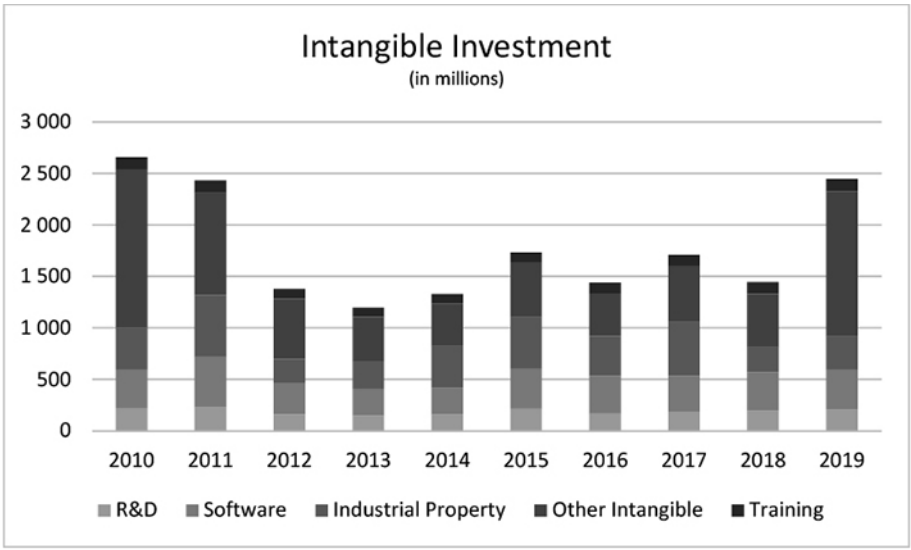
The investment of Portuguese companies had a "valley shape" behavior (in Graph 2), hitting bottom in 2012, with a recovery starting the next year. The 2017 investments exceeded the investments made in 2010. The largest investments in intangibles were made in 2010, 2011 and 2019.

In Graph 3 we see the evolution of investment in intangibles by type and note that investment in other intangibles is the largest item, while the spending on training was the smallest. In this graph we can better analyze the evolution of the total investment in intangibles and note some fluctuations between 2012 and 2018. The investment in intangibles in 2019 reached the amount of 2011 but not of 2010.

Graph 2: Tangible and intangible investment per year

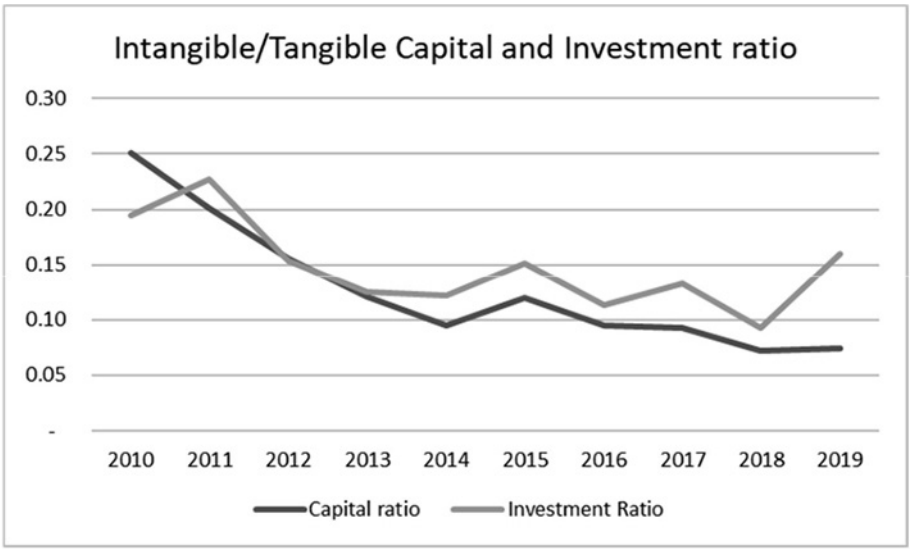


Graph 3: Evolution of intangible investment



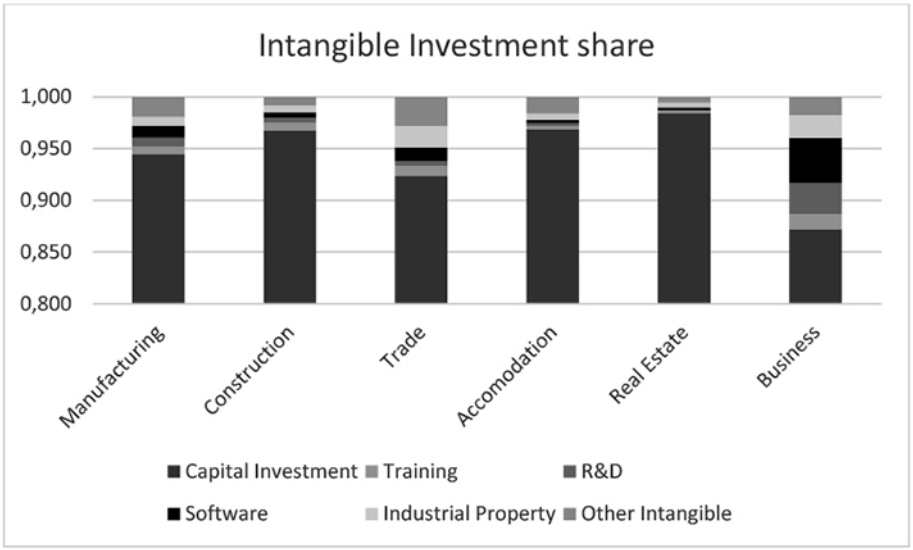
The evolution of investment and capital ratio between intangible and tangible can be seen in Graph 4. In both cases we have a descending trend, with a slight recovery in the investment ratio in 2019. The investment ratio starts slightly below 0.20 and ends above 0.15, with some fluctuation, and throughout the period in question we have a clear favoring of tangible investment over non-tangible investment. Regarding investments, the growth rates of tangibles were higher, compared to intangible growth rates; only in 4 years (2011, 2015, 2017 and 2019) the intangible growth rates were larger than tangible growth rates, but not the amount invested. The values of the capital ratio have a greater amplitude, starting at 0.25 and standing at 0.075, always falling, due to lower growth rates of investments in intangibles relative to tangibles, and the replaced intangible capital was not enough to recover depreciated capital (intangibles have higher depreciation rates than tangibles). The values of the capital ratios are very low even compared to other advanced economies, like that of Germany (see Roth et al., 2022) and USA (see Nakamura, 2010) which records ratios around 1.

Graph 4: Evolution of ratio of intangible over tangible for capital and investment



Finally, we analyzed the investment made by the companies in each sector (in Graph 5). In all sectors, the fixed capital factor share is the largest. The share of intangible investment is the largest In the Business and Trade sectors, and only in Business Services is it greater than 10%. The share of intangible investments in Manufacturing was 5.5%, with the other sectors being Construction (3.2%), Trade (7.6%), Accommodation (3.1%), Real Estate (1.6%) and Business (12,8%). In the Manufacturing sector, the item other intangibles have the largest share within intangibles, and the same holds true for Construction, Trade, Accommodation and Real Estate, while in the Business Sector, the largest share of intangible investment belonged to software.

Graph 5: Share of intangible investment across industries



4.2. Results and discussion

In presenting the results, we discuss them briefly and compare them with other studies (Marrocu et al., 2012; Crass and Peters, 2014; Roth et al., 2022).

Table 3 shows the estimation results for the entire sample between 2010 and 2019 (regression 1), which is then divided into two sub-periods, the first 2010-2014 (regression 2) – the period corresponding to the Great Recession – and the subsequent period of Economic Recovery in 2015–2019 (regression 3). The results with the amount of investment in disaggregated intangibles are also presented corresponding to regressions 4, 5, and 6. The Wald test demonstrates the existence of returns to scale in all models. The elasticities across the various models are similar, with the elasticity of the labor factor ranging between 0.433 and 0.460, and of the intermediate consumption between 0.628 and 0.658. The elasticities of the tangible capital factor are always higher than that of intangible capital, with those of tangible capital varying between 0.029 and 0.042, and those of intangible capital ranging from 0.003 to 0.017. All elasticities have the magnitudes found in the literature mentioned above, except the one pertaining to intermediate consumptions, which has a larger coefficient. The elasticity of intangible capital is positive in all models; however, it is only shown to be significant in regressions 1 and 2, but not in regression 3, thus reflecting the lower and decreasing amount of intangible capital in the stock of Portuguese firms. Analyzing the disaggregated investment in intangibles, the training sector is the only one that shows positive

and significant elasticity in all regressions; the other coefficients have negative elasticities and, in some cases, no statistical significance, and a coefficient close to zero.

Comparing our results with those of Marrocu et al., (2012) and Roth et al., (2022) in regard to these estimations, we find that our intangible capital coefficients are lower. In the study of Marrocu et al., (2012) the coefficient of intangible capital is 0.03 for France, 0.051 for Germany, 0.023 for Spain and 0.081 for the UK; the aggregate value is 0.038 in the four countries, and Roth et al., (2022) report a 0.034 intangible capital coefficient for Germany. Comparing our regressions with those of another country with results closer to the Portuguese reality, Spain in this case (Marrocu et al., 2012), the elasticity of tangible capital is 0.067, the elasticity of intangible capital is 0.023, and the elasticity of the labor factor is 0.381.

We interpret the low coefficients of capital, and negative in some cases for investment in intangibles, as a consequence of the low levels of investment made by Portuguese firms, which are not sufficient to increase their productivity and divert resources from other productivity-enhancing factors.

Table 3: Aggregate firm-level production function estimations for Portugal

Regression		(1)	(2)	(3)	(4)	(5)	(6)
Time period		2010-2019	2010-2014	2015-2019	2010-2019	2010-2014	2015-2019
Labour		0.448*** (0.002)	0.436*** (0.001)	0.460*** (0.001)	0.445*** (0.001)	0.433*** (0.001)	0.457*** (0.002)
Intermediate Consumptions		0.658*** (0.003)	0.651*** (0.002)	0.646*** (0.003)	0.628*** (0.001)	0.644*** (0.002)	0.631*** (0.006)
Tangible capital		0.042*** (0.004)	0.034*** (0.004)	0.029*** (0.003)	0.039*** (0.001)	0.042*** (0.006)	0.033*** (0.001)
Intangible Capital		0.017*** (0.005)	0.010*** (0.001)	0.003 (0.009)			
Investment	Training				0.009*** (0.000)	0.010*** (0.000)	0.008*** (0.000)
	R&D				-0.007*** (0.000)	-0.007*** (0.001)	-0.007*** (0.001)
	Software				-0.001** (0.000)	0.000 (0.000)	-0.002*** (0.000)
	Industrial Property				-0.006*** (0.001)	-0.007*** (0.001)	-0.006*** (0.000)
	Other Intangible Capital				-0.004*** (0.001)	-0.003** (0.001)	-0.006*** (0.000)
No. firms		340 760	256 893	281 737	340 760	256 893	281 737
No. observations		2 094 536	983 806	1 110 730	2 094 536	983 806	1 110 730
Wald test (χ^2 on CRS		38 931.47***	21 423.81***	19 287.35***	46 364.78***	26 444.74***	1 194.04***

Note: Standard errors in parentheses *p<0.10, **p<0.05, ***p<0.01. All estimates are calculated using the Levinshon and Petrin (2003) methodology. The estimation results include control for industry- and time- specific effects, as well as for firm age, dimension, exporter, and business cycle. CRS denotes constant returns to scale.

To better understand the impacts of production factors at the sector level, we also estimated production functions at the firm level for different sectors. The results of our estimation are presented in Table 4. The effects of intangible capital are smaller when compared to the results presented at the aggregate level (regressions 1 to 6). In some cases they have no statistical significance and/or are negative (regressions C1, T1, A1, RE1 and BS1); manufacturing is the only one in which the values are positive and significant (regression M1). The coefficients of investments in intangibles generally follow the signs of the aggregated models (regressions 4 to 6), being positive for training and negative for the other investment variables. We also highlight the positive effect of software investment in Trade (regression T2), Real Estate (regression RE2) and Business Services (regression BS2).

Moreover, the Accommodation (regression A2) and Real Estate (regression RE2) sectors have elasticities of labor that are relatively lower than the aggregate model, and the elasticities of intermediate consumption stand out from the other regressions by excess. Regarding tangible capital, the smallest elasticities are found in the Manufacturing industry (M2).

Finally, we disaggregate the manufacturing sector into its various component industries.

The lowest coefficient of labor elasticity is in the chemicals industry (regression MI11 and MI12), and largest in Textiles (regression MI3 and MI4); the elasticity of intermediate consumption varies between 0.474 in Textiles (regression MI4) and 0.736 in the Food industry (regression MI1); the tangible capital ranges between 0.006 in Chemicals (regression MI12) and 0.042 in Paper (regression MI10). In general, the coefficients of intangible capital and investment (Table 5.1 and 5.2) have lower absolute values relative to those in the aggregating models (Table 3 and 4). In most of the regressions, the coefficient of intangible capital is positive and not significant (regressions MI1, MI3, MI7, MI9, MI15, MI19, MI21 and MI23); in the regressions of Leather (regression MI5), Chemicals (regression MI11), Other Non-Metallic (regression MI13) and Electronic Equipment (regression MI5) industries the coefficient is negative. The coefficients for investments in intangibles are smaller than in the previous models and have the same sign as those of the aggregate models. The impact of training is positive for most regressions, except for Textiles (regression MI4), Paper (regression MI10) and Electronic Equipment (regression MI18). For R&D investment the impact is only positive for the Food industry regression (MI2); the software impact is non-negative for three industries, but the value is near zero (regressions MI18, MI22 and MI24), and the same is true for industrial property for the following regressions MI10, MI14 and MI22. Finally, the impact of other intangible capital is negative in most industries, being positive only in Leather (regression MI6), Wood (regression MI8), Paper (regression MI10) and Chemicals (regression MI12).

Table 4: Sector firm-level production function estimations for Portugal

Regression		M1	M2	C1	C2	T1	T2	A1	A2	RE1	RE2	BS1	BS2
(Macro) Industry		Manufacturing		Construction		Trade		Accommodation		Real Estate		Business Services	
Labour		0.409*** (0.005)	0.409*** (0.003)	0.461*** (0.001)	0.461*** (0.005)	0.471*** (0.004)	0.468*** (0.002)	0.358*** (0.003)	0.357*** (0.002)	0.323*** (0.016)	0.320*** (0.014)	0.466*** (0.004)	0.457*** (0.002)
Intermediate consumptions		0.613*** (0.005)	0.597*** (0.007)	0.576*** (0.009)	0.576*** (0.008)	0.685*** (0.008)	0.674*** (0.004)	0.713*** (0.000)	0.686*** (0.007)	0.687*** (0.011)	0.656*** (0.013)	0.599*** (0.002)	0.596*** (0.004)
Tangible capital		0.027*** (0.002)	0.014*** (0.002)	0.022*** (0.003)	0.033*** (0.003)	0.042*** (0.005)	0.056*** (0.001)	0.040*** (0.001)	0.029*** (0.009)	0.039*** (0.005)	0.034*** (0.005)	0.029*** (0.007)	0.023*** (0.002)
Intangible capital		0.005** (0.003)		0.008 (0.005)		-0.002 (0.005)		0.002 (0.002)		0.004 (0.005)		-0.000	
Investment	Training		0.003*** (0.000)		0.004*** (0.000)		0.010*** (0.001)		0.006*** (0.001)		0.011*** (0.002)		0.013*** (0.000)
	R&D		-0.003*** (0.000)		-0.005** (0.002)		-0.006*** (0.002)		-0.009*** (0.001)		-0.005 (0.009)		-0.008*** (0.002)
	Software		-0.005*** (0.000)		-0.001 (0.000)		0.003*** (0.001)		-0.002*** (0.001)		0.004 (0.003)		0.001*** (0.000)
	Industrial Property		-0.004*** (0.001)		-0.003 (0.002)		-0.004*** (0.001)		-0.003 (0.003)		-0.022*** (0.007)		-0.015*** (0.001)
	Other Intangible Capital		-0.003*** (0.002)		-0.003** (0.002)		-0.007*** (0.001)		-0.008*** (0.002)		-0.017** (0.007)		-0.012*** (0.002)
No. firms		46 134	46 134	48 689	48 689	108 366	108 366	45 516	45 516	15 344	15 344	57 441	57 441
No. observations		305 364	305 364	274 281	274 281	684 163	684 163	255 433	255 433	78 399	78 399	335 157	335 157
Wald test (χ^2) on CRS		64.97***	3 808.19***	20 939.04***	587.62***	182.77***	24.02***	4 803.01***	52.49***	392.86***	114.29***	5 959.78***	13 872.45***

Note: Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01. All estimates are calculated using the Levinshon and Petrin (2003) methodology. The model includes industry- and time-specific effects, as well as for firm age, dimension, exporter, and business cycle. CRS = Constant returns to scale.

Table 5.1: Manufacturing industries firm-level production function estimates for Portugal

Regression		MI1	MI2	MI3	MI4	MI5	MI6	MI7	MI8	MI9	MI10	MI11	MI12
Manufacturing Industry		Food		Textiles		Leather		Wood		Paper		Chemicals	
Labour		0.310*** (0.006)	0.311*** (0.003)	0.483*** (0.005)	0.483*** (0.003)	0.408*** (0.010)	0.407*** (0.007)	0.348*** (0.013)	0.347*** (0.010)	0.319*** (0.022)	0.317*** (0.006)	0.203*** (0.009)	0.203*** (0.029)
Intermediate consumptions		0.736*** (0.002)	0.726*** (0.005)	0.494*** (0.003)	0.474*** (0.009)	0.496*** (0.007)	0.486*** (0.007)	0.699*** (0.005)	0.693*** (0.006)	0.693*** (0.008)	0.699*** (0.008)	0.706*** (0.065)	0.701*** (0.009)
Tangible capital		0.039*** (0.006)	0.037*** (0.007)	0.015** (0.007)	0.010 (0.002)	0.016*** (0.005)	0.031*** (0.007)	0.025*** (0.002)	0.039*** (0.004)	0.040*** (0.007)	0.042*** (0.007)	0.012 (0.010)	0.006 (0.007)
Intangible capital		0.004 (0.004)		0.005 (0.006)		-0.007 (0.006)		0.001 (0.005)		0.002 (0.006)		-0.001 (0.005)	
Investment	Training		0.002** (0.001)		-0.000 (0.001)		0.003*** (0.001)		0.004*** (0.000)		-0.001 (0.001)		0.003*** (0.001)
	R&D		0.001 (0.001)		-0.005* (0.003)		-0.001 (0.003)		-0.001 (0.002)		-0.003* (0.001)		-0.003 (0.002)
	Software		-0.001 (0.001)		-0.004*** (0.000)		-0.004*** (0.001)		-0.001*** (0.000)		-0.003** (0.001)		-0.000 (0.002)
	Industrial Property		-0.005* (0.003)		-0.005*** (0.001)		-0.003 (0.002)		-0.016* (0.009)		0.000 (0.001)		-0.006*** (0.001)
	Other Intangible Capital		-0.002 (0.002)		-0.005*** (0.002)		0.000 (0.003)		0.001 (0.004)		0.001 (0.003)		0.004 (0.003)
No. firms		7 614	7 614	8 036	8 036	2 782	2 782	6 101	6 101	2 532	2 532	652	652
No. observations		51 622	51 622	49 717	49 717	17 276	17 276	39 934	39 934	17 865	17 865	4 345	4 345
Wald test (χ^2) on CRS		2 044.09***	363.60***	1 993.30***	45.97***	17.83***	313.03***	10.13***	36.41***	6.51**	67.11***	1 713.69***	10.89***

Note: Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01. All estimates are calculated using the Levinshon and Petrin (2003) methodology. The model includes time-specific effects, as well as for firm age, dimension, exporter, and business cycle. CRS denotes constant returns to scale.

Table 5.2: Manufacturing industries firm-level production function estimates for Portugal

Regression		MI13	MI14	MI15	MI16	MI17	MI18	MI19	MI20	MI21	MI22	MI23	MI24
Manufacturing Industry		Other non-metallic		Metals		Electrical equipment		Machinery		Transport equipment		Other manufacturing	
Labour		0.267*** (0.005)	0.266*** (0.002)	0.388*** (0.011)	0.388*** (0.012)	0.302*** (0.018)	0.301*** (0.022)	0.382*** (0.023)	0.381*** (0.013)	0.300*** (0.019)	0.301*** (0.012)	0.416*** (0.021)	0.415*** (0.010)
Intermediate consumptions		0.680*** (0.009)	0.647*** (0.005)	0.618*** (0.002)	0.602*** (0.005)	0.623*** (0.008)	0.635*** (0.023)	0.631*** (0.007)	0.617*** (0.007)	0.668*** (0.006)	0.665*** (0.004)	0.582*** (0.008)	0.591*** (0.003)
Tangible capital		0.024*** (0.005)	0.011*** (0.002)	0.039*** (0.006)	0.025*** (0.004)	0.022*** (0.007)	0.027** (0.013)	0.023*** (0.007)	0.037*** (0.007)	0.009 (0.008)	0.009 (0.003)	0.020*** (0.005)	0.018*** (0.006)
Intangible capital		-0.003 (0.010)		0.001 (0.004)		-0.018*** (0.004)		0.005 (0.003)		0.003 (0.003)		0.001 (0.005)	
Investment	Training		0.003*** (0.001)		0.002*** (0.001)		-0.000 (0.003)		0.005*** (0.001)		0.002** (0.001)		0.007*** (0.001)
	R&D		-0.003*** (0.001)		-0.004*** (0.001)		-0.004 (0.004)		-0.003*** (0.001)		-0.005*** (0.001)		-0.005** (0.003)
	Software		-0.002 (0.001)		-0.001*** (0.000)		0.000 (0.001)		-0.002* (0.001)		0.000*** (0.000)		0.000 (0.001)
	Industrial Property		0.001 (0.002)		-0.005** (0.002)		-0.006*** (0.002)		-0.006*** (0.001)		0.001 (0.001)		-0.008*** (0.002)
	Other Intangible Capital		-0.001 (0.001)		-0.001 (0.001)		-0.013*** (0.004)		-0.003 (0.005)		-0.003 (0.003)		-0.012** (0.006)
No. firms		3 654	3 654	8 270	8 270	826	826	1 347	1 347	509	509	4 031	4 031
No. observations		25 676	25 676	56 203	56 203	5 535	5 535	9 236	9 236	3 412	3 412	24 543	24 543
Wald test (χ^2) on CRS		1 355.63***	366.04***	3.09*	0.02	160.71***	4.47**	4.76**	43.97***	8.93***	465.15***	53.13***	104.56***

Note: Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01. All estimates are calculated using the Levinshon and Petrin (2003) methodology. The model includes time-specific effects, as well as firm age, dimension, exporter, and business cycle. CRS denotes constant returns to scale.

The impact of intangibles on production is positive since companies that invest in them have higher productivity. However it is not enough just to invest in intangibles, it is necessary to invest in large quantities; in cases where companies invest little, the impact is unable to be positive, and in fact, in these cases investing in intangibles can be harmful to productivity because their impact is not immediate and can lead to a diversion of resources that could be invested in other more productive factors (remember that the distribution of investment in intangibles is highly right-skewed). This is evidenced by the case of training, which is the type of intangible receiving the most investment, and in most regressions, the impact is positive.

5. Conclusion

The objective of this work was to understand the evolution of intangible assets and their impact on the productivity of Portuguese firms in the last decade, in the context of an economic recession and a recovery period. To this end, a Cobb-Douglas production function was estimated.

The reality of Portuguese firms is characterized by the fact that most of them are SMEs, which certainly affects the investment policy in intangible assets. Few firms, about 18.0% of those in the sample, invest in intangible assets, with investment in training and software being the most common type of investment. The aggregate levels of investment in intangible assets are low, with most firms investing little or not at all, and a few of them investing large amounts. The investment trend in intangible capital over the decade has been gradually negative, with the stock capital in 2019 already less than half of what it was in 2010.

Of course, over time, this development has brought firms a decreasing positive impact of intangible capital and investment on productivity, the latter being negative in many cases or insignificant in some industries. In manufacturing, intangible capital has the strongest impact on productivity. In the construction sector, the effect is positive but insignificant. For the business services and trade sectors, the effect is null and negative, respectively. When the manufacturing sector is split, the effect is larger in the textile industry and negative in the electrical industry. As in other studies, fixed capital has a greater effect on intangibles, and the elasticities observed at the aggregate level are larger than at the sector/industry level.

References

Aghion, P.; Howitt, P. (1992) A Model of growth through creative destruction. *Econometrica*, 60(2), 323-351.

Carreira, C.; Lopes, L. (2018) Regional knowledge spillovers: a firm-based analysis of non-linear effects. *Regional Studies,* 52(7), 948-958.

Corrado, C.; Haskel, J.; Jona-Lasinio, C.; Iommi, M. (2013) Innovation and intangible investment in europe, japan, and the United States. *Oxford Review of Economic Policy,* 29(2), 261-286.

Corrado, C.; Haskel, J.; Jona-Lasinio, C.; Iommi, M. (2016) *Intangible investment in the EU and US before and since the Great Recession and its contribution to productivity growth* (No. 2016/08). EIB Working Papers.

Corrado, C.; Hulten, C.; Sichel, D. (2009) Intangible capital and US economic growth. *Review of income and wealth,* 55(3), 661-685.

Crass, D.; Peters, B. (2014) Intangible assets and firm-level productivity. *ZEW-Centre for European Economic Research Discussion Paper*, (14-120).

Criscuolo, C.; Gal, P.; Leidecker, T.; Nicoletti, G. (2021) The Human Side of Productivity: Uncovering the Role of Skills and Diversity for Firm Productivity. *OECD Productivity Working Papers*, 29.

de Carvalho, P.; Serrasqueiro, Z.; Nunes, P. M. (2013) Profitability determinants of fitness SMEs: Empirical evidence from Portugal using panel data. *Amfiteatru Economic,* 15(34), 417.

Eberhardt, M.; Helmers, C. (2010) Untested assumptions and data slicing: A critical review of firm-level production function estimators. Economics Series Working Papers 513, University of Oxford, Department of Economics.

Grossman, G.; Helpman, E. (1991) Quality ladders and product cycles. *Quarterly Journal of Economics,* 106(2), 557-586.

Kaus, W.; Slavtchev, V.; Zimmermann, M. (2020) *Intangible capital and productivity: Firm-level evidence from German manufacturing* (No. 1/2020). IWH Discussion Papers.

Levinsohn, J.; Petrin, A. (2003) Estimating production functions using inputs to control for unobservables. R*eview of Economic Studies,* 70(2), 317-341.

Marrocu, E.; Paci, R.; Pontis, M. (2012) Intangible capital and firms' productivity. *Industrial and Corporate Change*, 21(2), 377-402.

Nakamura, L. (2010) Intangible assets and national income accounting. *Review of Income and Wealth,* 56, S135-S155.

Niebel, T.; O'Mahony, M.; Saam, M. (2017) The contribution of intangible assets to sectoral productivity growth in the EU. *Review of Income and Wealth*, 63(1), 49–67.

Nunes, P.; Almeida, A. (2009) The quadratic relationship between intangible assets and growth in Portuguese SMEs. *Amfiteatru Economic Journal*, 11(25), 151-158.

Oliveira, L.; Rodrigues, L.; Craig, R. (2010) Intangible assets and value relevance: Evidence from the Portuguese stock exchange. *British Accounting Review,* 42(4), 241-252.

Olley, S.; Pakes, A. (1992) The dynamics of productivity in the telecommunications equipment industry. *Econometrica,* 64(6), 1263-1297.

Piekkola, H. (2018) Broad-based intangibles as generators of growth in Europe. *Economics of Innovation and New Technology,* 27(4), 377-400.

Romer, P. (1990) Endogenous technological change. *Journal of Political Economy,* 98(5), S71-102.

Roth, F.; Sen, A.; Rammer, C. (2022) The role of intangibles in firm-level productivity: Evidence from Germany. *Industry and Innovation*, 1-23.

Rovigatti, G.; Mollisi, V. (2018) Theory and practice of total-factor productivity estimation: The control function approach using Stata. *Stata Journal*, 18(3), 618-662.

Silva, F.; Carreira, C. (2012) Do financial constraints threat the innovation process? Evidence from Portuguese firms. *Economics of Innovation and New Technology*, 21(8), 701-736.

Solow, R. (1957) Technical Change and the Aggregate Production Function. *Review of Economics and Statistics,* 39(3), 312-320.

Turovets, Y. (2021) Intangible assets and the efficiency of manufacturing firms in the age of digitalisation: The Russian case. *Engineering Management in Production and Services*, 13(1), 7-26.

Yallwe, A.; Buscemi, A. (2014) An era of intangible assets. *Journal of Applied Finance and Banking*, 4(5), 17.

Annex

Table A.1: Industry classification

NACE	Sector/Industry	Short name
10-33	Manufacturing	Manufacturing
10-11	Food products and beverages	Food
13-14	Textiles and wearing apparel	Textiles
15	Leather and leather products	Leather
16, 31	Wood and wood products; furniture	Wood
17-18	Pulp, paper, paper products and publishing	Paper
19-21	Chemical and chemical products	Chemicals
22-23	Rubber and plastic products; other non-metallic	Other non-metallic
24-25	Basic metals and fabricated metal products	Metals
26-27	Electronic and electrical equipment	Electrical equipment
28	Machinery and equipment	Machinery
29-30	Motor vehicles, trailers and other transport equip.	Transport equipment
32-33	Other manufacturing n.e.c. and recycling	Other manufacturing
41-43	Construction	Construction
45-47	Trade	Trade
55-56	Accommodation	Accommodation
68	Real estate	Real estate
62-63, 69-82	Business services	Business services

IMPRENSA DA UNIVERSIDADE DE COIMBRA
COIMBRA UNIVERSITY PRESS