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Intangible Capital and Labour Productivity Growth: A Review of the Literature

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Abstract. This paper surveys a wide range of studies on the impact of capital investment in intangible assets on labour productivity growth and highlights their main findings on. Surveying the literature at the country, industry and firm level, this paper finds evidence of the increasing importance of business investment in intangible assets in explaining the dynamics of labour productivity growth. Moreover, the findings reported in the literature surveyed suggest that in order to fully reap the benefits of investment in information and communication technology (ICT) and artificial intelligence (AI), it is essential for businesses to make complementary investment in intangible assets. In addition, the literature on the drivers of business capital investment in intangibles highlights the importance of having in place a well-endowed infrastructure of public intangibles. Judging from the wide range of economic literature surveyed, this paper finds that the contemporary economic debate now broadly acknowledges the importance of intangibles for the transformation of developed economies towards becoming fully-fledged knowledge economies.

Keywords. Intangible Capital, Labour Productivity Growth, Total Factor Productivity Growth, Information and Communication Technology, Artificial Intelligence, European Union

1. Introduction

Labour productivity growth is one of the main contributors to an economy's competitiveness (Krugman, 1994) and rising prosperity (Heil, 2018). This applies to the country, industry and firm level. The key concept of labour productivity growth can be defined as the ability of an economy to increase its output per hours worked by a more efficient usage of a given level of production inputs, such as tangible and intangible capital. The residual productivity component within the production input factors is called total factor productivity (TFP). TFP reflects the overall level of technology and other efficiency factors found in the realm of public intangibles, such as the quantity and quality of a high-skilled labour force, well-functioning formal and informal institutions and a well-designed policy framework. Differences in TFP explain a large fraction of variance in the income and wealth disparities across countries (Hall and Jones, 1999; World Bank, 2006), industries (Van Ark *et al.*, 2008) and firms (Syverson, 2011). When modelled as a Cobb-Douglass production function, labour productivity growth takes the following form: $q_{i,t} = A_{i,t} k_{i,t}^{\alpha} r_{i,t}^{\beta}\ \varepsilon_{i,t}$ where q is labour productivity growth, A is TFP, k is tangible capital deepening, r is intangible capital deepening and ε is the error term in country i at time t.

Recent research reports a disappointing performance in labour productivity growth among OECD countries in the midst the ongoing revolution in ICT and AI (OECD, 2015). This is partly due to mismeasurement of business intangibles in the official national accounting framework, as highlighted by Corrado, Hulten and Sichel (hereafter CHS) (2005, 2009). Mismeasurement, however, is not the only key to explaining the decline in labour productivity

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growth (Syverson, 2017; Haskel and Westlake, 2018b). Three recent prominent contributions have highlighted the contextual role of a decline in TFP in relation to the level of business investments in intangibles.

First, Van Ark and O'Mahony, as well as Bounfour and Miyagawa argue that the decline in labour productivity and TFP growth stems largely from a slower diffusion of technology and innovation due to low growth rates of investments in ICT and complementary intangibles (Bounfour and Miyagawa 2015; Van Ark and Jäger, 2017; Van Ark, 2016; Van Ark and O'Mahony 2016). Second, Haskel and Westlake (2018a, b) highlight a reduction in the spill-over effects of intangibles on TFP due to the widening gap of intangible investment between leader and laggard firms. Third, Brynjolfson *et al*. (2017) argue that more investment in complementary intangibles are needed to reap the full labour productivity growth benefits from AI.

But does the existing literature support such claims of a pivotal role played by business intangibles in labour productivity growth? Precisely what is the impact of business intangibles on labour productivity growth? Although there exists a broad range of surveys on productivity growth in general (Syverson, 2011) and on single business intangible capital dimensions, such as R&D (Belz *et al*., 2016; Heil, 2018; Zuñiga-Vicente *et al.*, 2012, there exists no individual survey on the impact of investment in intangible assets on labour productivity growth. This gap in the research is acknowledged by the existing surveys on labour productivity growth (Syverson, 2011, p. 341; Heil, 2018, p. 1361). With the aim of closing this gap, this contribution surveys the existing empirical evidence of the impact of capital investment by business in intangible assets on labour productivity growth with respect to five distinct aspects of the literature. It surveys studies that analyse: i) the country level, ii) the industry level, iii) the firm level, iv) complementarity investments and spillover effects and v) drivers of business intangibles.

The paper is structured in the following manner. Section 2 offers the most recent evidence concerning the decline in labour productivity growth across OECD countries. Section 3 identifies the methodological framework of the paper. Section 4 discusses the CHS approach in light of the existing business and economics literature. Section 5 surveys the literature on intangible capital and labour productivity growth with respect to the five distinct aspects. Section 6 concludes by discussing the implications and offering an outlook.

2. Declining Labour Productivity Growth

Figure 1 shows labour productivity growth for the four time periods – 1995-2000, 2001-2007, 2008-2013 and 2014-2017 – and compares the two Euro Area (EA) countries France and Germany with the average EA-18, the UK, the US and Japan. In line with the existing literature (Van Ark and Jäger, 2017), we detect a pronounced decline in labour productivity growth from 2008 onwards. Whereas labour productivity growth rates for the EA18 were still positioned at 2.8% and 2.6% from 1995-2000 and 2001-2007, respectively, one detects a strong decline in times of crisis from 2008-2013 to 0.8%, with a slight recovery to 1.3% from 2014-2017. The same pattern can be detected in the two largest EA countries Germany and France, while the UK's decline from 2008-2013 was more pronounced. A different pattern can be detected in the US and Japan, both of which experienced a steady decline in labour productivity growth from 1995 onwards, with growth reaching rates of 0.6% and 0.5%, respectively, in times of economic recovery.

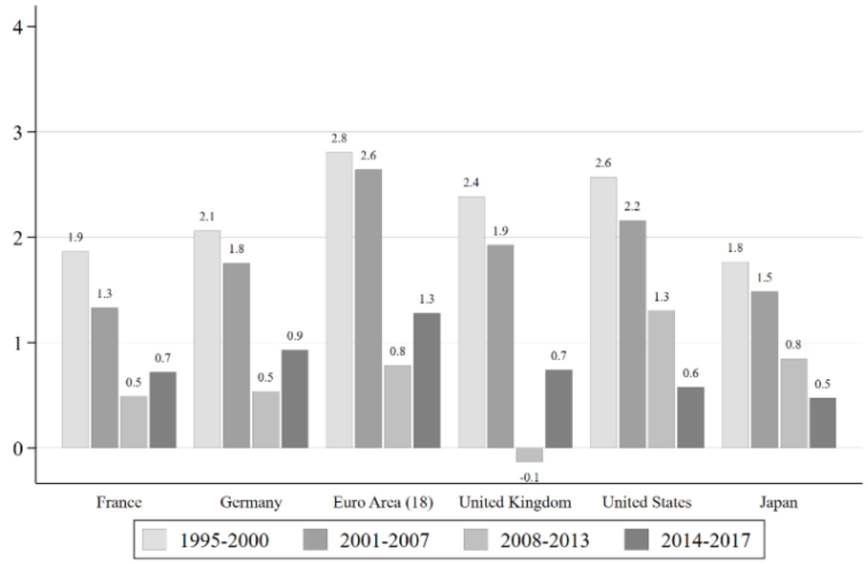

Figure 1. Labour Productivity Growth, EA, UK, US and Japan, 1995-2017.
Note: EA-18 uses a simple average, comprising all the 19 Euro Area countries except Malta.
Source: Own estimation based on EUKLEMS database (Stehrer *et al.*, 2019).

Figure 2 shows the time series pattern for tangible and intangible capital investment vis-à-vis labour productivity growth over the 20-year time period between 1995-2015 for the five largest EA economies Germany, France, Italy, Spain and the Netherlands, as well as an EA-18 country sample, the US and Japan. First, we detect a divergence in the pattern of investment in tangible in intangible assets since the start of the crisis (Corrado *et al.*, 2018, Roth 2019). Second, whereas we detect a small but steady increase in labour productivity growth in the EA-18, and its core countries Germany, France and the Netherlands, the Mediterranean country Italy shows no sign of labour productivity growth. And the non-EA countries – the UK, the US and Japan – only show a slowdown in labour productivity growth from 2008 onwards.

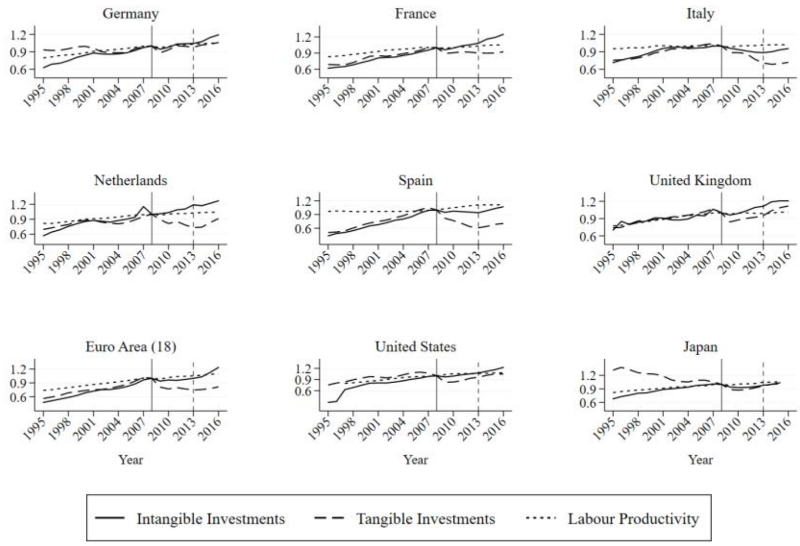

Figure 2. Tangible and Intangible Capital Investments and Labour Productivity, EA, UK, US and Japan, 1995-2017.
Note: EA-18 uses a simple average. Each of the three values is standardized in 2008. *Source:* Own estimations based on EUKLEMS database (Stehrer *et al.*, 2019).

3. A Framework for the Analysis[1]

Figure 3 displays the analytical framework devised for this paper. As shown in the figure, the survey of the analyses at the country level serves as the starting point. These analyses have been strongly influenced by the work of Nakamura (1999, 2001) and the seminal approach taken by CHS (2005, 2009), the later which developed a novel methodological framework for measuring business intangibles and analysing their impact on labour productivity growth in the US. Several growth accounting studies have been conducted applying the CHS framework to individual or groups of countries, particularly EU member states. In addition, growth econometric studies have been conducted at the country level (Roth and Thum, 2013), industry level (Niebel *et al.*, 2017) and firm level (Marrocu *et al.*, 2012). The need for country and firm analyses was originally commented upon by Solow (1987) for the country level and by Griliches (1979) for the firm level. Complementary investments alongside capital investments in ICT and AI foster both labour productivity and TFP growth. Endowments in public intangible assets are also acknowledged to act as a relevant driving force for business investment in intangible assets, as well as TFP growth. The studies surveyed in this paper therefore analyse the impact of intangible assets on labour productivity i) at the country level, ii) at the industry level, iii) at the firm level, iv) on complementary investments and v) as drivers of capital investment by business in intangible assets.

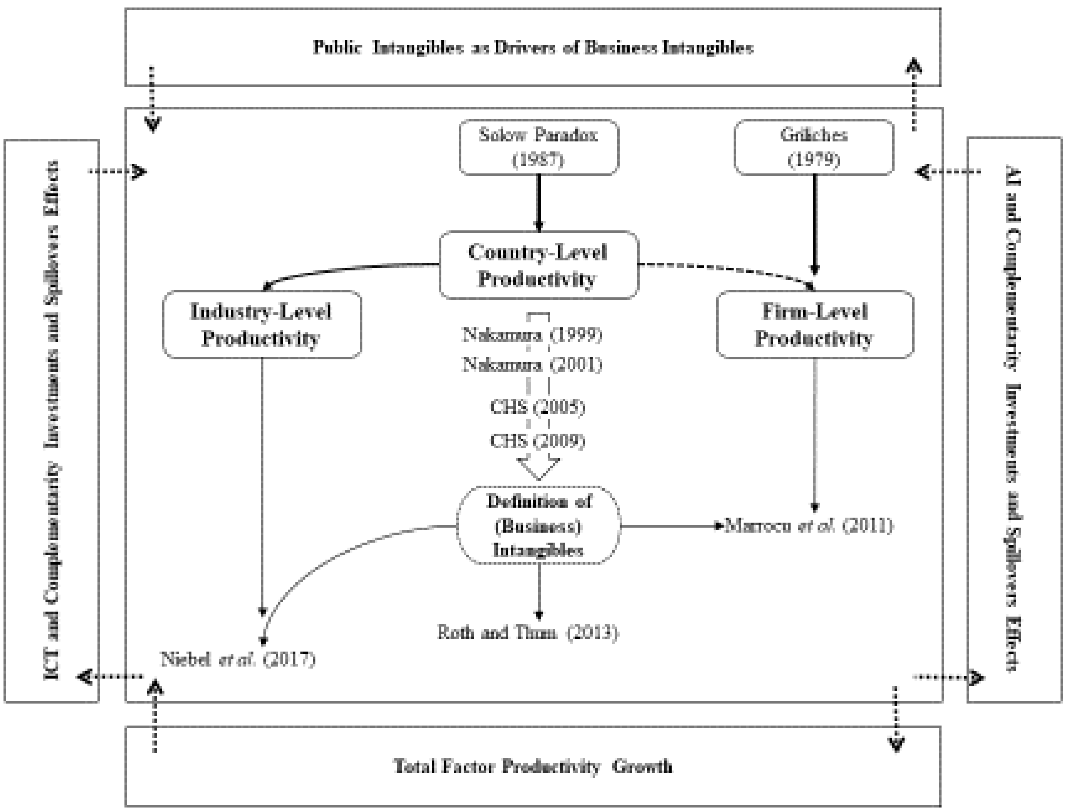

Figure 3. Analytical framework diagramming the seminal literature on intangible capital and labour productivity growth

4. Business Intangible Capital and the CHS Approach

4.1 *Business Literature*

Long before the economics literature turned its attention to the importance of investment in intangible assets to achieve labour productivity growth and firm competitiveness, the question had already been the focus of many influential studies in the business literature (see e.g. Teece, 1998; Webster, 2000; Lev and Radhakrishnan, 2003 and 2005; Cummins, 2005). A comprehensive review of the business literature has been conducted by Cañibano *et al.* (2000). Within their survey, Cañibano *et al.* (2000) stress the importance of economic competencies for firms, here in particular the importance to adopt a reliable and trustworthy *brand name* and to acquire adequate levels of firm-specific human capital. The former, according to Cañibano *et al.* (2000), is a pivotal asset for extracting higher profit margins from competitive markets. Firm-specific human capital, measured as the share of high-skilled workers within a firm, is also a key asset for establishing a competitive advantage in the market and, thus, earning larger profits (see also Abowd *et al.*, 2005). Lev and Radhakrishnan (2005, p. 75) enrich the discussion on single components of economic competencies by presenting the importance of organizational capital for modern firms, defined as "*an agglomeration of technologies – business practices, processes and designs and incentive and compensation systems – that together enable some firms to consistently and efficiently extract from a given level of physical and human resources a higher value of product than other firms find possible to attain*". The studies cited above- testify to the long-established acknowledgment of the importance of intangible investments for firms competing in modern economies within the business literature, well before the concept of business intangibles entered the scientific debate in the economics field.

4.2 *Origins of the thought in economics*

Within the economics discipline, Griliches (1981, p.183) was amongst the first to use the term "intangible capital", intended to mean a broad "stock of knowledge" approximated by R&D expenditures and patent applications. Following Griliches (1981), the term "intangible capital" entered the economics literature to encompass a set of intangible assets that, together, constitutes the firm's knowledge stock. The pioneering studies from Brynjolfson and Hitt (2000) and Brynjolfsson *et al*. (2002), from the microeconomic perspective, highlighted the necessity of complementary intangible investments (in particular in skilled workforce and organizational capital) alongside ICT and software investment to fully reap the benefits in terms of labour productivity growth.

Within the macroeconomics literature, the academic debate around business intangible investments was triggered by the famous 1987 quip from Robert Solow (1987) that "we can see the computer revolution everywhere except in the productivity data". The efforts at explaining this paradox led to assessments – and gradually acknowledgements – of the importance of the business investments in intangible assets from an economics perspective. While most studies within the macroeconomics field focused on the relationship between R&D and labour productivity growth (Lichtenberg, 1993; Coe and Helpman, 1995; Park, 1995; Guellec and van Pottelsberghe de la Potterie, 2001), Nakamura (1999, 2001) represented a pivotal step in more clearly defining a larger set of intangible investments and estimating, for the first time, the magnitude of such investments in the US economy.

With reference to this substantial body of previous work, CHS (2005) developed a coherent framework for business intangibles, which already included capitalized national account intangible, and identified new intangibles that still needed to be incorporated into the national accounts (NA) framework. In their book contribution, Haskel and Westlake (2018a) present further arguments supporting the inclusion of the new intangibles into the national accounts. They also give a brief historical account of the introduction of intangible assets into the discipline of economics.

4.3 *The CHS framework*

In 2005, Carol A. Corrado, Charles R. Hulten and Daniel E. Sichel (CHS) developed the first coherent framework to quantify data on business intangible capital. The three academics grouped nine items, which constitute the knowledge of the firm, into three broad categories: i) computerized information, ii) innovative property and iii) economic competencies. CHS (2005, p. 23) defined computerized information as: "*the knowledge embedded in computer programs and computerized databases*". This category was further subdivided into computer software and computerised databases. CHS (2005, p. 26) defined the category of innovative property as "*[…] not only the scientific knowledge embedded in patents, licenses and general know-how (not patented) but also the innovative and artistic content in commercial copyrights, licenses and designs*". The CHS definition of innovative properties, therefore, explicitly aims at creating a broader category than simply R&D expenditures, to comprise science and engineering R&D, mineral exploration, copyright and licensing costs and other product development, design and research expenses. CHS (2005, p. 28) define the third category, economic competencies, as "*the value of brand names and other knowledge embedded in firm-specific human and structural resources*" and include the following three dimensions: brand names, firm-specific human capital and organizational structure. CHS (2005) reports US investments in these nine intangible items as representing some 10-12% of GDP, amounting to annual investments of $1 trillion per year. The precise definition of the nine business intangible items divided into three categories and the first estimation of their sizable amount in the US economy opened-up the research field, which is surveyed in the section 5 of this paper. Table 1 gives an overview of the definitions of business intangibles in the CHS (2005) framework.

Category of intangible assets	**Definition by CHS (2005)**	**Business intangible item**	**Included in NA**
Computerized information	"knowledge embedded in computer programs and computerized databases" (P.23)	Computer software	Yes
		Computerised database	Yes
Innovative property	"not only the scientific knowledge embedded in patents, licenses and general know-how (not patented) but also the innovative and artistic content in commercial copyrights, licenses and designs" (P.26)	Science and engineering R&D	Yes
		Mineral exploration	Yes
		Copyright and license costs	Yes
		Other product development, design and research expenses	No (new intangible)
Economic competencies	"the value of brand names and other knowledge embedded in firm-specific human and structural resources" (P.28)	Brand equity	No (new intangible)
		Firm-specific human capital	No (new intangible)
		Organizational structure	No (new intangible)

Table 1. Overview of the definitions of business intangible assets in the CHS (2005) framework.
Note: NA=National Account.
Source: Own adaption of CHS (2005).

4.4 *Databases and EU Projects*

The European Commission's 6th and 7th Framework Programmes (FP) successfully addressed the issue of available data for analysing the impact of business intangibles on labour productivity growth by financing research projects aimed at delivering harmonised datasets on tangible and intangible investment (see Table 2 for an overview). The EUKLEMS dataset (O'Mahony and Timmer, 2009), financed by the European Commission from 2003 onwards, contains harmonized data for each of the 28 member states of the EU on Gross Fixed Capital Formation (GFCF), capital stocks and several productivity indicators. In editions released before November 2019, the dataset was based on official statistics in the national accounts.

Applying the EUKLEMS' methodology to the CHS intangibles not included in the EUKLEMS dataset (before November 2019), the INNODRIVE project delivered the first harmonized dataset on investments in and stocks of the CHS intangibles for an EU-27 + Norway country sample (Jona-Lasinio *et al*., 2011) over the time period 1995-2005. Following the INNODRIVE project, the INDICSER project (O'Mahony *et al.*, 2012) produced data on investments and stocks of the CHS intangible assets and the coherently revised productivity statistics. The INDICSER dataset provided disaggregated data at the industry-level from 1995-2007.

Project	**Main source**	**Period**	**Countries**	**Variables**	**Level**	**Economic sector**
EUKLEMS	O'Mahony and Timmer (2009)	1970-2015	EU-28, US	Tangibles and NA intangibles	Industry	Business
INNODRIVE	Jona-Lasinio *et al.* (2011)	1995-2005	EU-27, NO	CHS intangibles and adjusted productivity measures	Country	Non-agricultural and Business
INDICSER	O'Mahony *et al.* (2012)	1995-2007	AT, BE, CZ, DE, DK, ES, FI, FR, HU, IE, IT, NL, SE, UK	CHS intangibles, and adjusted productivity measures	Industry	Business
SPINTAN	Corrado *et al.* (2017b)	2000-2012	AT, BE, CZ, DE, DK, EE, EL, ES, FI, FR, HU, IE, IT, LU, NL, NO, PL, PT, SK, SE, UK, US	Public sector intangibles	Country	Public
INTAN-Invest	Corrado *et al.* (2018)	1995-2015	AT, BE, CZ, DE, DK, FI, FR, EL, ES, HU, IE, IT, LU, NL, PT, SK, SI, SE, UK, US	CHS intangibles, and adjusted productivity measures	Industry	Business
EUKLEMS (Statistical + Analytical Database)	Stehrer *et al.* (2019)	1995-2017	EU-28, JP, US	Tangibles, NA and CHS intangibles, adjusted productivity statistics	Industry	Whole economy

Table 2. Review of the existing datasets on intangible investments.
Note: AT=Austria, BE=Belgium, CZ=Czech Republic, DE=Germany, DK=Denmark, EL=Greece, ES=Spain, FI=Finland, FR=France, JP=Japan, HU=Hungary, IE=Ireland, IT=Italy, LU=Luxembourg, NL=Netherlands, NO=Norway, PL=Poland, PT=Portugal, SK=Slovakia, SE=Sweden, UK=United Kingdom, US=United States. EU-28 = European Union as of 2019 (including UK), EU-27=European Union as of 2011 (before Croatia's accession), NA=National Account.
Source: See column entitled "Main source" in the table.

Building upon the INNODRIVE dataset, the first release of the INTAN-Invest extended the timeframe to 2010 and added data for the US. The second release of the INTAN-Invest, published in 2017, provided data on the CHS Intangibles GFCF and the revised productivity statistics at industry-level for the timeframe 1995-2015. The SPINTAN project attempted to fill this gap by measuring the intangible investments undertaken by the public sector of most of the EU countries between 2000-2012 (Corrado *et al.*, 2017b).

The latest EUKLEMS release of 1 November 2019 (Stehrer *et al.*, 2019), funded by the European Commission, alongside the official national accounts fixed assets and productivity estimates, provides also data on the remaining CHS intangible assets (namely, own account and purchased organizational capital, marketing, advertising, branding and design expenditures and vocational training). The dataset covers the years 1995-2017 and public-sector intangible investments are also provided. As of today, the latest release of the EUKLEMS is the most up-to-date and largest dataset (both for countries and for industries) on intangible and tangible capital investments.

5. Capital Investment in Intangible Assets and Labour Productivity Growth

Empirical studies on the relationship between capital investment by business in intangible assets and labour productivity growth have become progressively more sophisticated over the last two decades. This section offers a survey of the latest academic literature investigating this important question. The studies examined are grouped into the following five categories: country-level (5.1), industry-level (5.2), firm-level (5.3), complementary investments and spill-over effects (5.4) and the drivers of investment in intangible assets (5.5).

5.1 *Country-Level*

The studies on intangible capital and labour productivity growth at the country level take the CHS (2005) framework as their point of departure. Once incorporating business intangibles into the national accounts and utilizing a growth accounting or cross-country growth accounting approach, these studies obtain three broad, internationally comparable[2] empirical results: i) a sizeable rate of intangible capital investments as a share of GDP (ICD/GDP); ii) a pronounced contribution of intangible capital deepening to labour productivity growth (ICD/LPG) and iii) a sizeable growth acceleration (GAC). Table A1 (found in the "Additional supporting information" section in the Appendix) compares the results of all analysed studies.

The seminal study for all country-level analysis is the 2009 contribution by CHS. Utilizing an intertemporal investment assumption, CHS (2009) is the first paper to add business intangibles to the standard growth accounting framework. Studying the case of the US economy between 1973-2003, CHS (2009) find that the US economy invested around 13% of its gross value added (GVA) in intangibles. In addition, CHS (2009) show that, once business intangible investments are incorporated into the boundaries of the national accounts, they explain 27% of labour productivity growth and would accelerate labour productivity growth by 11.2 percentage points. Similar results for the US investment rate on intangibles over the time period 2000-2007 are found by Nakamura (2010).

Following the CHS (2009) methodology, scholars applied the CHS framework to various individual countries, to assess whether the return to productivity from intangible investments was similar to that of the US. Outside of the US, insightful contributions came from the cases of the highly developed countries: Australia, Canada and Japan. Barnes and McClure (2009) conduct an intangible augmented growth accounting exercise for the Australian business sector over the time period 1974-2006. Over the time period 2005-2006, Australia spent 9.6% of its GDP in intangibles. Intangible capital deepening explained 18% of LPG, and their capitalisation increased the GVA growth rate by 3.7%. Baldwin *et al.* (2009, 2012) report the evolution of intangible investments in Canada's non-financial market sectors between 1976-2008 and find intangible investments of 13.2% of GDP. The contributions of intangible capital deepening to the LPG reached 29% in the period 1976-2000. The growth acceleration was 13.3%. Fukao *et al.* (2009) present the results of the growth accounting exercise carried out on the Japanese market economy between 1985-2005. Similar to the actions taken by US, Australia and Canada, Japan also spent a sizeable fraction (11.1%) of its GDP in intangibles. And again, in line with the US and Canadian experience, intangible capital deepening in Japan explained up to 27% of LPG and generated a faster GVA growth of up to 17.3%. While comparable to with the US results reported by CHS (2009), Fukao *et al.* (2009) highlight how investments in intangible assets slowed down in Japan between the late 1980s and the early 2000s, which may explain the lower LPG rates in Japan in comparison to the US.

Replicating the CHS (2009) approach for the Finnish case, Jalava *et al.* (2007) report the growth accounting results for the period 1995-2005. Similar to CHS, the authors find that the Finnish non-financial business sectors invested 9.1% of the country's GDP in intangible assets in 2005. The resulting intangible capital deepening explained up to 30% of LPG in the sub-period 2000-2005, and it triggered a growth acceleration of up to 13.2%. Edquist (2011) presents the case of Sweden. Analysing data from the market sectors in the timeframe 1995-2006 and comparing the results with those from CHS (2009), Edquist (2011) finds that the Swedish economy, in 2006, invested 10% of its GDP in intangibles, one percentage point more than Finland (Jalava *et al.*, 2007). In terms of the positive return on LPG, similarly to Finland, Sweden is reported to outperform the US, with 30% of LPG explained by intangible capital deepening. This result is interpreted as the high effectiveness of the Swedish intangible investments after the economic downturn of the late 1990s. Van Rooijen-Horsten *et al.* (2008), carry out a descriptive statistical analysis to compare the levels of investments in intangible assets in the Netherlands between 2001-2004. The authors find that the whole Dutch economy (including the public sector) invested 8.3% of its GDP in intangible assets, highlighting a gap with the Anglo-Saxon economies and with the other cases presented so far. In contrast to the Netherlands and in line with the Scandinavian countries and the US, the UK stands as a forerunner in the knowledge economy. Marrano *et al.* (2009) analyse the investments in intangible assets carried out in the UK market economy between 1990-2004. The authors provide evidence that the UK economy is a large investor in intangible assets, with investments of up to 13% of its GDP, which are in line with those from CHS (2009) for the US. In terms of the contribution of intangible capital deepening to LPG, the UK shows a lower impact of 20%, compared to the US. The later publication from Goodridge *et al.* (2013), performing a descriptive statistical analysis, confirmed the findings from Marrano *et al.* (2009) and further corroborated them by reporting that the correct measurement of the knowledge economy would explain around "5 percentage points of the 16 per cent [UK] productivity puzzle" (Goodridge *et al.*, 2013, p. 48).

Hao *et al.* (2009) is the first attempt at performing the growth accounting exercise on a group of EU countries, namely France, Germany, Italy and Spain, compared to the US and the UK. A situation of divergences between EU countries is depicted: Italy and Spain invest smaller shares of their GDP, both of them 5.2%, in comparison to Germany and France (respectively, 7.1% and 8.8%). Overall, the Anglo-Saxon countries invest higher shares of their GDP in intangibles, with the UK reaching 10.1% and the US 12.1%. Coherently, these are the countries where intangible capital deepening explains the higher shares of LPG. Van Ark *et al.* (2009) follow the same rationale of including within the growth accounting exercise 10 EU countries and the

US. Their findings widely confirm those from Hao *et al.* (2009): the European economies invest lower shares of their GDP in intangible assets compared to the US, with the UK being only exception (the Scandinavian economies are not in the data sample). In particular, the US invested around 12% of its GDP in intangible assets, and France, the largest EU investor after the UK, only 7.9%. The authors reported a high volatility across the EU countries, with Italy and Spain in particular investing less (around 5% of their GDP) and showing the lower values of LPG.

Corrado *et al.* (2013) add to the existing growth accounting studies by considering a wider sample size of 14 EU member states vis-à-vis Japan and the US and by using the first version of the INTAN-Invest (Revision 1) dataset. Conducting an intangible augmented growth accounting estimation over the period 1995-2007, the authors corroborate the finding of the EU economies lagging behind the US both in terms of intangible investments over GDP (with 6.6% being the EU-14 average against 10.6% for the US) and in terms of their return in higher LPG (23.8% of LPG is explained by intangible capital deepening in the EU, 28.4% in the US). In a similar vein, Corrado *et al.* (2018) conduct an intangible augmented growth accounting estimation for an EU-18 country sample with the help of the updated INTAN-Invest dataset over the time period 2000-2013, permitting them to compare a before-crisis with a crisis sample. The authors' analysis confirms the previous results showing the EU countries investing less in intangible assets (and obtaining a lower return on LPG) than the US, with the Scandinavian countries, France and the UK being the larger intangible investors in the EU. Interestingly, the paper finds that during the global financial crisis 2008-2009 the intangible investments in the EU experienced only a small drop and recovered more quickly than did tangible investments. Overall, Corrado *et al.* (2018) report that intangible capital deepening explains 30% of LPG in the EU14 countries.

In contrast to the growth accounting estimations described above, the contribution by Roth and Thum (2013) is the first to introduce a growth econometric estimation approach in this field of research. Utilizing the harmonized intangible capital macro dataset from the INNODRIVE project, Roth and Thum (2013) apply a cross-country growth accounting (CCGA) estimation approach to the CHS framework. The advantages of taking a CCGA estimation approach over the traditional growth accounting approach are first, that output elasticities are estimated, rather than imposed and second, that part of the model can be designed to explain the international variance in TFP growth. The authors retrieve data on 13 European countries over the period 1998-2005 by merging the EUKLEMS dataset with the INNODRIVE database. The findings by Roth and Thum (2013) corroborates most of the previously discussed findings using a simple growth accounting estimation. Their results suggest i) a pronounced average investment rate of intangible investment of 9.9% in the 13 EU countries, ii) a dominant contribution of intangible capital deepening to labour productivity growth, thereby explaining a labour productivity share as large as 50% and iii) a significant growth acceleration of 4.4%. The econometric results by Roth and Thum (2013) remain robust when controlling for endogeneity. Whereas some Scandinavian countries, e.g. Sweden, already outperform the US in terms of intangible investments, the Mediterranean countries Spain and Italy are clearly lagging. Latest results by Roth (2019), who replicated the study by Roth and Thum (2013) with the help of an EU-16 country sample over the time period 2000-2015, corroborate the findings of Roth and Thum (2013). Roth (2019) finds an investment share for intangible assets over GVA of 11%, and contributions to labour productivity growth and growth acceleration effects similar to the ones reported by Roth and Thum (2013). Moreover, by differentiating a crisis from an economic recovery period he finds that intangibles have remained positive throughout the crisis period and are strongly positively related to labour productivity growth in times of economic recovery.

Finally, Chen (2018) empirically proves how the full inclusion of intangible capital as a production factor explains up to 16 percentage points of cross-country income variation. This finding, obtained on a sample of 60 countries over the timeframe 1995-2011, confirms – interestingly, from a different viewpoint and with a different model – the theory that investments in intangible capital explain the level of labour productivity, and particularly that countries investing more in intangibles show higher average levels of output per worker.

5.2 *Industry level*

Surveying the studies at the industry level gives a deeper insight into how far the strong and positive impact of business intangible investments on labour productivity growth at the country level can be corroborated at a more disaggregated level. In contrast to the country level, the majority of the papers surveyed at the industrial level use growth econometric techniques, to adequately account for country-, and industry- and time-specific effects. Table A2 (found in the "Additional supporting information" section in the Appendix) compares the results of all analysed studies.

An early effort at applying the CHS framework to industry-level data came from Barnes (2010), who analyses the Australian business sector economy from 1993-2006. While confirming the general findings by Barnes and McClure (2009) at the country level, the authors find that the manufacturing sector is the most intangible-intensive, with 65% of intangible over tangible investments. The Australian services sector has the second-largest intangible over tangible share, with 50%. Among papers that review extra-US and EU countries, Dutz *et al.* (2012) presents the interesting case of the Brazilian economy between 2000-2008. From the country perspective, in spite of showing an average share of intangible investment over GDP of 4.72% (less than half of the values from the US, Japan and UK), the Brazilian economy shows a positive causal relationship between intangible investments and TFP growth. The medium/high-tech manufacturing sector is found to be the dominant intangible investor in the Brazilian economy- and the only sector that invests more resources in intangible than in tangible assets.

Miyagawa and Hisa (2013) analyse the Japanese business sector between 1981-2008, deepening the research from Fukao *et al.* (2009) presented in the previous section. The authors report a strong correlation between intangible investments and TFP growth, and interestingly theorise that the general slowdown of the Japanese TFP growth can be related to the slowdown of intangible capital deepening after the economic downturn of the early 2000s, especially in the key IT manufacturing sector. This last hypothesis opens up a new interesting point of view on the evolution of the Japanese economy in relation to its investments in intangible assets. Chun and Nadiri (2016) perform the growth accounting exercise on the Korean economy in the timeframe 1981-2008. The study reveals that intangible capital deepening switched from explaining only 3% of LPG in the period 1981-2008, to explaining 15% in the period 2001-2008. From the industry perspective, the Korean intangible-intensive industries have evolved over time to account for more than 60% of the Korean economy's real VA growth. Fleisher *et al.* (2015) present another interesting case from Asia: the Chinese manufacturing sector between 1999-2007. Retrieving data at industry level on VA and investments in innovative properties, the authors find that the most productive manufacturing subsectors of the Chinese economy are those that are investing higher shares in intangible capital. This result is interpreted as evidence that China's comparative advantage is shifting towards more innovative production.

Revisiting the papers focusing on EU countries, analogous with the previous section 5.1, this section examines the contributions from the industry-level literature, divided between single EU country cases, and groups of EU countries cases. The paper from Dal Borgo *et al.* (2013) applies the growth accounting framework to the UK economy between 2000-2008. The case is of particular interest in the light of the results analysed in the previous section from Marrano *et al.* (2009) and Goodridge *et al.* (2013). In line with those results, the authors find that as early as 2008 the UK business sector economy invested the highest share of its GVA in intangible assets (16% of GVA, against the 12% invested in tangible assets), testifying to the frontier role played by the UK in the transition to the knowledge economy. The manufacturing sector is found to be the most intangible-intensive also in the UK, accounting alone for 40% of total innovation (intended as intangible capital deepening + TFP). The financial sector is found to be also highly intangible-intensive, testifying to its high innovativeness in the UK economy. The growth accounting exercise reported that intangible capital deepening constitutes 23% of GVA growth in the timeframe 2000-2008. Crass *et al.* (2015) analyse the case of the German economy between 1995 and 2006, using a growth accounting estimation technique. The German country case study appears of particular interest in the EU scenario, in particular in comparison to the UK. The paper finds that the German economy has increased its intangible investments up to 89% of its tangible investments in 2006, in line with the UK economy. Almost half of these intangible investments are carried out by manufacturing firms, which invest heavily in R&D – more than twice as much as British manufacturing firms, as a share of gross output – confirming the high innovativeness of the German manufacturing sector and the concentration in this sector of the German investments in intangible assets (mostly R&D). In terms of LPG acceleration, the authors find that the capitalization of all the intangible investments would lead to up to 0.59 percentage points of growth acceleration in the manufacturing sector. After the UK and German country case studies, Delbeque *et al.* (2015) present an extensive review of the evolution of intangible investments in the French economy (including the public sector) between 1980-2007. The authors find that the manufacturing sector is also the forerunner in intangible investments in France and, similarly to what was observed by Crass *et al.* (2015) in Germany, the highest share of spending in this sector is devoted to R&D and engineering design. The econometric exercise, which used Fixed Effects and GMM-DIFF estimators, confirms the causal relationship between intangible investments and productivity growth, highlighting how the productivity of tangible capital and labour also increases when levels of intangible investments are higher.

Corrado *et al.* (2016) is the first paper to conduct the growth accounting exercise at the industry level for a group of 14 EU countries by using INTAN-Invest (first release) data. This paper confirms, over the period 1995-2010, the findings on the higher intangible-intensity of the manufacturing sector, which is, by far, the leader in R&D investments. The data presented closely match those from Dal Borgo *et al.* (2013), Crass *et al.* (2015) and Delbeque *et al.* (2015). In addition, the service sector of all EU countries – with Finland being the sole exception – shows rates of growth in intangible investments that are higher than those of the manufacturing sector, hinting to a catching-up of the former in innovation expenditures. Discussing LPG, Corrado *et al.* (2016) report an average contribution of intangible capital deepening of 25%, in both the services and manufacturing sectors. Similarly to Corrado *et al. (2016)*, Niebel *et al.* (2017) focus on the market sectors of ten EU countries between 1995 and 2007, retrieving data on harmonised intangible investments and stocks from the INDICSER dataset. Applying the growth accounting methodology, the authors report that the manufacturing and the financial sectors are the most intangible-intensive among the European economies analyzed. Country-wise, a wide dispersion is noted: highly innovative countries such as the UK and Finland, which invest heavily in intangibles and have above-average LPG rates, co-exist with countries with lower rates of intangible capital deepening and LPG, notably Italy and (on a smaller scale) Spain and Germany. All the findings reported so far for Niebel *et al.* (2017) are in line with the literature presented in this section, and notably with Corrado *et al.* (2016). The authors present the growth econometric exercise as well: using a Fixed-Effects and a System GMM estimator, they find a positive and significant effect of intangible capital (services) growth on VA growth. Qualitatively, this result is in line with the contributions presented in the previous section (see here Roth and Thum, 2013 and Roth, 2019), but the point estimates are more than halved. Piekkola (2017) makes several steps forward by increasing considerably the sample size (all EU-28 countries) and by focusing on the years of the eurozone crisis 2008-2013. The results of the growth accounting and growth econometric exercises in this paper confirm previous findings on intangible investments in the EU constituting a large share of VA (29.6%). The LPG effect of intangible capital deepening between 2008 and 2013, however, is found to be negative. The author attributes this important result to the decrease in the innovative base between 2008 and 2013 (Piekkola, 2017, p. 391), intended as the contemporaneous increase in unemployment and slowdown of intangible capital deepening. The economic sectors most affected by the crisis, moreover, were those producing intangible assets/services. In this light, the claim from Piekkola (2017) appears comparable to the Japanese case presented in Miyagawa and Hisa (2013): the stagnation in LPG rates is linked to an even-deeper crisis of the most innovative and productive sectors of the economy.

5.3 *Firm Level*

This section surveys studies that analyse the relationship between business intangibles and labour productivity growth at the firm level. The larger sample sizes and the general availability of information concerning the number of employees and the economic sector of the firm and of panel observations permits the surveyed papers in this field to exploit both the between and within variation of firms. Table A3 (found in the "Additional supporting information" section in the Appendix) compares the results of all analysed studies.

Whereas the studies surveyed at the country and industry level were strongly influenced by the seminal approach of CHS (2005), studies at the firm level have started analysing the impact of intangible capital investments on labour productivity growth following the business literature presented here in section 5.1. Thus, the present section will present both: i) papers that consider a wider range of intangible assets, but outside the CHS frameworks; and ii) papers that followed the CHS framework for the firm-level analysis.

Outside of the CHS (2005) framework, Ramirez and Hachiya (2008) focus on the productivity effect of intangible capital investments of the Japanese firms listed in the Tokyo Stock Exchange between 1997-2001. The paper considers as intangible assets the expenditures in advertising and R&D and accounts for the firm-specific organizational capital. The authors provide empirical evidence that, regardless of the size and the economic sector, intangible capital investments positively affect the growth in sales. Among the intangible investments, R&D positively affects only larger firms in the manufacturing sector, while advertising has a more generalised positive effect. Battisti *et al.* (2015) retrieve firm-level data from the Amadeus-2012 database for 20,793 firms from 16 European countries over the period 2003-

2009. The intangible investments from the CHS framework thereby analysed are those in R&D, training and goodwill expenditures. Investments in intangible assets are found to have a positive and significant effect on TFP. The paper assesses whether investing in intangibles increases the probability that the firm will also investing in better technologies, finding evidences in support of this hypothesis. Bontempi and Mairesse (2015) study a large sample of Italian manufacturing firms between 1982-1999. The intangible assets included in their paper are R&D, patents, trademarks and advertising, in line with Battisti *et al.* (2015). From the methodological point of view, the paper by Bontempi and Mairesse (2015) has the interesting feature of comparing the results from different specifications of the production function. The authors also find that the productivity of Italian manufacturing firms is positively affected by investments in intangible capital, quantifying for the median firm a return of €2-3 for each euro spent in intangible assets. Among the assets, investment in intellectual capital has the highest return at the (manufacturing) firm level. Shakina *et al.* (2016) present the interesting case of the gap in intangible investments between Russian and European firms. The authors report both lower levels of average productivity and of intangible investments in Russian firms, in comparison to their European competitors. Carrying out an empirical exercise, the authors link the lower productivity of the Russian firms to their lower levels of intangible investments, highlighting the most important gaps in R&D spending in the manufacturing sector and in organizational capital. Both these causes appear well in line with other results hereby presented: the importance of R&D investments in the manufacturing sector is a recurrent motif in the industry-level literature (e.g. Crass *et al.*, 2015); the high relevance of organizational capital investments at the firm-level is one of the main finding from Ilmakunnas and Piekkola (2014).

Görzig and Gornig (2013) assess the volatility of the rate of return on investments between 1999-2003 in German firms. This contribution is closer to CHS for the intangible assets analysed, but it interprets them as the missing link to explain the high volatility in firms' returns on their investments. Once intangible assets are accounted, the dispersion in the rate of return in investments observed is reduced strongly. The authors argue that German firms successfully increase their productivity by investing in intangible assets, but if the accounting practices to calculate the returns on investment do not consider the spending in intangible assets as capital investments, then their outcome is more volatile and upwardly-biased, because a large share of investments are not considered. Similar to Görzig and Gornig (2013), Piekkola (2016) retrieves financial and investment data on Finnish firms between 1997-2011 to assess the patterns of intangible investments and how they affect the firms' market value. While observing that, by the end of the timeframe, the amount of intangible capital investment has reached that of investments in machinery and equipment, Piekkola (2016) reports a positive effect of a firm's intangible capital on that firm's market value.

Among the papers more closely embedded in CHS, De and Dutta (2007) appears as the earliest attempt to analyze the impact of investing in intangible assets on firms' productivity. The authors use data for Indian firms operating in the IT software industry between 1997-2005 and find a positive and significant effect of the investments in brand capital and organizational capabilities on firms' productivity. While the inclusion of firms belonging only to the IT software industry strongly limits the external validity of the results, the main contribution of this paper is to adapt the CHS framework to the firm-level analysis. Further evidence from India is discussed in Goldar and Parida (2017). The authors analyse the data from around 3,200 Indian firms in 2012 and 2013. Following the same approach of Bontempi and Mairesse (2015), Goldar and Parida take important steps forward in capitalizing the intangible investments applying the PIM to 10 years of prior investments, coherently with the country- and industry-level databases presented in the previous sections. In line with the results from De and Dutta (2007), intangible investments are found to have a strong and positive effect on Indian firms' productivity, which is even greater for firms operating in the manufacturing sectors and with higher stocks of ICT capital. Moreover, similar to the Russian case presented in Shakina *et al.* (2016), Indian firms appear to be investing lower shares of their VA in intangibles compared to EU and US firms, thereby highlighting the big potential of intangible investments in India. Aiming at assessing the state of the art of the New Zealander economy in the knowledge economy, Chappel and Jaffe (2018) analyze a rich dataset of more than 12,500 New Zealand firms between 2005-2013, having observations for all three dimensions of the CHS intangibles. Chappel and Jaffe (2018) empirically test the effectiveness of intangible investments on a wider variety of firm indicators, namely productivity, profitability, LPG and customers satisfaction. Surprisingly, the authors find that intangible investments have a significant effect on the gross output growth and on customers' satisfaction, but not on the profitability or LPG. This finding, as the authors themselves discuss, is at odd with the literature and may be related to biases in the dataset used or hinting at limited productivity effects in the mature New Zealand economy.

Shifting the attention to papers embedded in the CHS framework that study EU countries' cases, Marrocu *et al.* (2012) is hereby the most influential paper studying the effectiveness of investments in intangible capital on productivity at the firm level. Moreover, this contribution focuses on six of the largest EU countries, similarly to the empirical country- and industry-level studies. Retrieving data from the BVD database for the timeframe 2002-2006, the authors observe that there is an overall trend in raising the share of intangible over tangible capital. The econometrics exercise reveals, coherently, that these investments in intangible capital are enhancers for a firm's productivity. Due to data limitations, Marrocu *et al.* (2012) does not include data on organizational capital investments and excludes observations on German firms. Notwithstanding these limits, this paper is a key contribution in bridging the country-level with the firm-level analysis.

Crass and Peters (2014) follow closely the approach from Marrocu *et al.* (2012). The authors analyse a panel dataset of only German companies between 2006-2010 retrieved from the Mannheim Innovation Panel (MIP). This paper, thus, attempts to enrich Marrocu *et al.* (2012) by addressing: i) the lack of observations on German firms and ii) the lack of variables measuring the organizational capital. With regard to this latter issue, the authors retrieved only qualitative information from the MIP (i.e., *yes/no* variables) about past changes in the business processes or any new organization of the workplace. The results of Crass and Peters (2014) widely confirm those of Marrocu *et al.* (2012): intangible capital investments have a positive and significant effect on German firms' productivity, with R&D, branding and firm-specific human capital (training) expenditures having the strongest effect.

Consistent with Crass *et al.* (2015) presented in the previous section, the high-tech manufacturing firms in Germany are the top investors in intangible assets. Ilmakunnas and Piekkola (2014) analyse firm-level data for 1,714 Finnish firms between 1998-2008. This paper exploits a labour-oriented perspective focused on the impact that workers engaged in intangible activities (i.e. marketing, R&D and organisational matters) have on the firm's TFP. The authors find that the jobs related to managerial and marketing activities have the highest positive return on TFP, followed by the R&D-related jobs. Organisational activities are reported to be even more productivity-enhancing for the firms operating in the service sectors. Ilmakunnas and Piekkola (2014), therefore, stress the importance of the organizational capital among all the intangible assets, which indeed appears as one of the most debated topics within the strand of literature reviewed in this contribution.

Verbič and Polanek (2014) follow a similar labour-oriented approach and analyse the impact of R&D, firm-specific human capital and organizational capital investments on sales on a sample of 3,370 firms in Slovenia between 1994 and 2005. Using a fixed effects estimator, the authors find that investments in firm-specific human capital and R&D are the most beneficial for sales' growth. The effect of organizational capital is lower in Slovenia than in Finland (Ilmakunnas and Piekkola, 2014), and driven by the initial years of the sample, i.e. those of the transition following the dissolution of Yugoslavia. Lalovic and Koman (2018) review survey data on intangible investment carried out by the largest manufacturing firms in Slovenia between 2011 and 2014. Analogous to Chappel and Jaffe (2018), the authors include all three dimensions of CHS intangible assets. Lalovic and Koman (2018) report that the most productive firms in Slovenia are indeed those that are spending the most in intangible assets, specifically in firm-specific human capital, organizational capital and marketing.

5.4 *Complementary investments and spillover effects*

This section surveys studies examining additional channels through which intangible investments affect LPG. They focus on the existence of complementary intangible investments that increase the effectiveness of ICT and AI capital investments, as well as on the spillover effects generated by intangible investments. Table A4 (found in the "Additional supporting information" section in the Appendix) compares the results of all analysed studies.

The idea that the knowledge economy benefits from complementary investment in intangible capital aimed at ICT, in the form of firms' organizational and firm-specific human capital, has been prominently shown by Brynjolfsson and Hit (2000). The authors highlighted how investment in ICT (the focus of their study) needs even higher commitments to modern forms of firms' organizational structure and to firm-specific human capital to be effective. The authors estimate that the ratio between ICT and complementary intangible investments is 1:9. Chen *et al.* (2016) fully embed the research on the complementarities between ICT and intangible investments following on from Brynjolfsson and Hit (2000) within the CHS framework. The authors retrieve data on gross value added (GVA), and on tangible and intangible investments for ten EU countries over the period 1995-2007 from the INTAN-Invest (first release) and EUKLEMS databases. After ranking the economic sectors by their ICT-intensity, the paper provides an empirical analysis and finds that the most ICT-intensive sectors have the higher return in productivity from intangible investments. This finding supports the hypothesis that intangible and ICT are complementary in production and corroborate the early hypothesis from Brynjolfsson and Hit (2000) concerning the pivotal role of organizational capital. Moreover, Corrado *et al.* (2017a) retrieve data for 10 EU countries from 1998-2007 from the INTAN-Invest (first release) and EUKLEMS databases and perform an empirical analysis to explore the complementarity between ICT stocks and intangible investments. Using both country- and industry-level data, the authors confirm the hypothesis of the complementarity between the levels of ICT stocks and intangible investments. The authors also report evidence that intangible capital investments trigger wider productivity effects.

The existence of spillover effects, stemming from investments in intangible assets, is another topic of debate on intangible literature, before and after CHS. O'Mahony and Vecchi (2009) is an early attempt to analyse spillover effects, at the firm level, stemming from investments in R&D and a better-skilled workforce. Using data on five large OECD economies between 1988 and 1997, the authors find that the firms operating in the most R&D- and skill-intensive sectors have from 2-5% higher productivity growth. This finding is interpreted as the spillover effect that the sense of belonging to an intangible-intensive industry has on firms. Similarly, Elnasri and Fox (2017) study the case of intangible investments in Australia between 1993-2013. The authors find that private intangible investments have a general positive TFP effect in Australia, interpreted as a spillover effect. Elnasri and Fox (2017) report the positive relationship between higher educational levels, the presence of research agencies and TFP. Goodridge *et al.* (2017) set an empirical exercise similar to that of Corrado *et al.* (2017a), but one focused on the effect of the general "knowledge stock" on industries' TFP growth.

The argument tested by the authors is that each industry receives a positive TFP effect from the intangible capital accumulated in other industries, implying that intangible investments carried out in one industry spill over into all the others. The authors argue, however, that *outside knowledge stock* spillovers are not contemporaneous, but rather that they emerge within the span of three periods. The empirical analysis widely supports this hypotheses, confirming the existence of extra-industry knowledge spillovers over time. Keeping the focus on the UK, Melachroinos and Spence (2019) make a pioneering attempt to study the effectiveness of intangible investments on GVA, from the point of view of districts within the UK (the NUTS3 regions in the Eurostat's nomenclature). Using a panel of 128 UK districts over the timeframe 1995-2007, the authors find that intangible investments are concentrated in some areas of the country, mainly in London and the South-East. This finding carries two insights: firstly, imbalances in intangible investments foster regional disparities within the UK, and secondly, and most interestingly for this section, there is evidence of an agglomeration effect of the most innovative firms in some areas of the UK. In combination with the outside knowledge stock hypothesis from Goodridge et al. (2017), the agglomeration effect suggested by Melachroinos and Spence (2019) hints at the existence of persistent spillover effects, concentrated in the main intangible UK hubs (e.g., London).

Finally, it is worth mentioning some observations here related to the strand of literature focusing on Artificial Intelligence (AI), and specifically on Brynjolfsson *et al.* (2017). The authors argue that AI appears as a very promising general-purpose technology that will bring a positive productivity shock to most economic sectors. However, similar to ICT capital, AI capital will need complementary investments in intangible capital, such as complementary investments in firm-specific human capital and organizational structures.

5.5 *The Drivers of Intangible Investments*

This section surveys the literature that analyses the drivers of business intangible investments, focusing on the endowments of public intangibles, such the quantity and quality of a high-skilled labour force, well-functioning formal and informal institutions and a well-designed policy framework. Table A5 (found in the "Additional supporting information" section in the Appendix) compares the results of all analysed studies.

From the perspective of what drives business intangibles at the firm level, Arrighetti *et al.* (2014) present evidence for the Italian case. Using a panel dataset of Italian manufacturing firms for the years 2001-2003, the authors find that a larger firm size, higher educational levels of the workforce and higher stocks (and therefore, past levels) of intangible investments increase the propensity of investing in intangible capital. The latter, among the three drivers identified by the authors, has the strongest effect on intangible investments, being a key factor in explaining the striking quantiles divergences observed (i.e. a few firms account for the highest share of intangible investments). Yang *et al.* (2018) perform a firm-level exercise similar to that of Arrighetti *et al.* (2014), retrieving cross-sectional data on a representative sample of Chinese manufacturing firms in 2011. Similar to the Italian case, the authors find that the size of larger firms and the higher education of their workforce increase the propensity to invest in intangible assets. In addition, the authors find a negative correlation between the level of competitiveness in the market and firms' investments in intangible, observing that the firms operating in oligopolies have the highest likelihoods of carrying over intangible investments. This last finding seems to open up a new discussion within this strand of literature. Ahn (2019) has studied the drivers of intangible investments in a large sample of quarterly observations taken of US manufacturing firms between 1986 and 2016. Differently from Arrighetti *et al.* (2014) and Yang *et al*. (2018), the focus in Ahn (2019) is on comparing the reaction of tangible and intangible investments to exogenous shocks (as the 9/11 attacks) and to their own past levels. An interesting finding of the paper is that the exogenous shocks have a negative impact only on tangible investments, while intangible investments – proxied by R&D expenditures – are positively driven by their own past values. The latter finding is in line with Arrighetti *et al.* (2014) and corroborates the hypothesis that the firms are persistent in their choice of investing (or not investing) in intangible assets.

The other viewpoint discussed in the literature about drivers of intangible investment approaches the question from the country level, focusing on a country's public intangible endowments. Gros and Roth (2012) is an early attempt to setup an empirical framework to highlight the key drivers at country level for intangible investments. Using INNODRIVE and Eurostat data, their main finding, based on a sample consisting of all EU-27 countries between 1995-2005, is that government effectiveness acts as a significant driver of intangible investments. Gros and Roth (2012) thus highlight the key role of efficient legislation on intellectual property rights (IPR), copyright and trademarks in fostering investments in intangible capital. Andrews and Criscuolo (2013) contributes to the discussion by analysing the trends in intangible investments (as in CHS) and their drivers in the OECD countries. From a legislative point of view, the authors confirm the findings by Gros and Roth (2012) that effective IPR regulations are the key drivers of intangible investments and illustrate the importance of adopting bankruptcy laws that do not over-penalise entrepreneurs for failure.

From a financial point of view, the authors stress the importance of well-functioning venture capital markets to foster well-grounded and innovative firms. Demmou *et al.* (2019) perform an extensive empirical analysis at industry level on a large panel of OECD countries, to assess the impact of the financial development on productivity growth in intangible-intensive sectors. The authors confirm the view of Andrews and Criscuolo (2013) about the importance of well-functioning equity and venture capital markets and of not over-penalising bankruptcy laws, and the finding by Gros and Roth (2012) on the general effectiveness of laws governing the enforcement of contracts. Moreover, Demmou *et al.* (2019) stress the role, especially in developing countries, of liberalised financial markets and competitive banking sectors to improve the efficiency of capital allocation, thereby making them more open to opportunities to finance intangible investments. Similar results are highlighted by Guo-Fitoussi *et al.* (2019), who report that today's top-innovative firms thrive from a combination of various IPR applications (e.g. patents and trademark protection for the same product, as in the case of smartphones), and hence underlining the high importance of effective IPR legislation.

Thum-Thysen *et al*. (2019) conducted an empirical analysis to test whether macro-economic conditions, the regulatory framework, financial conditions and levels of human capital have an impact on the level of intangible, tangible and total investments. The paper retrieves data for 15 EU countries from the INTAN-Invest database, EUKLEMS, OECD, World Bank and Eurostat for the timeframe 1995-2013. The authors find that higher levels of tertiary education and of public R&D expenditures drive higher intangible capital investments by businesses.

Similarly, better financial conditions (proxied by long-term interest rates and debt-to-equity ratios) drive higher levels of intangible investments, in line with the findings from Demmou *et al.* (2019). In contrast, more stringent employment protection legislation is negatively correlated with intangible investments. A tighter labour market, according to the authors, represents an obstacle for the most innovative and flexible firms and it acts as a brake on intangible investments.

6. Conclusions, Implications and Outlook

6.1 *Conclusions*

This paper surveys a wide range of studies and highlighted the main findings of the existing literature regarding the impact of business intangible capital on labour productivity growth. Surveying the literature at the country, industry and firm level, this paper found evidence of the increasing importance of business intangibles in explaining labour productivity growth dynamics. Moreover, according to the results in the surveyed papers, in order to fully reap the benefits of investment in Information and Communication Technology (ICT) and Artificial Intelligence (AI), complementary investments in business intangibles are also essential. In addition, the literature on the drivers of intangible capital held by the business sector highlights the key importance of a well-endowed infrastructure of public intangibles. Judging from the wide range of economic literature surveyed, this paper suggests that the contemporary economic debate has now broadly acknowledged the importance of intangibles for the transformation of developed economies towards fully-fledged knowledge economies.

6.2 *Implications*

The results of the surveyed papers clarified that investments in business intangibles have a pronounced impact on labour productivity growth. This applies to the incorporation of the complete framework of business intangibles, as well as the incorporation of three individual dimensions: i) software, ii) innovative property and iii) economic competencies. An immediate challenge for the responsible decision-makers in the statistical institutes is now of how to adequately incorporate the new intangibles, such as branding, firm-specific human capital and organizational capital, into the asset boundary of the national accounts. The results of surveyed papers underline the necessity to incorporate intangibles into today's national accounting frameworks in order to correctly depict the levels of capital investment being made in economies around the world. These levels are significantly higher than is currently reflected in official statistics. As a consequence, labour productivity growth rates are underestimated.

6.3 *Outlook*

At the start of today's digital and knowledge economy, the CHS (2005) framework successfully managed, to better account for the inventories of intangible capital accumulated by technological companies, resembling many of today's world's largest firms. They developed a coherent framework for measuring investment in intangible capital, which has been identified as a necessary complement to investment in ICT (Van Ark *et al*., 2008) and AI (Brynjolfson *et al.*, 2017), in order to reap the full benefit for labour productivity growth. The challenge now will be to adequately account for the complementary public intangibles needed to maintain and stimulate business intangibles (Haskel and Westlake, 2018a). A natural next step is to undertake the wider adaptation of the national accounting framework to also reflect environmental, educational, health and social capital in order to account for today's knowledge economy.[3]

Notes

1. This paper follows the methodological approach suggested by Roth and Thum (2013) and conceptualizes intangible capital as "*an umbrella term for all those capital forms that are theoretically important for productivity but are not tangible in nature*". As such the term is used to include business intangibles as defined by CHS 2005 as well as public intangibles, such as the quantity and quality of a highly-skilled labour force, well-functioning formal and informal institutions and a well-designed policy framework (see e.g. Aghion and Howitt, 2006; Hall and Jones, 1999). Using such a definition of intangible capital also facilitates the awareness that the largest share of income and wealth of advanced economies stems from services of intangible capital stocks (World Bank, 2006).
2. With the exception of the studies by Nakamura (2010) and Chen (2018).
3. It remains an open question which range of public intangible capital should be incorporated into the asset boundary (Hill, 2009; Stiglitz et al., 2009).

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table A1. Summary of the studies at the country level
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Appendix

Table A1. Summary of Studies at the Country Level

Authors	Countries	Method	Time Period	D.V.	Data Source(s)	Economic Sectors	Main Results
Jalava *et al.* (2007)	FI	GA	1975-2005	/	Eurostat, EUKLEMS	Non-financial BS	ICD/GDP: 9.1%; ICD/LPG: [16%; 30%]; GAC:[2.1%; 13.2%]
Van Rooijen-Horsten *et al.* (2008)	NL	DA	2001-2004	/	Dutch NA, Dutch Satellite accounts, Survey data	Whole economy	ICD/GDP: 8.3% ICD/LPG: / GAC: /
Corrado, Hulten and Sichel (2009)*	US	GA	1973-2003	/	BLS, Survey data	Non-farm BS	ICD/GDP: ~ 13%; ICD/LPG: 27%; GAC: 11.2%
Baldwin *et al.* (2009)	CA	DA	1981-2001	/	Statistics Canada, Survey data	Non-financial BS	ICD/GDP: ~ 19%; ICD/LPG: /; GAC: /
Barnes and McClure (2009)	AU	GA	1974-2006	/	ABS data, Survey data	BS	ICD/GDP: 9.6%ICD/LPG: 18% GAC: 3.7%
Fukao *et al.* (2009)*	JP	GA	1985-2005	/	JIP database, Survey data	BS	ICD/GDP: 11.1% ICD/LPG: [16%; 27%] GAC: [1.4%; 17.3%]
Hao *et al.* (2009)	DE, ES, FR, IT	GA	1995-2003	/	Eurostat, OECD STAN, EUKLEMS, Financial reports, Survey data	BS	ICD/GDP: [5.2%; 8.8%] ICD/LPG: [31%; 64%] GAC: [10.5%; 40%]
Marrano *et al.* (2009)*	UK	GA	1990-2004	/	ONS, Eurostat, OECD, I/O tables, Survey data	BS	ICD/GDP: ~ 13% ICD/LPG: 20% GAC: 13.1%
van Ark *et al.* (2009)	AT, CZ, DE, DK, EL, ES, FR, IT, SK, UK, US	GA	1995-2006	/	EUKLEMS, Eurostat, Survey data	BS	ICD/GDP: [5.0%; 7.9%] ICD/LPG: [15%; 41%] GAC: [2.2%; 37%]
Nakamura (2010)	US	DA	2000-2007	/	/	Whole economy	ICD/GDP: Intangible = Tangible; ICD/LPG: /; GAC: /
Edquist* (2011)	SE	GA	1995-2006	/	EUKLEMS, OECD, Statistics Sweden, Survey data	BS	ICD/GDP: 10% ICD/LPG: 30%; GAC: 5.3%
Baldwin *et al.* (2012)	CA	GA	1976-2008	/	Statistics Canada	BS	ICD/GDP: 13.2% ICD/LPG: 29%; GAC:13.3%
Corrado *et al.* (2013)*	EU-14	GA	1995-2007	/	INTAN-Invest (Revision 1), EUKLEMS	BS	ICD/GDP: 6.6% (EU14); 10.6% (US) ICD/LPG: 23.8 (EU14); 28.4% (US) GAC: /
Goodridge *et al*. (2013)*	UK	DA	1995-2011	/	ONS, Eurostat, EUKLEMS	BS	ICD/GDP: /; ICD/LPG: /; GAC: 16%[a]
Roth and Thum (2013)*	EU-13	CCGA	1998-2005	LPG	INNODRIVE, EUKLEMS, Eurostat	BS	ICD/GVA: 9.9% ICD/LPG: 50% GAC: 4.4%
Chen (2018)*	6o World Economies	Variance decomposi tion	1995-2011	GDP p.c.	ILO, PWT, BLS, WARC, ESOMAR, UNESCO, Eurostat	Business sectors	ICD/GDP: /; ICD/LPG: /: GAC: /
Corrado *et al.* (2018)	EU-18	GA	2000-2013	/	INTAN-Invest (Revision 2), EUKLEMS	BS	ICD/GDP: 7.2% (EU14); 6.4% (NMS); 8.8% (US); ICD/LPG: 30% (EU14); 10% (NMS); GAC: /
Roth (2019)*	EU-16	CCGA	2000-2015	/	INTAN-Invest (Revision 2), EUKLEMS	BS	ICD/GVA: 11% ICD/LPG: 56%; GAC: 6.3%

Notes: ICD = Intangible Capital Deepening; LPG = Labour Productivity Growth; GAC = Growth Acceleration; GVA = Gross Value Added; GDP = Gross Domestic Product; GA = Growth Accounting; DA=Descriptive Analysis; CCGA= Cross-country Growth Accounting; D.V. = Dependent Variable; * Published as peer reviewed article; [a] = values after 20

Table A2. Summary of Studies at the Industry Level

Authors	**Countries**	**Method**	**Time Period**	**D.V.**	**Data Source(s)**	**Economic Sectors**	**Main Results**
Barnes (2010)	AU	GA	1993-2006	/	Australian Bureau of Statistics	Business sectors	Intangible over tangible capital investments are 65% in the manufacturing sector and 50% in the service sector.
Dutz *et al.* (2012)	BR	GE (FE)	2000-2008	TFP	PAS, PIA, PAC, PAIC, PINTEC Surveys from the Brazil Institute of Geography and Statistics	Whole economy	Intangible assets positively affect TFP, despite the lower investment shares in Brazil on intangibles.
Dal Borgo *et al.* (2013)*	UK	GA	2000-2008	/	EUKLEMS, Survey data on Intangibles**	Business sectors	Intangible capital deepening accounts for 23% of VA growth. The manufacturing sector is the most intangible intensive.
Miyagawa and Hisa (2013)*	JP	GE (OLS and GMM)	1981-2008	TFP growth	JIP database	Business sectors	Investments in intangibles are positively correlated to TFP growth. The slowdown after 2000 of the Japanese economy is related to a slowdown in intangible capital deepening.
Crass *et al.* (2015)	DE	GA	1995-2006	/	EUKLEMS, Survey data on intangibles**	Business sectors	Intangible capital deepening has an enhancing effect on LPG in all sectors, ranging between 0.17 (construction) and 0.59 (manufacturing).
Delbecque *et al.* (2015)*	FR	GE (FE – GMM)	1980-2007	VA growth	IO Tables, Final Uses Table, EEC, IREP; STAN	16 Industries (incl. public and agriculture sector)	Intangible investments have a general positive effect on productivity, but they differ widely among industries.
Fleisher *et al.* (2015)*	CN	GE (FE, LP estimator)	1999-2007	VA growth	China's National Bureau of Statistics	Business sectors	The sectors investing more in intangibles are the most productive in the Chinese economy, especially after the country's WTO accession.
Chun and Nadiri (2016)*	KR	GA	1981-2008	/	Bank of Korea data, KIP, IO Tables, other Survey data on Intangibles**	Whole Economy	While LPG in Korea is generally low, intangible-intensive industries (IT sector) show the highest LPG growth rates.
Corrado *et al.* (2016)	AT, BE, DE, DK, EL, ES, FI, FR, IE, IT, NL, PT, SE, UK	GA	1995-2010	/	EUKLEMS, INTAN-Invest	Business sectors	Intangible capital deepening explains 25% of LPG for both manufacturing and service sectors.
Niebel *et al.* (2017)*	AT, CZ, DE, DK, ES, FI, FR, IT, NL, UK	GA and GE (POLS, LSDV, FE, GMM-SYS)	1995-2007	VA growth	EUKLEMS, INDICSER	Business sectors	Output elasticities of intangibles are positive and significant, but lower compared to country-level studies. LPG growth due to intangibles is higher in the manufacturing and finance sectors.
Piekkola (2017)*	AT, BE, CZ, DE, DK, EE, EL, ES, FI, FR, HU, IT, LT, LV, NL, NO, RO, SE, SI, SK, UK	GA and GE (OLS, MG, WLP)	2008-2013	VA growth	Own constructed dataset from EUROSTAT indicators	Business sectors	Output elasticities of intangibles are positive and significant, and of a similar magnitude to country-level studies. The positive effect is not found in the years of the financial crisis 2008-2013.

Notes: *Published as peer reviewed article. D.V. = Dependent Variable

Table A3. Summary of Studies at the Firm Level

Authors	Countries	Estimation Method	Time Period	D.V.	Data Source(s)	Economic Sectors	Main Results
De and Dutta (2007)*	IN	GMM, FE	1997-2005	Output growth	Centre for Monitoring Indian Economy	IT and software industry	Organizational capabilities and human capital have a positive impact on output growth.
Ramirez and Hachiya (2008)*	JP	OLS (FE – LSDV)	1997-2001	Sales growth	Nikkei Corporate Financial Database, Toyo Keizai Stock Price Data Bank	Whole economy	Intangible investments have a general positive effect on sales. R&D spending are effective only in the manufacturing sector. Advertisement is generally effective.
Marrocu *et al.* (2012)*	ES, FR, IT, NL, SE, UK.	Semi-parametric (OP – LP)	2002-2006	VA	BVD Amedeus Database	Manufacturing and services sectors	Intangible investments drive productivity at the firm level. Overall growing shares of intangible over tangible investments.
Görzig and Gornig (2013)*	DE	Growth accounting	1999-2003	-	Eukleed.	Market sector, excluding agriculture, fishing and real estate activities	Dispersion in the rate of return of investments is reduced once Intangibles are capitalised.
Crass and Peters (2014)	DE	Semi-parametric (OP – LP)	2006-2010	TFP, labour productivity, VA	Mannheim Innovation Panel	Manufacturing and service sectors	Positive effect of intangibles on productivity. The most productive investments are those in R&D, branding and human capital.
Ilmakunnas and Piekkola (2014)*	FI	Semi-parametric (OP – LP) GMM-SYS	1998-2008	TFP	Confederation of Finnish Industries data and Suomen Asiakastieto data	Business sectors	Investments in managerial and marketing workers have a strong positive effect on TFP. R&D workers have a lower positive return.
Verbič and Polanek (2014)*	SI	FE	1994-2005	Sales growth	AJPES, TORS, SRDAP	Business sectors	Investments in human capital and R&D have a positive and significant effect on sales. Organizational activities have a lower positive return.
Battisti *et al.* (2015)*	AT, BE, CZ, DE, ES, FI, FR, HU, IT, NL, NO, PT, SE, SI, SK, UK	LOGIT FE, GLS	2003-2009	TFP, probability of adopting technology	Amadeus – 2012 database	Manufacturing sector	Investments in intangible assets have positive effects on TFP and stimulate firms to invest in complementary technology.
Bontempi and Mairesse (2015)*	IT	OLS (FE – FD)	1982-1999	Output growth, TFP	CADS database and SIM database.	Manufacturing sector	The median firm has a return of €2-3 per year for each euro invested in intangible assets.
Shakina et al. (2016)*	RU	FE	2004-2013	Intangible endowment gap	Amadeus, Bloomberg, Corporate annual reports	Business sectors	Comparing Russian and European firms, a significant gap in intangible investments is revealed and explains the lower productivity of the Russian firms.
Piekkola (2016)*	FI	FE - RE	1997-2011	Output growth, market value	Confederation of Finnish Industries data and Suomen Asiakastieto data	Business sectors	The intangible investments have reached the investments in machinery and the equipment at the end of the sampling period. Positive effect of intangible investments on the firm's market value.
Goldar and Parida (2017)*	IN	OLS (FE – FD)	2012-2013	Output growth, TFP	ACE Equity Database	Manufacturing and service sectors	Intangible capital has a positive and significant effect on firms' productivity, stronger in the manufacturing sector.
Chappel and Jaffe (2018)*	NZ	OLS (FE)	2005-2013 (odd years)	LPG, profitability, output growth	LBD Database	Whole economy	Intangible investments enhance the growth of firms but have no clear effect on productivity or profitability.
Lalovic and Koman (2018)*	SI	Descriptive statistics	2011-2014	/	Ad-hoc Survey data from 364 SI companies with > 100 employees	Manufacturing sector	The best-performing firms are those with higher intangible investments.

Notes: * Published as peer reviewed article. D.V. = D

ependent Variable.

Table A4. Summary of studies on complementarity investments and spillover effects

Authors	**Countries**	**Estimation Method**	**Time Period**	**D.V.**	**Data Source(s)**	**Economic Sectors**	**Main Results**
Brynjolfsson and Hit (2000)*	\	Descriptive analysis	\	\	\	Whole Economy	Investments in intangible capital (organizational and human capital) are complementary to ICT.
O'Mahony and Vecchi (2009)*	DE, FR, JP, UK, US.	GMM, FD	1988-1997	Output growth, TFP growth	Worldscope	Business sectors	Firms operating in R&D and skill-intensive sectors have from 2% to 5% higher productivity.
Chen *et al.* (2016)*	AT, CZ, DE, DK, ES, FI, FR, IT, NK, UK	FE, IV	1995-2007	GVA growth	INTAN-Invest, EUKLEMS	Business sectors	Intangible investments have a higher positive productivity effect in ICT-intensive industries.
Corrado *et al.* (2017a)*	AT, DE, DK, ES, FI, FR, IT, NL, SE, UK	FE, RE, IV	1998-2007	LPG, TFP growth	INTAN-Invest, EUKLEMS	Business sectors	Investments in intangible assets and in ICT are complementary to labour productivity. Evidence for productivity spillovers to increases of intangible capital.
Goodridge *et al.* (2017)*	UK	FE	1992-2007	(lags of) TFP growth	EUKLEMS, Individual sources for Intangibles	Business sectors	Lagged outside knowledge stock and lagged external R&D are correlated with TFP, providing evidence for extra-industry intangible spillovers.
Elnasri and Fox (2017)*	AU	OLS	1993-2013	TFP growth	NA Data	Business sectors	Private sector's knowledge capital generates positive spillovers. Higher education and research agencies generate positive spillovers, among the publicly funded bodies.
Brynjolfsson *et al.* (2017)	US	Descriptive analysis	\	\	\	Whole Economy	AI is a type of intangible capital (software) that needs complementary investments in other intangible assets (databases, firm specific human capital, organizational capital) and tangible assets (ICT).
Melachroinos and Spence (2019)*	UK	GMM	1995-2007	GVA	ONS	Business sectors	At the NUTS3 level, intangible investments have an overall positive effect on GVA, but they are unevenly distributed towards London and the South-East and foster divergence within the UK.

Notes: * Published as peer reviewed article. D.V. = Dependent Variable.

Table A5. Summary of studies on drivers of business intangible investments

Authors	Country(ies)	Estimation Method	Time Period	D.V.	Data Source(s)	Economic Sectors	Main Results
Gros and Roth (2012)	EU-27	OLS	1995-2005	Intangible capital investments	INNODRIVE, Eurostat, Governance indicators	Business sectors (without agriculture)	Better government effectiveness (efficient judicial system, rule of law) enhance intangible investments.
Andrews and Criscuolo (2013)	OECD countries	Cross-country analysis	\	\	\	\	Policies designed to enhance knowledge-based capital formation should target well-functioning labour and venture capital markets, well defined intellectual property rights and revisit bankruptcy laws.
Arrighetti *et al.* (2014)*	IT	Probit, IV	2001-2003	Probability of being in the top decile of intangible investors	Capitalia's Survey on Manufacturing firms and AIDA database	Manufacturing sector	Larger firm size, better educational skills of the workforce and higher past levels of intangible investments increase the likelihood of investing in intangible assets.
Yang *et al.* (2018)*	CN	Probit, Tobit	2011	Intangible capital investments	China Enterprise Survey	Manufacturing sector	Larger firm size and better educational skills of the workforce increase the likelihood of investing in intangible capital, while higher market competition generally lowers it.
Demmou *et al.* (2019)	OECD countries	FE	1990-2014	LPG	OECD, IMF, Eurostat, World Bank, Compustat.	Whole economy (excluding public and financial sectors)	Intangible-intensive industries have the higher benefits from financial development, from more access to equity/venture capital and from more efficient insolvency regimes.
Ahn (2019)*	US	FE	1986-2016	Tangible and intangible investments	Compustat, S&P data, Cboe	Manufacturing sector	Intangible investments are less responsive to tangible investments to external shocks, and strongly depends on their own past levels.
Thum-Thysen *et al.* (2019)*	AT, BE, DK, FI, FR, DE, EL, IE, IT, NL, ES, SE, UK	FE, VIF	1995-2013	Tangible, intangible and total investments	INTAN-Invest, EUKLEMS, OECD, Eurostat	Business sectors	A flexible regulatory framework, higher public R&D spending, higher levels of Tertiary education are enhancers of Intangible investments. More favorable financial conditions enhance only tangible investments.

Notes: * Published as peer reviewed article. D.V. = Dependent Variable.