INVESTMENT IN KNOWLEDGE-BASED CAPITAL AND PRODUCTIVITY: FIRM-LEVEL EVIDENCE FROM A SMALL OPEN ECONOMY†

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This paper examines the responsiveness of firm productivity to investment in knowledge-based capital (KBC) including a range of intangible assets such as research and development (R&D), intellectual property assets, computer software, organizational, and branding capital. A dynamic econometric model is estimated with micro-data from Ireland over the period 2006–2012. *Ceteris paribus*, the estimated average elasticity of productivity with respect to investment in KBC per employee is 0.3. In comparison to previous empirical studies, this paper goes beyond the representative firm approach and accounts for the heterogeneous behavior of firms which differ by ownership, size, export participation, and sector of activity. Further, the analysis finds that investing simultaneously in multiple KBC assets has complementary as well as substitution effects on firm productivity, with different interdependence patterns for specific investment combinations across groups of firms and sectors.

1. INTRODUCTION

In recent years, there has been an increased focus on investment in knowledge-based capital (KBC) as a source of innovation and productivity

growth.[1] KBC comprises a broad range of intangible assets such as research and development (R&D), computer software and datasets, organizational know-how, firm-specific human capital, designs, and other intellectual property assets (Andrews and De Serres, 2012). This approach has been driven by the rapid growth of information and communication technologies (ICT) in the 1990s as a new general-purpose technology and the need to undertake complementary investments such as investment in skills and organizational change required to exploit the opportunities that ICT offered.[2]

Measuring investment in KBC[3] and its impacts is challenging given the non-physical nature of intangible assets. To overcome this challenge, several methodological frameworks have been put forward. Among these, the mostly used is the one proposed by Corrado *et al*. (2005, 2009) known as the CHS framework. On the basis of the economic theory underpinning the optimal growth literature (Weitzman, 1976; Hulten, 1979), the authors have formalized their view that expenditures on a broad range of intangibles should be capitalized in company and National Accounts. Such expenditures have been grouped in three categories: (a) *computerized information*: knowledge codified in computer programs and databases; (b) *innovative property*: R&D and intellectual property assets such as patents, copyrights, designs, and trademarks; (c) *economic competencies*: knowledge embodied in firm-specific training, organizational know-how, and branding.

Using the CHS framework, recent research has helped to progress the quantification of investment in KBC assets at the industry level and to assess its contribution to productivity growth by exploiting growth accounting methodologies (Corrado *et al.*, 2012, 2014, 2018; Dal Borgo *et al.*, 2013; OECD, 2013; Niebel *et al.*, 2017). Evidence provided by Corrado *et al.* (2018) shows that over the 2000–2013 period, investment in intangible capital contributed substantially to labor productivity growth in several countries including the U.S. and EU.[4] Corrado *et al.* (2017) go one-step further and uncover complementarities between investing in ICT and other intangible capital assets. Further, they identify positive externalities from knowledge spillovers as a channel linking investment in KBC to productivity gains. Jona-Lasinio and Meliciani (2019) also use the CHS framework in a multi-country analysis and find that investment in intangible capital amplifies the productivity effect of participation in Global Value Chains. Finally, Chen (2018) studies the contribution of intangible capital to the international income differences. To be able to perform the analysis on a large number of countries, this work adopts a narrower definition of intangibles compared to the CHS framework, but finds that including intangible investment as a factor of production allows to explain a larger fraction of the cross-country

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[1]Recent international evidence is reviewed by OECD (2013) and Corrado *et al.* (2018).
[2]Karlsson *et al.* (2010) reviews the international evidence on the role of ICT as a new general purpose technology and complementary investments needed to exploit the growth opportunities ICT offer.
[3]Throughout this paper we use the terms knowledge-based capital (KBC) and intangible assets interchangeably.
[4]Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Portugal, Slovakia, Slovenia, Spain, Sweden, the United Kingdom.

income variation, relative to analyses based on the traditional production factors only.

Firm-level evidence on the impact of investment in KBC on productivity is more limited due to constraints imposed by data availability. Most firm-level analyses have focused on the impact of R&D expenditures and more broadly innovation expenditures on innovation and productivity growth.[5] A recent literature uses a broader definition of intangible assets and considers aggregate intangible capital as an additional input in a production function setting (Marrocu *et al.*, 2012; Battisti *et al.*, 2015). Chappell and Jaffe (2018) link survey and administrative firm-level data from New Zealand and examine the association between investment in intangibles, firm characteristics, and a range of firm performance measures. They find that higher investment in intangibles is associated with higher revenue but not with the productivity. However, these contributions do not separate out the effect of the various types of intangible assets on productivity. Disaggregating intangibles by asset type is relevant given their different features and the interdependence of their effects on productivity: so far, only a small number of studies distinguish and quantify investment in specific KBC assets such as innovative property, computerized information, and economic competencies.

To the best of our knowledge, previous firm-level analyses of the relationship between productivity and investment in KBC using a production function framework have estimated static models, have mostly focused on average effects across firms, and have performed the analysis on data from large economies. Riley and Robinson (2011) exploit employer-employee data from the UK and focus on specific intangibles embedded in knowledge workers.[6] They find a positive link between KBC assets and productivity, with organizational capital having a greater impact than R&D or IT capital. Crass and Peters (2014) examine the effects of investment in a comprehensive range of intangibles in German firms and identify R&D, branding, and firm-specific human capital as assets with strong productivity-enhancing effects. Furthermore, the authors provide evidence on the complementary effects from investment in R&D and the patent stock; investments in innovative capital and firm-specific human capital; and for investments in innovative capital and brand equity. Bontempi and Mairesse (2015), using data from Italian firms, separate intangibles depending on their accounting treatment (capitalized intangibles versus intangibles measured from expenses) and their economic nature (intellectual versus customer capital) and estimate that intangibles have a higher marginal productivity than tangible capital, with intellectual capital yielding higher returns than customer capital. Higón *et al.* (2017) estimate the effects of investments in R&D, advertising and human capital on total factor productivity in Spanish manufacturing firms. They find evidence of complementarities between investments in R&D and advertising, and between investment in advertising and human capital.

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[5]Recent evidence is reviewed by Hall (2011), Broström and Karlsson (2017) and Roth (2019).
[6]Organizational workers (managers and marketing related occupations) as a proxy for economic competencies assets; R&D workers measuring innovative property assets; and IT workers measuring computerized information assets.

This paper uses a panel of annual firm-level data from Ireland over the period 2006–2012 and provides novel evidence on the relationship between productivity and investment in R&D and in other knowledge-based assets such as copyrights, patents, licenses, computer software, organizational, and branding capital. The empirical analysis is underlined by a production function framework, more specifically a Cobb-Douglas production function augmented with knowledge-based capital. Building on this theoretical framework, we make three contributions to the literature. First, we model the relationship between productivity and investment in KBC in a dynamic set up to account for productivity's persistence and path-dependency. Second, in contrast with the evidence from large economies discussed above, we model the relationship between productivity and investment in KBC in the context of a small open economy, Ireland, one of the most globalized economies in the world. The small open economy modelling set up differs from the one of a large economy, which is relatively less open to trade, in that it accounts more directly for the role of international trade and inward foreign direct investment in the relationship between investment in KBC and productivity. This specific feature is relevant given that openness to trade and foreign direct investment are likely to impact on the returns to investment in KBC. Third, and related to the small open economy set up, we relax the assumption of a homogeneous behavior of a representative firm and allow the link between investment in KBC and productivity to differ across sectors (manufacturing and services) and across different groups of firms (domestic-owned and foreign-owned;[7] small, medium-sized and large; exporters and non-exporters).

Throughout the empirical analysis, in addition to aggregate investment in KBC, we examine the marginal productivity of investments in specific KBC assets. Furthermore, we analyze the complementarity/substitutability of multiple investments in specific KBC assets.

The key results indicate that on average, over and above other factors, investment in knowledge-based capital is positively linked to firm productivity: an increase in investment in knowledge-based capital by ten per cent translates into a three per cent productivity gain. There is considerable heterogeneity across intangible assets of different nature and across firms with different characteristics. The evidence shows that productivity is most sensitive to investment in R&D intangibles assets in firms which are Irish-owned and operate in manufacturing sectors; in contrast, in foreign-owned and services firms, productivity is most strongly linked to investment in non-R&D intangible assets such as computer software and organizational and branding capital. The analysis also finds that investing simultaneously in multiple intangible assets has complementary as well as substitution effects on firm productivity, depending on specific investment combinations and firm and sector characteristics. One key finding of this analysis is that investing in R&D and IP assets enhances the productivity returns of investments in other intangible assets.

The remainder of this paper is structured as follows. Section 2 discusses the theoretical framework that underlies the empirical analysis. Section 3 describes the

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[7]The analysis of the behavior and performance of foreign-owned firms relates to the activity of these firms reported in Ireland.

data, the firm level measures of KBC used in the analysis and some key characteristics of the sample analyzed. Section 4 explains the econometric methodology and Section 5 discusses the empirical results. Finally, section 6 summarizes the main findings and discusses implications for the design of enterprise policies aiming to foster productivity growth and competitiveness.

2. THEORETICAL FRAMEWORK

The initial point of departure for our empirical analysis is a theoretical framework based on a Cobb-Douglas production function[8] augmented with knowledge-based capital (K) following Griliches (1979, 1980, 1998) and Pakes and Griliches (1984). We also add to the functional form human capital as in Lucas (1988), Romer (1990), and Mankiw *et al.* (1992).

In this initial analytical set up, output at the firm level is a function of observable production inputs (labor, physical capital, knowledge-based capital or intangible capital, and human capital) and an unobserved measure of efficiency assumed to be factor-neutral:

$$(1) \qquad Q_{it} = A e^{\lambda_{it}} L_{it}^{\alpha_l} C_{it}^{\alpha_c} K_{it}^{\alpha_k} H_{it}^{\alpha_h} e^{\varepsilon_{it}}$$

Q_{it} is output (real value added) in firm i, at time t. A is a constant and λ_{it} is the unobserved time and firm-specific rate of disembodied technical change. L and C are standard input factors, that is, labor and physical capital. K denotes knowledge-based (intangible capital) and H represents human capital. $\alpha_l, \alpha_c, \alpha_k, \alpha_h$ are the elasticities of output with respect to input factors.

The log-linear production function derived from equation (1) that can be easily estimated is as follows:

$$(2) \qquad q_{it} = \alpha_0 + \lambda_{it} + \alpha_l l_{it} + \alpha_c c_{it} + \alpha_k k_{it} + \alpha_h h_{it} + \varepsilon_{it}$$

The small letters in equation (2) denote the respective log values of output and production inputs in firm i at time t. α_0 captures the average efficiency of production across all firms. ε_{it} denotes the error term that accounts for unobserved shocks and measurement errors.

Productivity measured as output per employee is obtained from Eq. (2) as follows:

$$(3) \qquad q_{it} - l_{it} = \alpha_0 + (\alpha_l - 1)l_{it} + \alpha_c c_{it} + \alpha_k k_{it} + \alpha_h h_{it} + \lambda_{it} + \varepsilon_{it}$$

equation (3) can be further written as follows:

$$(4) \quad q_{it} - l_{it} = \alpha_0 + (\alpha_l + \alpha_c + \alpha_k + \alpha_h - 1)l_{it} + \alpha_c(c_{it} - l_{it}) + \alpha_k(k_{it} - l_{it}) + \alpha_h(h_{it} - l_{it}) + \lambda_{it} + \varepsilon_{it}$$

Assuming constant returns to scale $\alpha_l + \alpha_c + \alpha_k + \alpha_h = 1$, equation (4) becomes:

$$(5) \qquad q_{it} - l_{it} = \alpha_0 + \alpha_c(c_{it} - l_{it}) + \alpha_k(k_{it} - l_{it}) + \alpha_h(h_{it} - l_{it}) + \lambda_{it} + \varepsilon_{it}$$

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[8]While alternative functional forms could be used (for example CES or translog functions), the Cobb-Douglas production function has analytical advantages as a first order-approximation to any production function. Syverson (2011) discusses in more details the choice of production functional forms.

$q_{it} - l_{it}$: labor productivity of firm i at time t, measured as real value added per employee;

$c_{it} - l_{it}$: physical capital per employee in firm i at time t;

$k_{it} - l_{it}$: knowledge-based capital per employee in firm i at time t;

$h_{it} - l_{it}$: human capital per employee in firm i at time t.

The parameter of main interest in our analysis is α_k which captures the elasticity of productivity with respect to knowledge-based capital.

We build on the production function model described above and add to equation (5) a number of features to contextualize it in line with recent advances in the literature on productivity. First, a well-established literature (see Syverson, 2011 for a review) has highlighted the role path-dependency in shaping the productivity performance of firms. Persistent differences in productivity between firms have been shown to be widespread (Bartelsman and Doms, 2000) and have been mostly attributed to firms' selection at entry (Hopenhayn, 1992; Melitz, 2003), demand channels[9] (Moreira, 2017), learning-by-doing, innovative efforts, investment in higher quality managerial capital, as well as characteristics of the environment in which firms operate such as market structure, and competition (Syverson, 2011). To account for this productivity feature, we augment the model described by equation (5) with the lagged productivity, $(q_{it-1} - l_{it-1})$.

Second, in the static Cobb-Douglas production function model, the effect of competition on productivity is captured by an increase in the average efficiency across firms. Following on from existing evidence on the effects of competition on increasing intra-industry market shares of more efficient firms[10] (see for example Syverson, 2004a; Foster *et al.*, 2008; and Syverson, 2011 for a recent review of this evidence), we add to the model a measure of firm-specific intra-industry market share.

Third, in order to contextualize the Cobb-Douglas production model to the analysis of the relationship of investment in knowledge-based capital on productivity in a small open economy, we augment equation (5) with additional variables, which account for the engagement of firms in exporting and for the presence of foreign-owned affiliates. These variables capture both knowledge-spillovers and international competition effects.

Finally, following on from recent contributions to the literature on productivity dispersion across firms[11] we test whether the relationship between productivity and investment in KBC is heterogeneous across different groups of firms (domestic-owned and foreign-owned; small, medium-sized and large; exporters and non-exporters); and across sectors (manufacturing and services). Firm heterogeneity implies that not all firms have the same capability to translate investment in KBC into productivity gains.

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[9]Demand accumulation through consumer reputation and brand awareness.

[10]This mechanism is also referred to as Darwinian selection *between* firms (Syverson, 2011). However, there might additionally be *within* firm increases in productivity from heightened competition, due to productivity raising actions undertaken by producers.

[11]Bartelsman and Doms (2000) review this literature. Eaton and Kortum (2002) and Melitz (2003) have conceptualized the role of productivity dispersion on trade intensive and extensive margins. Syverson (2004b) provides evidence on productivity dispersion within industries in the U.S.

The augmented theoretical framework discussed above underlines the empirical models we estimate. Given the available data, the analysis focuses on the marginal productivity of investment in intangible assets rather than the marginal productivity of intangible capital stocks. Because the available panel data is unbalanced and it covers a short period (seven years), capital stocks of tangible, and intangible assets could be estimated with substantial measurement error. Furthermore, in our view, because the dependent variable and the other explanatory variables are flows, investment in tangible, and intangible assets is more relevant for productive efficiency. We therefore chose to estimate productivity returns to investments flows rather than capital stocks. This choice implies that, in our econometric set up, the coefficients can be interpreted as the short run returns to investing in a specific fixed asset, in terms of labor productivity (for a similar empirical approach see among others Hall *et al.*, 2013), rather than as the user cost of capital.[12] The estimated coefficients in this case may reflect technological differences across producers (hence our focus on firm heterogeneity), and/or across fixed intangible assets, for which certain investments are more productivity enhancing than others. Alternatively, different initial levels of capital stocks across firms or intangible assets, or different depreciation rates, could also impact on the estimated coefficients.[13]

The next section describes the data and the measures of investment in intangibles used in the empirical analysis. In addition, we discuss patterns of investment in KBC by groups of firms and by sector, highlighting the importance of accounting for the heterogeneity of investment behavior.

3. Data, Measurement, and Descriptive Analysis

This analysis uses two datasets provided by Ireland's Central Statistics Office (CSO): the Census of Industrial Production (CIP) and the Annual Service Inquiry (ASI).

The CIP survey covers firms with three or more persons engaged and having their primary activity in mining and quarrying, manufacturing and utilities. The CIP contains information on location of ownership, turnover, employment and gross earnings, changes in capital assets, purchases of goods and services other than capital items. A more detailed questionnaire including information on changes in intangible assets is sent to firms with 20 and more persons engaged.

The ASI survey covers firms having their primary activity in the distribution and services sectors.[14] The ASI is based on a census of firms with 20 and more

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[12]In a production function with capital stocks, the user cost of capital interpretation implies that coefficients reflect a mixture of depreciation, capital gain/losses and net return to capital.

[13]Diminishing marginal returns to capital could imply that larger/smaller coefficients are due to different initial levels of capital stocks, across firms and/or assets. Furthermore, if a fixed asset depreciated much faster than another over a short time span, investment in the former asset could appear to be more productivity enhancing than investment in the latter.

[14]The sectors covered by the ASI are: retail; wholesale; transportation and storage; accommodation and food; information and communication; real estate; professional, scientific, technical, administrative; and other selected services.

persons and a stratified random sample for firms with less than 20 persons engaged. The data collected with a more detailed questionnaire sent to firms with 20 or more persons engaged includes the variables of interest for this analysis collected also with the CIP.

The broadest coverage of the available data on intangible assets in the CIP and the ASI is for the period 2006–2012. Taken together all data available from the CIP and ASI, our analysis is based on an unbalanced panel of annual data comprising 11,346 unique firms over the seven years period, which results in 38,647 firm-year observations.[15] All monetary variables used in the analysis are deflated by the producer price indices for manufacturing industries at NACE 2-digit level and the consumer price index for the remaining sectors.[16]

To construct measures of investment in KBC at firm level, we follow the widely adopted methodological framework proposed by Corrado *et al.* (2005, 2009), known as the CHS framework. The CHS framework has been developed initially as a macroeconomic approach using available data for the U.S. and has subsequently been exploited to produce comparable data on investment in KBC across industries and countries. It provides a conceptual framework for measuring three types of KBC assets: (1) *computerized information*: knowledge codified in computer programs and computerized datasets, (2) *innovative property*: R&D and knowledge assets that are protected through intellectual property (IP) rights such as patents, designs, copyrights, and trademarks, and (3) e*conomic competencies*: knowledge embedded in a firm's human and structural resources such as firm-specific training, organizational capital, and branding.[17]

The CHS approach is based on expenditures on own produced intangible assets and purchased knowledge services. Following this approach, we have first extracted information on firms' own account investment in knowledge-based capital assets, available from the CIP and the ASI surveys: these are annual additions to capitalized R&D; software; copyrights, patents and licenses for intellectual property; and other fixed intangible assets. Subsequently, in order to obtain a broader measure of investment in KBC to also include purchased knowledge services, we added annual expenditures on purchased R&D services; royalties on technical know-how; and expenditure on management and marketing fees as proxy for organizational and branding capital.[18] Finally, we have constructed measures of investments in KBC,

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[15]On average each firm appears 3.4 times in the analyzed panel data. This average is due to some firms entering and exiting over the 2006–2012 period, either because of cessation of economic activity, or because of mergers and acquisitions. Other reasons could include changes in employment with downsized firms with less than 20 employees not being included in the more detailed surveys.

[16]Deflators for specific intangible fixed assets or price indices for gross fixed capital formation were not available to us at the time this analysis was carried out. However, capital stocks by manufacturing industry and by asset type in constant and current prices were made available recently. We therefore tested the robustness of our findings using these asset specific deflators for both tangible and intangible assets. The results are quantitatively and qualitatively similar with the estimates reported in Tables 3-5. These results are available from the authors upon request.

[17]Expenditures on market research and advertising.

[18]The expenditures data on knowledge services are available in the CIP and the ASI, in addition to the investment variables.

by aggregating the capitalized and current expenditures for own account knowledge-based assets and purchased knowledge services as follows:

- *investment in R&D*: annual capitalized R&D expenditure and expenditures for purchased R&D services;
- *investment in intellectual property*: annual capitalized expenditures on copyrights, patents and licenses and expenditures on royalties on technical know-how;
- *investment in software*: annual capitalized expenditures for computer software;
- *investment in organizational and branding capital*: expenditures on management and marketing fees;
- *investment in other intangibles*: capitalized expenditures on other intangible fixed assets;

- *total investment in intangibles*: investment in R&D, software, organizational, and branding capital, intellectual property, and other intangible assets.

Given the advantage of the granularity of our data, we analyze investment in R&D and investment in intellectual property assets (henceforth IP) as distinct investments.[19]

One of the key contributions of this paper is the analysis of the heterogeneous investment behavior and performance of different types of firms. Firms' decisions related to investment in KBC are likely to be influenced by their ownership status (Irish or foreign-owned), their sector of activity, their involvement in exporting and their size. This perspective is informed by previous firm-level evidence on investment in innovation[20] and further supported by the descriptive analysis in this section.

Table 1 explores the differences in the average amounts invested in intangibles assets and reveals systematic and statistically significant gaps across the various subgroups in which the main sample was divided. For each subsample, two sets of figures are shown: the mean value regardless of firms' investment status and, in parenthesis, the mean value computed only on the fraction of firms reporting positive investment figures. The share of firms with positive investment, also reported (Investment >0), varies substantially across subsamples and needs to be taken into account in order to compare the investment behavior accurately. Firms might, in fact, self-select into investing in intangibles, with this propensity varying between the various categories of firms analyzed.[21]

Irish-owned firms show a lower intensity[22] of investment in KBC than foreign-owned firms, in all types of intangible assets: the gap is largest for IP assets, followed by investment in organizational capital and investment in R&D. The

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[19]Aggregating R&D and IP assets does not affect the empirical findings. These results are available on request from the authors.

[20]This evidence has been obtained with analysis based on the CDM model (Crépon et al. 1998). Recent reviews of this evidence include Mairesse and Mohnen (2010), Ruane and Siedschlag (2013), and Broström and Karlsson (2017). Siedschlag and Zhang (2015) provide evidence for Ireland.

[21]From an econometric point of view, the selection bias is not problematic since we observe both investors and non-investors in intangibles and we exploit all firms in the analysis.

[22]Measured as investment per employee.

TABLE 1
MEAN DIFFERENCES IN KEY VARIABLES BY FIRM GROUPS

	(1) / (2)	Irish (1) / Foreign (2)	Manufacturing (1) / Services (2)	Non-Exporters (1) / Exporter (2)	SMEs (1) / Large (2)	Small (1) / Medium and Large (2)
Intangibles/Empl.	Mean (1)	3 (6.6)	11.2 (26.4)	6.9 (16.4)	12.7 (26.3)	9.2 (20.4)
	Investment >0	45.9%	42.4%	42.4%	48.4%	45%
	Mean (2)	84.6 (119)	35.9 (50.7)	39.3 (59.0)	80.4 (107)	29.6 (51.0)
	Investment >0	70.2%	70.5%	66.3%	73.5%	57.9%
	Diff: (1)-(2)	*** (***)	*** (***)	*** (***)	*** (***)	*** (***)
R&D/Empl.	Mean (1)	0.3 (9.5)	0.5 (9.3)	0.3 (4.0)	1.1 (9.4)	1 (8.5)
	Investment >0	11.4%	5.8%	6.7%	12%	11.4%
	Mean (2)	5 (54.3)	2.9 (9.5)	3 (17.6)	1.4 (7.6)	1.4 (11.8)
	Investment >0	17.5%	30.6%	24.5%	18.2%	14%
	Diff: (1)-(2)	*** (***)	*** (0)	*** (***)	0 (0)	* (0)
IP Assets/Empl.	Mean (1)	0.6 (4.5)	6.9 (60.3)	4 (32)	6.9 (44.9)	4.9 (8.7)
	Investment >0	14.4%	11.4%	12.6%	15.4%	14.6%
	Mean (2)	55.9 (216)	21.1 (70)	23.8 (97)	57.1 (190)	18.7 (10.0)
	Investment >0	25.6%	30.1%	24.6%	30%	19.1%
	Diff: (1)-(2)	*** (***)	*** (0)	*** (***)	*** (***)	*** (***)
Software/Empl.	Mean (1)	0.1 (0.8)	0.1 (1.1)	0.1 (0.9)	0.1 (1.0)	0.1 (0.9)
	Investment >0	8.9%	10.6%	8.7%	9.1%	8.2%
	Mean (2)	0.3 (2.2)	0.1 (1.5)	0.2 (1.5)	0.5 (2.1)	0.2 (1.4)
	Investment >0	15.1%	8.2%	12.6%	21.9%	12.6%
	Diff: (1)-(2)	*** (***)	0 (0)	*** (0)	*** (0)	*** (**)
Org. Cap./Empl.	Mean (1)	1.7 (5.4)	3.3 (11.6)	2.3 (7.7)	4.3 (12.2)	2.8 (8.7)
	Investment >0	32.2%	28.2%	30.2%	34.9%	32.6%
	Mean (2)	29.7 (54.5)	16.7 (29.4)	15.8 (32.5)	39.1 (73.2)	12.4 (29.8)
	Investment >0	54.5%	56.7%	48.6%	53.4%	41.5%
	Diff: (1)-(2)	*** (***)	*** (***)	*** (***)	*** (***)	*** (***)
	No. (1)	31536	27711	25897	35618	22830
	No. (2)	6756	9863	12395	2674	15462

Notes: The figures are in thousands of Euro, in constant 2010 prices. SMEs includes small and medium-sized firms. We report two mean investment values for each asset and for each subsample of firms: the first is computed using all firms in a subsample, including firms with zero investment (figures not in parentheses), the second is computed using only firms reporting positive investment values (figures in parentheses). Inv. >0 denotes the share of firms with positive investment in each subsample. Diff: (1)-(2) denotes the statistical significance of the difference in mean values between the subsamples, for the null hypothesis that the mean difference is equal to zero: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$, and 0 when null hypothesis is upheld (in parenthesis the significance of the difference in means computed for firms with positive investment values only).

Source: Authors' calculations based on CIP and ASI data. Firms with 20 or more employees are included in the analysis.

intensity of investment in software is similar, but still significantly larger for foreign-owned firms. It is worth noting that despite the differences in the shares of firms investing in intangibles, the gap between Irish-owned and foreign-owned firms remains significant also when considering only investors.

On average, manufacturing firms invest more in intangibles per employee relative to service firms, although the difference is attenuated when considering only firms that report positive investment. The gap is widest for organizational capital; for IP assets and R&D the difference becomes insignificant once only the share of investors is accounted for, while for investment in software the difference is insignificant regardless of the sample considered.

Also being engaged in exporting is linked to the amount invested in intangible assets, with exporters investing more than non-exporters. The differences are all statistically significant, except for software, when comparing only firms reporting positive investment.

Across the three main size groups in which we divide all firms (small, medium, and large), the largest gap in the intensity of investment in intangibles emerges between large firms and the other two categories (grouped as SMEs), in favor of the former. Grouping medium-sized firms together with large ones and comparing them to small firms reveals differences in intangibles investment which are less sharp than if SMEs are compared to large firms.

An additional important aspect to consider when analyzing the relationship between investment in intangibles and productivity is potential reverse causality: firms invest in intangibles if they have resources to do so, such that more productive firms might be more likely to invest (Baum *et al.*, 2017). The econometric methodology we exploit in this paper allows to deal with this simultaneity issue (more on this in the next section). However, a first descriptive exploration of the association between productivity measured as real value added per employee and investment in intangibles is provided in Table 2.

Table 2 reports mean differences in value added per employee between firms that invest and firms that do not invest in intangibles, split by the various subsamples analyzed. As expected, in most cases there are statistically significant differences in productivity between investors and non-investors. While significant differences in productivity between investors and non-investors for all KBC assets exist in the case of Irish-owned firms, for all the other firm groups, investing in intangibles is related to higher productivity in at least two out of four KBC assets.

Taken together, these descriptive patterns provide motivation for our econometric analysis of the relationship between investment in KBC and productivity for all firms as well as by firm groups and sectors. The next section discusses the empirical strategy and model specifications to be estimated.

4. Econometric Methodology

4.1. *Baseline Model Specification*

Our empirical analysis of the relationship between investment in KBC and firm productivity is underlined by the production function theoretical model discussed in Section 2. As mentioned above, we estimate a dynamic econometric

TABLE 2

MEAN DIFFERENCE IN PRODUCTIVITY BETWEEN NON-INVESTORS (1) AND INVESTORS (2)

	(1) Irish Firms	(2) Foreign firms	(3) Manufacturing	(4) Services	(5) Non-Exporters	(6) Exporters	(7) Small firms	(8) SMEs	(9) Large firms
All Intangibles									
Mean (1)	139.8	553.8	133.4	192.7	148.3	307.9	180	178.4	311.7
Mean (2)	161.3	637.4	182.5	326.2	263.3	300.3	296.3	273.1	332.3
Diff (1)-(2)	***	0	***	***	***	0	***	***	0
R&D									
Mean (1)	152.1	554.5	168.1	226.9	184.1	309.2	221	212.1	318.5
Mean (2)	130.2	889.7	167.8	620.6	381.1	283.1	319.8	313.3	364.2
Diff (1)-(2)	**	***	0	***	***	0	***	***	0
IP assets									
Mean (1)	154.6	551.5	99.3	244	198.2	261.3	232.9	219.9	164.7
Mean (2)	119.9	787.1	327.5	288.9	188.7	431.5	227.3	247.5	708.8
Diff (1)-(2)	***	**	***	0	0	***	0	0	***
Software									
Mean (1)	145.9	623.9	163.3	245.2	192.3	297.7	228	217.9	342.4
Mean (2)	188.1	548.7	220.3	282.3	246.9	338.6	278.5	287.2	270.2
Diff (1)-(2)	***	0	***	0	0	0	0	**	*
Org. Cap.									
Mean (1)	143.7	587.1	111.3	218.4	171.2	278.5	205	199.1	199.4
Mean (2)	162.2	633.6	211.2	327.2	256.6	328.5	288.4	270.8	436.5
Diff (1)-(2)	***	0	***	***	***	***	***	***	***

Notes: The rows report mean productivity computed for firms investing in a specific intangible asset, regardless of whether a firm invests also in another intangible asset, that is, multiple investors contribute to more than one mean productivity figure. Figures are in thousands of Euro, in constant 2010 prices. SMEs includes small and medium-sized firms.

$*p < 0.10$, $**p < 0.05$, $***p < 0.01$, for the null hypothesis that the mean difference is equal to zero.

The "0" entries denote cases where fail to reject the null hypothesis that the mean difference is equal to zero.

Source: Authors' calculations based on CIP and ASI data. Firms with 20 or more employees are included in the analysis.

model, which accounts for the persistence of firm productivity over time and its dependence on past performance. In assessing the responsiveness of productivity to investment in KBC, we therefore account for the self-perpetuating productivity process triggered by the innate skills embodied in firms at entry, demand factors and the intangible capital already accumulated by firms in the past. In particular, we strive to eliminate the likely endogeneity arising from past productivity being correlated with current KBC investment. For these reasons, in the estimation set up we link firm productivity to its productivity performance in the previous year.[23]

In addition, we control for other firm-level factors related to productivity and investment in KBC suggested by the literature on determinants of productivity. Finally, we exploit the panel nature of the data, which allows us to account for unobserved time invariant confounding factors at the firm, industry and year level.[24] Taken together all these factors, we estimate the following dynamic model:

$$
\begin{aligned}
\ln\left(VA/Empl_{ij,t}\right) = {}& \beta_0 + \beta_1 \ln\left(VA/Empl_{ij,t-1}\right) + \beta_2 \ln\left(Intangibles/Empl_{ij,t}\right) \\
& + \beta_4 \ln\left(Tangibles/Empl_{ij,t}\right) + \beta_5 \ln(Wage/Empl)_{ij,t} \\
& + \beta_5 \ln(Age)_{ij,t} + \beta_5(For)_{ij,t} + \beta_6 \ln(Mark.Sh.)_{ij,t} \\
& + \beta_7(\text{Exp})_{ij,t} + \delta_t + \sigma_i + \rho_j + \mu_{ijt}
\end{aligned}
$$

(6)

The dependent variable, firm productivity[25], is measured as real value-added per employee[26] $\text{Ln}\left(VA/Empl_{ij,t}\right)$ of firm i in NACE 2-digit sector j and year t, taken in its natural logarithm. The lagged value of the dependent variable accounts for the dynamic process driving firm productivity. The main variable of interest is

[23]Controlling for past productivity over two periods instead of one leaves the results unchanged; furthermore, the second productivity lag turns out to be insignificant in the aggregate sample and most of the subsamples. These estimates are available on request.

[24]A possible source of concern could be measurement error due to firms' mis-reporting of capitalized expenditures. Since we have no reason to believe that this mis-reporting might not be random, this would bias the estimated coefficients towards zero.

[25]We use labor productivity instead of alternative measures of firm efficiency, such as TFP mainly because of data limitations. While information on investment at firm-level is available, information on physical capital stock at firm level is not available. Estimates obtained with the perpetual inventory method appear to be affected by measurement error most likely due to assumptions related to initial stocks and depreciation rates and the lack of sufficiently long time series.

[26]Given that information on physical output is not available, the productivity is measured on the basis of deflated sales. This implies that the productivity measure, particularly in the case of foreign-owned firms may be distorted by transfer pricing. Since transfer pricing is not observed in the data, to ensure that revenue distortions do not impact systematically the results of this analysis, the key regressions are run separately for Irish-owned and foreign-owned firms.

investment in intangible assets per employee,[27]Ln $\left(Intangibles/Empl_{ij,t}\right)$, whose association with productivity is identified by the parameter β_2.

We augment the theoretical model discussed in Section 2 with the time-varying explanatory variables, suggested by the literature on determinants of firm productivity:[28] the amount invested in tangibles per employee, the wage per employee (a proxy for a firm's human capital, or skill intensity), the age of the firm, an ownership indicator, a firm's market share (a proxy for a firm's market power), and a binary variable identifying export participation as a proxy for exposure to international competition. The remaining variables, δ_t, σ_i and ρ_j, denote a set of time, firm, and NACE 2-digit industry[29] fixed effects.[30]

The dynamic-panel setting applied to the available data requires instrumenting the lagged dependent variable Ln $\left(VA/Empl_{ij,t-1}\right)$ to circumvent the correlation of this regressor with the residual of the model (Nickell, 1981). For this purpose, we apply a generalized method of moments (GMM) estimation, exploiting further lags of the dependent variable to instrument Ln $\left(VA/Empl_{ij,t-1}\right)$. After verifying the correct specification of the model,[31] we make a choice in favor of the system-GMM estimator (Blundell and Bond, 1998). The system GMM jointly estimates the dynamic model both in differences and in levels,[32] using lagged levels as instruments for the regression in differences (from t-2 to t-6) and lagged differences as instruments for the regression in levels (dated t-1).[33] Estimating the model in both differences and levels addresses the weak instrument problem arising from using lagged-levels of persistent explanatory variables as instruments for the regression in differences, other than allowing the use of a larger portion of the sample.

[27]It can be argued that past investment in intangibles could have an impact on productivity beyond the effect of current investment, for reasons such as learning-by-doing or persistence of innovative efforts (Piva and Vivarelli, 2007). For this reason, we attempted to extend the dynamics of our model adding the lags of intangibles to the specification but failed to estimate any significant effect from past intangibles over and above the effect of current intangibles.

[28]See Syverson (2011) for a review of the recent literature on determinants of productivity and Arrighetti et al. (2014) for an analysis of the determinants of investment in intangibles.

[29]The NACE dummies are estimated only for a handful of firms which change sector over the period we analyse.

[30]Details of all variables and data sources are given in Table A1 in the Appendix.

[31]To guide the choice of the estimator and reassure about the correct specification of the GMM model, we compare results from a pooled-OLS model, a fixed-effects "within" estimator, a difference-GMM and a system-GMM estimator. While being both biased in a dynamic panel setting, the POLS and the FE estimators can be taken as, respectively, an upper and a lower bound estimate of the lagged dependent variable coefficient. Bond (2002) suggests that the GMM estimate of the lagged dependent variable should lie in between the POLS and the FE estimates, and that the system-GMM is to be preferred to the difference-GMM in case the latter estimate is close or below the FE estimate: this rule-of-thumb applies neatly in our context and suggests that the system-GMM is the appropriate estimator. These results are available on request from the authors.

[32]However, an assumption of this approach is that changes in the instrumental variables are uncorrelated with the fixed effects: this might appear as a strong assumption in our context, but given the similarity of results between the difference-GMM (which doesn't rely on this assumption) and the system-GMM estimators, we consider this shortcoming as not very worrisome.

[33]In the interest of space, we report results with one set of lags used as instruments (the t-2 to t-6 lags in levels for the differences regressions and the t-1 lag in differences for the level regressions). However, we estimated all regressions in this analysis exploiting all the possible combinations of lags (starting from t-2 and ending at t-6), in order to reassure about the robustness of the system-GMM estimates. The results are extremely similar across all lags specifications and are available on request from the authors.

The exogeneity of the lags exploited in the instrumentation is confirmed by the Arellano-Bond test for serial autocorrelation, which fails to reject the null of no first-order correlation in the residuals.[34] In addition, we report the Hansen J-test of the null hypothesis that the over-identifying restrictions are valid: we always fail to reject the null hypothesis, confirming the validity of the instrumentation procedure. In order to minimize the shortcomings associated with instruments over-proliferation, we present results that rely on the collapsed set of instruments obtained applying the method proposed by Roodman (2009). This method reduces drastically the number of instruments in estimation and the risk of over-fitting the model and obtaining inconsistent estimates (Newey and Smith, 2004).[35]

The GMM instrumentation procedure can help to instrument additional regressors, which are likely to exhibit a correlation with the residual of the model, other than the lagged dependent variable. In this context, it could be argued that investment in intangibles is determined simultaneously with firm productivity, causing a reverse causality bias. Similarly, also the value of investment in tangibles, the average wage per employee and a firm's market share are likely to be endogenous to productivity due to a simultaneity issue. To circumvent these endogeneity concerns we instrument investment in intangibles, investment in tangibles, wage per employee and the market share with their past values, exploiting the same lag structure exposed for the instrumentation of the lagged dependent variable.

4.2. *Testing for Complementarity/Substitution of Multiple Investments in KBC Assets*

In this paper, we go beyond the analysis of independent relationships between investment in intangible assets and firm productivity and examine whether interdependence might exist between simultaneous investments in multiple intangibles in their effect on productivity. Firms are likely to combine their resources and the marginal return from investing in one intangible asset might be higher if firms invest contemporaneously in another asset. In this case, the two investments are considered to be complementary; in the opposite case (i.e. of lower marginal returns), the two investments are seen as substitutes.

Previous studies exploring complementarity and substitution across investment in intangibles reported evidence of complementarities between R&D and patents, patents and marketing, patents and human capital (Crass and Peters, 2014); as well as complementarities between advertising and R&D and advertising and human capital (Higón *et al.*, 2017).

These papers, however, analyzed samples of firms pooled together, while we allow for the relationship between investment in intangibles and productivity to be different for different groups of firms and sectors. We show that analyzing the aggregate sample only misses important relevant results on the interplay of investments

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[34]This implies that lags starting at *t*-2 are uncorrelated with the residual and are valid instruments for the lagged dependent variable.

[35]We provide more details in a Technical Appendix available from the authors. In this Appendix we also provide estimates based on the principal components instrumental variables reduction method proposed by Bontempi and Mammi (2015), as a robustness check.

in the specific intangibles assets and argue, once again, that firm heterogeneity is a key factor in the link between investment in intangibles and productivity.

A further difference with respect to previous studies is methodological. Both Crass and Peters (2014) and Higón *et al.* (2017) apply the methodology of Carree et al. (2011) in order to investigate the existence of complementarity or substitutability effects. Carree et al. (2011) estimate the econometric model with interaction terms representing all the possible cross combinations of investments. Our approach is simpler and offers results whose interpretation, while being different, is in our view more convenient. We interact each (continuous) investment variable with a binary variable identifying whether firms invest contemporaneously in another intangible asset. The interactions allow us to explore how investing in a certain asset (identified by the dummy variable) influences the relationship between investing in each of the other intangible assets and firm productivity. This approach also allows us to keep the estimation procedure lighter, and not to overflow the GMM setting with a very large number of interaction terms, which would require instrumentation with past lags.

In order to test the existence of complementarity or substitutability between investments in various intangibles, we augment the econometric model described by equation (6) with a series of interaction terms as follows:

$$
\begin{aligned}
\ln\left(VA/Empl_{ij,t}\right) = {}& \beta_0 + \beta_1 \ln\left(VA/Empl_{ij,t-1}\right) + \beta_2 \ln\left(\textbf{\textit{Int(A)}}/\textbf{\textit{Emp}}_{ij,t}\right) + \beta_3 \textbf{\textit{int(B)}}_{ij,t} \\
& + \beta_4 \ln\left(\textbf{\textit{Int(A)}}/\textbf{\textit{Emp}}_{ij,t}\right) * \textbf{\textit{int(B)}}_{ij,t} + [\dots] + \beta_5 \ln\left(Tang/Emp_{ij,t}\right) \\
& + \beta_6 \ln\left(Wage/Emp\right)_{ij,t} + \beta_7 \ln\left(Age\right)_{ij,t} + \beta_8 \left(For\right)_{ij,t} + \beta_9 \ln\left(Mark.Sh.\right)_{ij,t} \\
& + \beta_{10}\left(Exp\right)_{ij,t} + \delta_t + \sigma_i + \rho_j + \mu_{ij,t}
\end{aligned}
$$
(7)

To capture complementarity/substitution effects, the amount invested in a certain intangible (say, A) is interacted with a binary variable taking value 1 if the firm is contemporaneously investing also in another intangible (say, B). The coefficient β_4 on the interaction term captures whether the contemporaneous investment in intangible B has a positive or negative effect on the relationship between investment in intangible A and firm productivity. We interpret a positive β_4 coefficient as indicating that investment in intangible B enhances the effect of investment in intangible A (i.e. the two investments are complementary), and a negative β_4 coefficient indicating that investment in intangible B is a substitute for investment in intangible A. We include in the model described by equation (7) investments in all specific intangible assets available in our dataset (R&D, IP assets, software, organizational and branding capital, and other intangibles), together with all pair-wise interactions.

5. Empirical Results

In this section we report the estimates of models (6) and (7), exploring the relation between investment in KBC assets and firm productivity. We start by presenting the findings for the aggregate of all intangibles; next, we analyze the productivity returns linked to investments in the specific KBC assets. Finally, we

discuss the results of our analysis of complementarity/substitutability of pair-wise combinations of investments in KBC.

5.1. *Investment in All Intangible Assets and Firm Productivity*

Tables 3 and 4 analyze the relationship between investment in all intangibles and firm productivity across various firm groups.

Before exploring the effect of investment in intangibles, in line with a large literature, our estimates confirm that a positive and significant determinant of firm productivity is its past performance. This result is found consistently across all the specifications estimated and firm groups analyzed. Persistence is rather high, with a ten percent higher productivity reflected, on average for all firms, in 5.4 percent higher productivity in the next time period.

The key finding of this analysis, in line with many other empirical studies (Riley and Robinson, 2011; Marrocu *et al.*, 2012; Crass and Peters, 2014; Higón *et al.*, 2017), is that investing in KBC is positively and significantly associated with firm productivity: an increase in investment in KBC per employee by ten percent translates into a 2.8 percent higher productivity.[36] This result, statistically robust and economically sizeable, is found when all firms are analyzed. However, as shown in Table 3, important heterogeneity exists across various groups of firms.

As mentioned in the Introduction, a novelty of our study is the separate analysis of indigenous and foreign-owned firms. Productivity is more responsive to investment in KBC in foreign-owned firms than in Irish-owned firms. This result suggests that productivity returns to investment in intangibles are larger in firms, which are more productive initially and are better at internalizing the returns from investment in intangible assets. An alternative (but not unrelated) explanation could lie in the fact that foreign firms might be endowed with more qualified personnel: Arrighetti *et al.* (2014) find that firm-level capabilities are an important source of heterogeneity in intangible investment, which in our context might explain the different productivity returns between indigenous and foreign-owned firms.

Contrasting manufacturing and service firms, we find that investment in KBC is positively linked to productivity for both types of firms, but the effect is statistically stronger for manufacturing firms relative to service firms. This result differs from Crass and Peters (2014) who find that, in Germany, productivity is (marginally) more responsive to investment in KBC in services than in manufacturing. In the context of our analysis for Ireland, this result can be explained by looking at the separate effects of investments in the various intangibles (Table 4 in the next subsection), of which, unlike for services, most of them are positive determinants of productivity in manufacturing firms.

Separating exporters and non-exporters shows that the elasticity of productivity with respect to KBC is marginally larger for non-exporters than for exporters. This is somewhat surprising, given that the sample of non-exporters is

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[36]The magnitude of the effects we estimate is larger than in some of the above-mentioned studies, although the figures are not directly comparable because of the different measures of KBC and empirical methodology.

predominantly composed of indigenous firms. However, the statistical significance of these coefficients is too low to draw strong implications from this result.

Finally, across the three size classes, investment in KBC appears positively associated with productivity in small and medium-sized firms (with up to 250 employees), with the coefficient being positive but insignificant for large firms.

With respect to other covariates, many of the estimated coefficients are statistically insignificant. This is to be expected, given the presence of firm fixed effects, for which what identifies the coefficients are changes in the respective variables over time, within firm. It appears that investment in tangible capital per employee does not have a significant effect on firms' productivity, over and above the impact of investment in KBC. Unlike services, manufacturing firms with an increasing market share are more productive, possibly reflecting a different role of scale economies in manufacturing firms relative to services firms.[37] In both sectors, firms operating in international markets (foreign-owned and exporters) are more productive than firms serving only the domestic market. This result is in line with the international evidence.[38]

5.2. *Investment in Specific KBC Assets and Firm Productivity*

This section examines how investment in specific KBC assets relates to firm productivity and provides insights on one of the key contributions of this paper: we show that investments in the various intangibles have different effects across firm groups, proving that firm heterogeneity is a key feature for the analysis of productivity returns to investment in intangibles.

Besides investment in R&D, whose effects have been investigated since a long time (see Hall *et al.*, 2010 for a review), our results indicate that investment in non-R&D assets also affects firm productivity. Investment in intellectual property (IP) assets (patents, copyrights, royalties, licenses), computer software, and organizational and branding capital have heterogeneous and often non-overlapping effects across firm groups. The results are reported in Table 4.

Among all types of investment in KBC, firm productivity is mostly sensitive to investment in computer software: the result in the aggregate sample is very large and more than proportional, with an elasticity of 1.6. Interestingly, this effect is confined to a few specific subsets of firms, as it appears to be driven by foreign-owned firms, firms in services, firms which export and firms that are of medium size (50 to 250 employees). Notwithstanding the different methodology and data used,[39] our sectoral results are comparable to those obtained by Riley and Robinson (2011) who find a larger effect of IT capital in services than in manufacturing.

In line with a large literature, we find that investment in R&D is positively associated with productivity. With the exception of the subsample of Irish firms, the related coefficient is lower compared to that of investment in software, with

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[37]This result is likely to also reflect the ability of larger firms to attract better inputs and better workers.

[38]For a review of this evidence see, for example, Greenaway and Kneller (2007).

[39]Riley and Robinson (2011) measure IT capital with the number and wages of workers in IT occupations.

an elasticity ranging between 2 and 0.3. It is noteworthy that investment in R&D tends to be positively linked to productivity in those firm groups where investment in software is not significantly associated with productivity: Irish-owned and manufacturing firms. Investment in R&D is also associated with the productivity of exporters, while having no effect on non-exporters. The finding that investments in software and in R&D seem to have opposing effects on the productivity of different firms might suggest that the two intangible assets are partly substitutable with each other, and that different firms might find it optimal to invest in either of the two assets, but not both. We investigate this aspect in the next section.

Related to investment in R&D is investment in IP, as both assets are classified as innovative property assets (Corrado *et al.*, 2005). Previous studies (Crass and Peters, 2014; Higón *et al*, 2017) found no significant association between investing in IP assets (specifically patents) and firm productivity. While we confirm this finding when analyzing all firms (the coefficient is only modestly significant), when unpacking the effect across firm groups, we find that in foreign owned and manufacturing firms productivity is strongly associated with IP investment, unlike Irish and services firms, where the coefficient is close to zero. In addition, also medium-sized firms, in contrast to small firms moreover and large firms on the other, are found to benefit from investing in IP assets. Although our results might not be directly comparable to the literature because of the peculiar features of our data, they again highlight the importance of considering heterogeneous effects when analyzing the impact of intangibles on productivity.

Investment in organizational and branding capital is strongly associated with the productivity gains, with most of the firm subgroups reporting a positive and significant coefficient. The estimated elasticity of this asset ranges between 0.2 and 0.5, with the most affected firms being those with foreign ownership, active in services sectors, and having more than 250 employees. Interestingly, among the size groups, large firms are the only ones where organizational capital investment appears linked to higher productivity: this highlights that, beyond a certain scale of operations, investing in managerial skills can be a crucial factor for productivity gains. In our data, organizational practices and marketing investment are bundled together in one variable; however, some comparison with previous studies can be made. Riley and Robinson (2011) also find organizational practices[40] having a positive impact on productivity, even exceeding that of software and R&D. Crass and Peters (2014) and Higón *et al*. (2017) unambiguously confirm that investment in advertising has a positive impact on productivity, in all firms. In contrast, in our analysis the productivity of manufacturing firms appears to be linked to investment in organizational and branding capital in a weaker way than that of services firms.

Finally, investment in other intangible assets (not classified in one of the above-mentioned categories) is found to be associated with higher productivity particularly in firms with foreign ownership and with more than 250 employees. It is difficult to comment on this result, since we are unable to identify which assets fall in this category. What appears interesting, however, is that there might be a

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[40]They exploit the number and wages of organizational workers, that is, managers and marketing workers.

tendency for foreign and large firms to ascribe a relevant fraction[41] of their intangibles investment to this residual group.

5.3. *Complementarity/Substitution Effects of Investment in Multiple Intangible Assets*

Estimates of complementarity/substitutability of pair-wise combinations of investments in intangible assets are presented in Table 5.[42] Important interaction effects are found for investment in the various intangible assets, with heterogeneous effects across the subsamples of firms.

Before proceeding to the exposition of the findings, a word of caution is needed. Notice that, in Table 5, the Hansen test of over-identifying restrictions upholds the null of instrument validity; however, the *p*-values equal to one are too high for the test to be considered meaningful.[43] The large number of regressors which we instrument (for reverse causality concerns) in the regressions based on specification (7), determine a rapid increase of the moment conditions in the GMM estimation, which weaken the power of the test (Bowsher, 2002). Unfortunately, a large number of (highly correlated) instruments could be problematic also for the consistency of the estimates (Ziliak, 1997; Newey and Smith, 2004). In Table 5, despite collapsing the instruments as suggested by Roodman (2009), the Hansen *p*-values do not allow us to eliminate the concerns linked to instrument over-proliferation. For this reason, we use alternative strategies to reduce the number of instruments, based on the principal component analysis (PCA) suggested by Bontempi and Mammi (2015).[44] The PCA strategy also yields Hansen *p*-values of one and does not inform our choice of which results are to be considered superior. We are aware that the identification of complementarities is a demanding exercise given the available data we analyze, and therefore these results should be interpreted as suggestive only. Even if our approach is more conservative than that proposed by Carree et al. (2011), our estimates are not completely free of concerns linked to instrument validity. Taking into account these concerns, we report the obtained complementarity/substitution estimates by imposing a further restriction: while we present the estimates obtained following the Roodman (2009) methodology (which yields results that are preferable to the PCA approach for the regressions results presented in Tables 3 and 4), we only interpret the estimated coefficients which hold[45] across both the estimation based on collapsing the instruments (reported in Table 5) and the principal component analysis (reported in Table 5B and C in the Technical Appendix).

The results suggest that investment in R&D is an important driver of the link between investment in intangibles and productivity. Firms that invest in R&D and simultaneously in other (non-R&D) intangibles have higher productivity returns from their investment in IP assets and in organizational capital. Investing in R&D

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[41]For their productivity.
[42]Table 5 shows only the main model coefficients and the interactions which turn out to be significant.
[43]The Hansen test suffers from a severe under-rejection problem in case of instrument proliferation.
[44]These results are presented in a Technical Appendix available from the authors upon request.
[45]Have same sign and significance, these coefficients are presented in bold.

appears to enhance the productivity returns of investment in IP assets in small firms and non-exporters; whereas in medium-sized firms investment in R&D is found to strengthen the impact of investment in organizational capital on productivity.[46] These results point to the crucial importance of investment in R&D for building a knowledge base that enable firms to exploit more efficiently other inputs, as shown among others by Teece (1986), Griffith *et al.* (2004), and Belderbos *et al.* (2014).

Investment in IP assets is also found to be an important complement of investment in other intangibles. Specifically, investing in IP assets increases the productivity returns of investment in R&D and in organizational and branding capital. The complementarity of investment in IP assets and in R&D is found for services firms, while in non-exporting firms, investing in IP assets is complementary to investment in organizational capital. These findings highlight the importance of prior knowledge, embedded in patents, licenses and copyrights, in enhancing the absorptive capacity of firms (Cohen and Levinthal, 1990) which make investment in R&D, management and marketing more productive (Crass and Peters, 2014). Furthermore, in the case of firms in services, productivity returns to investment in R&D are enhanced by investment in software. This result is consistent with recent evidence on complementarities between investments in R&D and information and communication technologies provided by Corrado *et al.* (2017) and Mohnen *et al.* (2018).

In addition to uncovering the complementarity of investments in R&D and IP assets, this paper makes a further contribution to the literature suggesting that investments in organizational and branding capital might substitute investments in other intangibles. It is worth noticing that investment in organizational capital appears to be substitutable to investments in intangibles which, for specific firm groups, are not significantly associated with firm productivity (for a comparison see Table 4). Investment in organizational capital is a substitute for investment in R&D in the case of exporters and in medium sized firms, and a substitute for IP assets in non-exporting firms.[47] We consider this finding interesting, because it suggests that while investment in organizational and branding capital has an overall positive effect on productivity, it could be a substitute for investment in intangibles, such as R&D in the case of exporters and IP assets in the case on non-exporters, which appear to have no significant effect on productivity in these firm groups. To the best of our knowledge, this evidence is new to the literature. Further research could shed light on the robustness of this result in the context of other countries' economic structures and institutional frameworks.

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[46]In one case, for non-exporters, R&D seems to decrease the effectiveness of another intangible, namely organizational capital.

[47]This peculiar result of organizational capital being a substitute of investments which, themselves, are not found to be associated with productivity gains, applies also for a number of other cases (for R&D investment of foreign, service and small firms; for IP investment of non-exporters). These coefficients, however, are not robust to applying the principal component analysis suggested by Bontempi and Mammi (2015).

TABLE 3
INVESTMENT IN ALL INTANGIBLE ASSETS AND FIRM PRODUCTIVITY

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent Variable					Ln (VA/Employee)					
Sample	All Firms	Irish	Foreign	Services	Manufacturing	Non-Exporters	Exporters	Small	Medium	Large
Ln(VA/Employee)$_{t-1}$	0.544***	0.510***	0.561***	0.561***	0.502***	0.469***	0.620***	0.520***	0.546***	0.566***
	(0.052)	(0.040)	(0.089)	(0.073)	(0.052)	(0.059)	(0.090)	(0.062)	(0.075)	(0.104)
Ln(Intangibles/Employee)	0.276**	0.287	0.374***	0.293*	0.294***	0.291†	0.208†	0.196**	0.193*	0.177
	(0.140)	(0.254)	(0.113)	(0.174)	(0.069)	(0.183)	(0.132)	(0.098)	(0.116)	(0.281)
Ln(Tangibles/Employee)	−0.078	−0.193	−0.028	0.045	0.097	−0.014	−0.116	0.029	−0.079	−0.098
	(0.124)	(0.168)	(0.151)	(0.155)	(0.139)	(0.171)	(0.152)	(0.198)	(0.145)	(0.180)
Ln(Wage/Employee)	−0.251	−0.115	−0.487	−0.117	0.102	0.548†	−0.916†	0.555†	−0.139	0.051
	(0.234)	(0.484)	(0.474)	(0.290)	(0.275)	(0.345)	(0.612)	(0.340)	(0.412)	(0.888)
Ln(Age)	0.020**	0.019***	0.031	0.023**	0.009	0.026***	0.009	0.012†	0.025**	0.015
	(0.009)	(0.007)	(0.025)	(0.010)	(0.010)	(0.009)	(0.016)	(0.008)	(0.012)	(0.037)
Foreign-owned	0.098***			0.072**	0.104***	0.062**	0.117***	0.103***	0.072**	0.074
	(0.022)			(0.029)	(0.021)	(0.030)	(0.024)	(0.030)	(0.031)	(0.054)
Ln(Market Share)	0.938†	1.325†	0.355	0.344	1.154**	1.152†	0.946	3.701	0.889	0.036
	(0.623)	(0.918)	(0.839)	(0.991)	(0.549)	(0.774)	(0.658)	(2.619)	(1.069)	(0.806)
Exporter	0.040***	0.046***	0.007	0.037**	0.025***			0.019†	0.030	0.080*
	(0.011)	(0.014)	(0.041)	(0.016)	(0.007)			(0.012)	(0.024)	(0.042)
Constant	−0.001	−0.017†	0.107**	0.014	−0.009	−0.040***	0.066**	−0.009	0.007	−0.017
	(0.011)	(0.011)	(0.050)	(0.014)	(0.010)	(0.012)	(0.032)	(0.010)	(0.023)	(0.042)
Time FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NACE 2-dig FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N observations	25674	20729	4945	17336	7809	16405	9269	14560	9069	2045
GMM instr.	39	38	38	39	39	38	38	39	39	39
P value AR2 test	0.964	0.734	0.980	0.635	0.379	0.469	0.298	0.468	0.767	0.692
P value Hansen test	0.200	0.366	0.228	0.722	0.993	0.275	0.568	0.273	0.214	0.168

Notes: Estimates are obtained with a system-GMM estimator. We instrument all the continuous variables, except age, with lagged levels dated from t-2 to t-6 in the equation in difference and lagged differences dated t-1 in the equation in levels. Instruments are collapsed following Roodman (2009), in order to prevent estimates distortion arising from instrument over-proliferation (see Technical Appendix for details). Standard errors clustered at the NACE 2-digit sector level in parentheses.
†$p < 0.15$, *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Source: Authors' calculations based on data from on CIP and ASI data.

TABLE 4
INVESTMENT IN SPECIFIC INTANGIBLES ASSETS AND FIRM PRODUCTIVITY

Dependent Variable	Ln (VA/Employee)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sample	All Firms	Irish	Foreign	Services	Manufacturing	Non-Exporters	Exporters	Small	Medium	Large
Ln(VA/Employee)$_{t-1}$	0.513***	0.485***	0.515***	0.494***	0.485***	0.475***	0.587***	0.520***	0.609***	0.475***
	(0.045)	(0.039)	(0.068)	(0.068)	(0.050)	(0.049)	(0.078)	(0.064)	(0.089)	(0.079)
Ln(Software/Employee)	1.610***	2.213	1.648***	2.246*	0.761	1.000	1.607***	−1.379†	3.427*	0.937
	(0.561)	(1.842)	(0.574)	(1.176)	(0.616)	(1.924)	(0.541)	(0.924)	(2.030)	(0.717)
Ln(R&D/Employee)	0.102	2.149***	0.107	−0.164	0.286**	−0.071	0.354*	0.016	0.173	−0.399
	(0.255)	(0.807)	(0.226)	(0.735)	(0.139)	(0.308)	(0.185)	(0.321)	(0.218)	(0.407)
Ln(IP Assets/Employee)	0.130†	0.092	0.171**	0.008	0.263***	0.334	0.071	0.046	0.243***	−0.070
	(0.088)	(0.254)	(0.077)	(0.129)	(0.036)	(0.285)	(0.105)	(0.198)	(0.055)	(0.141)
Ln(Org. & Branding/Empl)	0.359***	0.384†	0.436***	0.302***	0.194†	0.198**	0.385***	0.127	0.152	0.526***
	(0.092)	(0.246)	(0.117)	(0.109)	(0.122)	(0.099)	(0.132)	(0.218)	(0.123)	(0.189)
Ln(Other Intang./Employee)	1.129**	0.001	1.356***	1.275**	0.599*	−0.326	0.304	0.020	−0.104	0.530**
	(0.518)	(0.252)	(0.474)	(0.558)	(0.357)	(0.727)	(0.265)	(0.329)	(0.207)	(0.266)
Ln(Tangibles/Employee)	−0.126	−0.072	−0.260*	−0.104	−0.023	−0.090	−0.188†	0.092	−0.204*	−0.056
	(0.153)	(0.151)	(0.153)	(0.158)	(0.103)	(0.156)	(0.125)	(0.149)	(0.115)	(0.178)
Ln(Wage/Employee)	0.209	0.112	0.130	0.566	0.190	0.735	−0.021	0.923*	−0.059	1.291
	(0.245)	(0.456)	(0.489)	(0.401)	(0.314)	(0.654)	(0.476)	(0.532)	(0.313)	(1.000)
Ln(Age)	0.014*	0.020**	0.018	0.014	0.008	0.021***	−0.003	0.008	0.023*	−0.010
	(0.007)	(0.008)	(0.025)	(0.011)	(0.012)	(0.007)	(0.015)	(0.007)	(0.012)	(0.035)
Foreign-owned	0.081***			0.054*	0.102***	0.043	0.082***	0.087***	0.055**	0.069*
	(0.019)			(0.031)	(0.019)	(0.036)	(0.020)	(0.028)	(0.027)	(0.041)
Ln(Market Share)	0.851	0.276	0.535	1.309	1.345**	1.938*	0.369	3.955†	0.787	−0.211
	(0.656)	(0.842)	(0.767)	(1.258)	(0.669)	(1.057)	(0.708)	(2.634)	(0.707)	(0.727)
Exporter	0.029***	0.040***	0.002	0.015	0.024***			0.011	0.029†	0.070*
	(0.011)	(0.012)	(0.033)	(0.017)	(0.008)			(0.017)	(0.018)	(0.039)

TABLE 4 (CONTINUED)

Dependent Variable Ln (VA/Employee)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sample	All Firms	Irish	Foreign	Services	Manufacturing	Non-Exporters	Exporters	Small	Medium	Large
Constant	−0.004	−0.007	0.129***	−0.009	−0.021**	−0.045**	0.034*	−0.018	−0.018	−0.063†
	(0.010)	(0.014)	(0.032)	(0.016)	(0.010)	(0.018)	(0.021)	(0.016)	(0.013)	(0.039)
Time FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NACE 2-dig FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N observations	25674	20729	4945	17336	7809	16405	9269	14560	9069	2045
No. GMM instr.	63	62	62	63	63	62	62	63	63	63
P value AR2 test	0.657	0.574	0.516	0.486	0.449	0.426	0.501	0.369	0.775	0.952
P value Hansen test	0.303	0.323	0.412	1.000	1.000	0.501	0.386	0.315	0.236	0.637

Notes: Estimates are obtained with a system-GMM estimator. We instrument all the continuous variables, except age, with lagged levels dated from t-2 to t-6 in the equation in difference and lagged differences dated t-1 in the equation in levels. Instruments are collapsed following Roodman (2009), in order to prevent estimates distortion arising from instrument over-proliferation (see Technical Appendix for details). Standard errors clustered at the NACE 2-digit sector level in parentheses.
†$p < 0.15$, *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Source: Authors' calculations based on data from on CIP and ASI data.

TABLE 5
INVESTMENT IN INTANGIBLES AND PRODUCTIVITY: INTERDEPENDENCE PATTERNS BY FIRM SIZE AND GROUPS

Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					Ln (VA/Employee)					
Sample	All firms	Irish	Foreign	Services	Manufacturing	Non-Exporters	Exporters	Small	Medium	Large
Ln (VA/Empl)$_{t-1}$	0.506***	0.531***	0.516***	0.529***	0.463***	0.427***	0.556***	0.520***	0.611***	0.523***
	(0.045)	(0.050)	(0.077)	(0.066)	(0.052)	(0.050)	(0.050)	(0.059)	(0.067)	(0.072)
Ln (Soft/Emp)	2.453†	−3.531	1.876*	2.109	6.254	0.992	1.015	−9.550	5.904***	3.050
	(1.615)	(3.772)	(1.047)	(3.061)	(12.525)	(1.316)	(1.926)	(6.940)	(1.032)	(2.294)
Ln (R&D/Emp)	0.377	1.123**	0.270	0.184	0.501***	−0.282	0.380	0.324	0.201	−0.449
	(0.311)	(0.552)	(0.283)	(0.398)	(0.177)	(1.011)	(0.325)	(0.871)	(0.190)	(0.752)
Ln (IP Ass./Emp)	0.123†	0.431†	0.165**	0.047	0.274***	0.039	0.099	−0.040	0.220**	0.027
	(0.081)	(0.263)	(0.082)	(0.047)	(0.059)	(0.068)	(0.121)	(0.061)	(0.095)	(0.131)
Ln (Org Cap/Emp)	0.285***	0.054	0.282***	0.139*	0.184	0.302***	0.264**	0.215***	0.065	0.311**
	(0.065)	(0.267)	(0.073)	(0.072)	(0.593)	(0.112)	(0.108)	(0.074)	(0.132)	(0.158)
Ln(Soft/Emp) * R&D	0.194	2.364	−0.176	−2.276	−0.526	−1.070	−1.605	−6.484	3.547†	−0.129
	(1.024)	(1.980)	(1.311)	(2.326)	(1.936)	(2.782)	(2.194)	(6.808)	(2.225)	(0.780)
Ln(Soft/Emp) * Org Cap	−0.692	1.893	−0.371	1.082	1.096	−1.981	1.843	7.697	−6.449**	−2.008
	(1.409)	(2.685)	(1.366)	(1.812)	(2.588)	(2.401)	(2.451)	(7.593)	(2.521)	(1.437)
Ln(Soft/Emp) * IP Ass.	−0.027	1.461	−0.082	−0.654	−5.565	3.766*	0.009	10.527†	−2.414	0.237
	(2.082)	(1.792)	(1.223)	(2.887)	(15.296)	(2.262)	(2.273)	(7.277)	(1.697)	(0.936)
Ln(R&D/Emp) * Soft.	−0.095	−0.332	−0.135	0.604***	−0.233	−0.086	−0.175	−0.531†	−0.136	0.530
	(0.255)	(0.646)	(0.223)	(0.184)	(0.385)	(1.111)	(0.326)	(0.327)	(0.310)	(0.419)
Ln(R&D/Emp) * Org Cap	−0.264**	−0.346	−0.305**	−0.762***	−0.235*	0.508	−0.191**	−0.410*	0.381***	0.496
	(0.115)	(0.743)	(0.126)	(0.290)	(0.122)	(0.950)	(0.082)	(0.213)	(0.124)	(0.879)
Ln(R&D/Emp) * IP Ass.	0.057	0.045	0.131	0.674***	0.026	0.145	0.020	0.007	0.214	−0.501
	(0.273)	(0.605)	(0.230)	(0.185)	(0.166)	(0.833)	(0.298)	(0.916)	(0.230)	(1.083)
Ln(Org Cap/Emp) * Soft	−0.056	1.262	0.035	0.486†	−0.199	0.155	−0.048	0.189	0.132	−0.191

TABLE 5 (CONTINUED)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent Variable					Ln (VA/Employee)					
Sample	All firms	Irish	Foreign	Services	Manufacturing	Non-Exporters	Exporters	Small	Medium	Large
	(0.219)	(0.959)	(0.202)	(0.299)	(0.333)	(0.407)	(0.153)	(0.262)	(0.202)	(0.220)
Ln(Org Cap/Emp) * R&D	−0.153	−0.139	−0.060	0.046	0.007	**−0.513**	0.082	−0.174	**0.303**	−0.024
	(0.161)	(0.423)	(0.114)	(0.178)	(0.090)	**(0.240)**	(0.104)	(0.259)	**(0.154)**	(0.201)
Ln(Org Cap/Emp) * IP Ass.	0.411*	−0.632	0.315†	0.216	0.185	**0.496***	0.054	−0.064	−0.160	0.233
	(0.243)	(0.528)	(0.202)	(0.293)	(0.751)	**(0.292)**	(0.247)	(0.245)	(0.147)	(0.388)
Ln(IP Ass./Emp) * Soft	−0.056	−0.162	0.014	0.021	0.208***	−0.097	0.025	0.116	**0.396***	−0.062
	(0.183)	(0.351)	(0.162)	(0.074)	(0.067)	(0.162)	(0.121)	(0.253)	**(0.151)**	(0.084)
Ln(IP Ass./Emp) * R&D	0.052	−0.230	−0.010	0.076	0.005	**0.386**	−0.089†	**0.420**	−0.027	−0.068
	(0.111)	(0.429)	(0.072)	(0.143)	(0.067)	**(0.152)**	(0.061)	**(0.205)**	(0.053)	(0.121)
Ln(IP Ass./Emp) * Org Cap	−0.145	−0.322	−0.151	−0.245	−0.012	**−0.285**	0.005	**0.201**	0.023	−0.021
	(0.130)	(0.369)	(0.116)	(0.175)	(0.090)	**(0.141)**	(0.067)	**(0.101)**	(0.063)	(0.085)
Other Firm Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NACE 2-dig FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N observations	25674	20729	4945	17336	7809	16405	9269	14560	9069	2045
GMM instruments	243	242	242	243	243	242	242	243	243	243
P value AR2 test	0.758	0.386	0.776	0.728	0.955	0.322	0.405	0.277	0.408	0.918
P value Hansen test	1	1	1	1	1	1	1	1	1	1

Notes: Estimates are obtained with a system-GMM estimator. We instrument all the continuous variables, except age, with lagged levels dated from $t-2$ to $t-6$ in the equation in difference and lagged differences dated $t-1$ in the equation in levels. Instruments are collapsed following Roodman (2009), in order to prevent estimates distortion arising from instrument over-proliferation (see Technical Appendix for details). Standard errors clustered at the NACE 2-digit sector level in parentheses. Bold indicates coefficients.

†$p < 0.15$, *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Source: Authors' calculations based on data from on CIP and ASI data.

6. CONCLUSIONS AND POLICY IMPLICATIONS

This paper extends a Cobb-Douglas production function theoretical framework and provides novel evidence on productivity returns of investment in intangible assets in a small open economy. To the best of our knowledge, we make three methodological contributions to the literature. First, we model the relationship between investment in KBC and productivity as a dynamic process accounting for productivity's persistence and path-dependency. Second, we contextualize the relationship between investment in KBC and productivity to the features of a small open economy accounting for the role of exporting and inward foreign investment. Third, and related to a small open economy framework, we relax the assumption of a homogeneous behavior of a representative firm and allow the link between productivity and investment in KBC to differ across groups of firms and sectors.

The results of this analysis indicate that investment in KBC is positively associated with firm productivity. On average, *ceteris paribus*, a ten percent increase in the investment in KBC per employee is associated with a three per cent productivity gain. However, this aggregate result hides heterogeneous effects across firm groups, which in a small open economy like Ireland are more evident than in large economies.

Our estimates identify a larger responsiveness of productivity to investment in KBC for foreign-owned firms in comparison to Irish-owned firms. Across size groups, the sensitivity of productivity to investment in KBC is found to be greater for small and medium-sized firms (with less than 250 employees). A noteworthy finding of this research is that investment in KBC appears to be more important for productivity than investment in tangible assets which, over and above other factors, does not have a significant effect. A possible explanation for this observation might be the small variation over the analyzed period in investment in tangible capital, as well as the limited impact on productivity due to pre-existing large stocks of physical capital.

Investment in R&D is positively linked to firm productivity in some of the sub-samples of firms analyzed, namely indigenous firms, manufacturing firms and exporters, with no distinction found among firms with different size. The productivity of foreign-owned firms, and of those active in services sectors is mainly associated with investment in non-R&D intangible assets, including software and organizational and branding capital.

In the case of investment in non-R&D assets (IP assets, software, organizational and branding capital, and other intangibles), investment in software is most strongly associated with higher productivity (both economically and statistically). Higher investment in organizational and branding capital also appears to positively affect the productivity of the various types of firms analyzed, with distinctions in terms of firms' ownership or sector of activity being more nuanced. In contrast, investing in IP assets only affects the productivity of foreign-owned firms, medium sized firms and manufacturers.

Furthermore, this analysis finds that investments in multiple intangible assets could be complementary as well as substitutable depending on the specific combination of investments and firm and sector characteristics. One key result is that investing in R&D and IP assets enhances the productivity returns of simultaneous

investments in other intangible assets. This result highlights the importance of investment in R&D and prior knowledge for building firms' absorptive capacity as suggested by, among others, Griffith *et al.* (2004) and Belderbos *et al.* (2014). Another novel result of this analysis is that investments in management and marketing are substitutable with investments in other intangible assets, particularly for firms where these (other) investments do not appear to matter for productivity.

Taken together, our research results indicate that productivity responds differently to investments in various types of KBC across Irish-owned and foreign-owned firms. For Irish-owned firms, productivity is most strongly linked to investment in R&D intangible assets and in organizational and branding capital. For foreign-owned firms, productivity is most strongly linked to investment in non-R&D intangible assets such as computer software, intellectual property assets and organizational and branding capital.

It is widely acknowledged that given market and systemic failures specific to knowledge-based capital,[48] firms tend to underinvest in such assets, below the socially desirable level. The empirical evidence provided in this paper suggests a number of implications for the design of policies and strategies aimed at incentivizing investment in KBC in the enterprise sector.

First, the results of this analysis indicate that a more comprehensive policy approach to incentivize investment in a broader range of intangible assets beyond R&D such as IP assets, computer software, and organizational and branding capital could be beneficial. Second, the results also indicate that incentivizing firms to invest in R&D could enhance the productivity returns of investments in other intangible assets. In contrast, over-investing in management and marketing could be counterproductive. Third, the evidence provided in this paper suggests that policy measures should be targeted to specific groups of firms with similar characteristics, such as: domestic versus foreign-owned; SMEs versus large; manufacturing versus services firms.

While this paper highlights the importance of investments in a broad range of intangible assets for firm productivity, further research could provide useful evidence. Possible research directions that could be explored include identifying factors driving firms' choice of investments in various intangible assets and how these choices affect firm performance outcomes such as exporting and employment growth.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web site:

Table A1. Description of variables

Table A2. Descriptive statistics for regression variables