Revisiting intangible capital and labour productivity growth, 2000–2015

Accounting for the crisis and economic recovery in the EU

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Abstract

Purpose – This paper aims to revisit the relationship between intangible capital and labour productivity growth using the largest, up-to-date macro database (2000–2015) available to corroborate the econometric findings of earlier work and to generate novel econometric evidence by accounting for times of crisis (2008–2013) and economic recovery (2014–2015).

Design/methodology/approach – To achieve these aims, this paper employs a cross-country growth accounting econometric estimation approach using the largest, up-to-date database available encompassing 16 EU countries over the period 2000–2015. The paper accounts for times of crisis (2008–2013) and of economic recovery (2014–2015). It separately estimates the contribution of three distinct dimensions of intangible capital: (1) computerized information, (2) innovative property and (3) economic competencies.

Findings – First, when accounting for intangibles, the paper finds that these intangibles have become the dominant source of labour productivity growth in the EU, explaining up to 66 percent of growth. Second, when accounting for times of crisis (2008–2013), in contrast to tangible capital, the paper detects a solid positive relationship between intangibles and labour productivity growth. Third, when accounting for the economic recovery (2014–2015), the paper finds a highly significant and remarkably strong relationship between intangible capital and labour productivity growth.

Originality/value – This paper corroborates the importance of intangibles for labour productivity growth and thereby underlines the necessity to incorporate intangibles into today's national accounting frameworks in order to correctly depict the levels of capital investment being made in European economies. These levels are significantly higher than those currently reflected in the official statistics.

Keywords Intangible capital, Labour productivity growth, Crisis, Recovery, European Union

Paper type Research paper

1. Introduction

Recent research reports a disappointing performance in labour productivity growth among European Union (EU) and euro area (EA) countries since the start of the crisis from 2008 to 2015

The author wishes to thank the participants at the 15th World Conference on Intellectual Capital for Communities in Paris (July 2019), the GLOBALINTO meeting in Athens (September 2019) and the GLOBALINTO workshop on Advancing the Measurement of Intangibles for European economies in Brussels (January 2020) for constructive comments. He would also like to thank Simone Calió for excellent research assistance. Moreover, Dr. Roth is grateful for a grant received from the European Commission under the Horizon 2020 programme for the GLOBALINTO project (Capturing the value of intangible assets in micro data to promote the EU's growth and competitiveness, contract number 822259). And finally, he expresses his gratitude to Ahmed Bounfour, Hannu Piekkola, Felicitas Nowak-Lehmann, Thomas Straubhaar, Iulia Siedschlag, Robert Stehrer and Josh Martin for their valuable comments.

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(Van Ark and Jäger, 2017). According to this literature, this performance stems largely from a slower diffusion of technology and innovation due to low growth rates of information and communication technology (ICT) and complementary intangible capital investment (Van Ark and Jäger, 2017, p. 15; Van Ark, 2016, pp. 37–41; Van Ark and O'Mahony, 2016, pp. 132–138). Indeed, a recent growth-accounting study at the macro level over the period 2000–2013 identifies the deepening of intangible capital as a main driver of labour productivity growth (Corrado *et al.*, 2018, p. 11). Such findings are in line with existing growth-accounting studies for the US (Corrado *et al.*, 2009), the UK (Marrano *et al.*, 2009), Japan (Fukao *et al.*, 2009), Sweden (Edquist, 2011) and the EU-15 (Corrado *et al.*, 2013).

Within this substantial body of growth-accounting evidence, however, there exists only scarce econometric evidence at the macro level of the impact of intangible capital investment on labour productivity growth. The only existing econometric study analyses an EU-13 country sample for pre-crisis times from 1998 to 2005 (Roth and Thum, 2013). This scarcity of growth econometric studies is remarkable in light of their general advantages in comparison to growth accounting studies (Temple, 1999, pp. 120–121). To help close this gap in the research, this paper conducts an econometric analysis using a cross-country growth-accounting approach covering 16 EU countries over the period 2000–2015. This approach overcomes earlier work in two ways. First, the paper is able to corroborate earlier econometric findings (Roth and Thum, 2013) with the help of a greatly extended dataset containing more than two and half times the number of overall observations (256 versus 98). Second, by covering a period until 2015, the paper is able to generate novel econometric findings on the impact of intangible capital deepening on labour productivity growth by accounting for times of crisis (2008–2013) and times of economic recovery (2014–2015).

By matching the most recent release of the INTAN-Invest (NACE2)[1] dataset (Corrado *et al.*, 2018) with the latest figures from the EU KLEMS[2] dataset (Jäger, 2017), in combination with a wide range of growth-relevant policy variables from Eurostat, OECD and the World Bank, this paper provides the largest up-to-date intangible capital panel dataset at the macro-level containing an overall number of 256 country observations. Estimating a slightly modified model specification as developed within the existing literature (Roth and Thum, 2013, p. 495) with the help of a cross-country growth-accounting econometric approach, the paper reaches three major findings. First, in line with the previous growth econometric literature (Roth and Thum, 2013), the paper confirms that once intangibles are accounted for, they become the dominant source of labour productivity growth in the EU, explaining up to 66 percent of this growth. Second, when accounting for times of crisis (2008–2013), this paper finds that even when the relationship between tangible capital and labour productivity turned negative, the impact of intangibles on growth remained solidly positive. Third, when accounting for the economic recovery (2014–2015), we find a highly significant and remarkably strong relationship between intangible capital and labour productivity growth.

2. Theoretical linkages between intangible capital and labour productivity growth

The earliest work highlighting the importance of intangible capital for labour productivity reaches back as far as the 1960s (Haskel and Westlake, 2018, p. 38). Based on research by Brynjolfson *et al.* (2002) and Nakamura (2001), amongst others, Corrado *et al.* (2005) developed a methodological framework for the US of how to account for business intangibles in the "new economy". The authors used an intertemporal framework for investment and grouped the various business intangibles into three broad dimensions: 1) computerized information, namely software, 2) innovative property, namely research & development (R&D) and 3) economic competencies, namely brand names, firm-specific human capital and organizational capital. Conducting a growth-accounting analysis alongside their methodological framework, Corrado *et al.* (2009) showed that business intangibles were able to explain a significant share of labour productivity growth. Using growth-accounting studies, similar results were found for the UK (Marrano *et al.*, 2009), Japan (Fukao *et al.*, 2009), Sweden (Edquist, 2011) and the EU (Corrado *et al.*, 2013 and 2018). Econometric cross-country growth-accounting studies for the EU (Roth and Thum, 2013) find an even stronger impact of intangibles on labour productivity growth. In addition, the positive relationship between intangible capital and labour productivity was prominently discussed and established in the work of Bounfour (Bounfour and Miyagawa, 2015; Delbecque *et al.*, 2015); Piekkola (2016 and 2018) and Miyagawa (Miyagawa and Hisa, 2013; Bounfour and Miyagawa, 2015).

The positive relationship between computerized information and labour productivity growth – particularly the interaction between software and organizational capital (Brynjolfsson *et al.*, 2002) – and R&D and labour productivity growth (Guellec and van Pottelsberghe de la Potterie, 2001) has already been well established in the literature. Consequently, the three intangible assets – software, R&D and entertainment, artistic and literary originals and mineral exploration – were already included in the asset boundary of the national accounts. Given that economic competencies in particular were not yet included in the national accounts, it seems necessary to once more elaborate their positive role in labour productivity growth. Concerning *brand names,* Cañibano *et al.* (2000) argue that the ownership of an attractive brand permits a seller to retain a higher margin for goods or services compared to his competitors. Since the consumer is driven by his perceptions in choosing among the products of competing firms, the development of an appealing image or brand is crucial in producing future benefits. Concerning training or *firm-specific human capital,* the same authors stress that a firm with higher-skilled employees is likely to attain higher profits than competitors whose workers are less competent. This observation is in line with Abowd *et al.* (2005), who argue that the value of a firm will increase if the quality of its firm-specific human capital resources improves. Concerning *organizational capital*, Lev and Radhakrishnan (2005, p. 75) define organizational capital 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 authors classify this as the only competitive asset truly possessed by a firm, whereas the others are exchangeable and thus can be obtained by any company prepared to make the necessary investment.

3. Estimates on intangible capital

A methodological framework originally developed by Corrado *et al.* (2005) for measuring business intangibles in the US has become widely used internationally. The framework was adopted in individual country-case studies for the UK (Marrano *et al.*, 2009), Japan (Fukao *et al.*, 2009) and Sweden (Edquist, 2011). Adapting this methodological framework to the EU, the FP7 INNODRIVE project[3] constructed the first harmonized dataset for an EU-27 country sample (plus Norway), alongside the three dimensions mentioned above. It contained two "old" national account intangibles and eight "new" intangibles over the time period 1980–2005 (INNODRIVE, 2011; Jona-Lasinio *et al.*, 2011; Gros and Roth, 2012; Roth and Thum, 2013). The INNODRIVE macro database was used as the base for the EU-27 countries within the first version of the INTAN-Invest (NACE1) dataset[4]–a harmonized and updated intangible dataset covering the EU and the US over the time period 1980–2010 (Corrado *et al.*, 2013). In developing the second version of the INTAN-Invest (NACE2) dataset, Corrado *et al.* (2016, 2018) significantly altered their methodology to provide information on intangible capital on single-digit NACE2 economic sectors and updated their dataset in the latest January 2019 release until the year 2015.

The INTAN-Invest (NACE2) covers 19 EU countries plus the US over the period 1995–2015. The dataset measures three "old" national account intangibles and five "new" intangibles. The dataset groups business intangibles under three dimensions: (1) computerized information, (2) innovative property and (3) economic competencies. The first dimension, i.e. computerized information, contains computer software and databases. The second dimension, i.e. innovative property, contains (1) entertainment, artistic and literary originals and mineral exploration, (2) R&D, (3) design and (4) new product development in the financial industry. The third dimension, i.e. economic competencies, contains (1) brand, (2) firm-specific human capital and (3) organizational capital. A detailed explanation of the altered methodology of the INTAN-Invest (NACE2) dataset is provided in Corrado *et al.*, (2016), pp. 42–47.

4. Previous empirical results

Table I gives an overview of the existing empirical results of the growth-accounting and cross-country growth econometric literature analyzing the relationship between business intangible capital and labour productivity growth by businesses at the macro level. The table displays three distinct effects once intangible capital has been incorporated into the asset boundary of the national accounts.

In the first instance, the table clarifies that investments in intangible capital reach significant levels, once they are fully accounted for. Analyzing the business investment level for the US in pre-crisis times, Corrado *et al.* (2009) find a business investment level of 13 percent of non-farm business output, whereas Nakamura (2010) finds equal shares of intangible and tangible capital investments. Similar investment rates for pre-crisis times are found for Japan (Fukao *et al.*, 2009) and the UK (Marrano *et al.*, 2009) with 11.1 percent of GDP and 13 percent of adjusted MGVA (market sector gross value added), respectively. With a value of 16 percent of GVA (gross value added), higher business investment rates are found in Sweden (Edquist, 2011). Utilizing INNODRIVE data, Roth and Thum (2013) find an average business investment rate for pre-crisis times (1998–2005) for 13 EU countries of 9.9 percent of GVA. Utilizing the first version (NACE1) of the INTAN-Invest dataset, Corrado *et al.* (2013) find an average business investment rate of 6.6 percent of GDP for an EU-15 country sample from 1995 to 2009. Utilizing the second version of the INTAN-Invest (NACE Rev.2) dataset, Corrado *et al.* (2018) find an average investment rate for business intangibles for the EU-14 and NMS-4 of 7.2 and 6.4 percent of GDP, respectively, from 2000 to 2013.

Second, the contribution from intangible capital services to labour productivity growth is significant. Once business intangible capital is accounted for, 27 percent and 20 percent of labour productivity growth were explained in the US and the UK, respectively. The same and higher values of up to 41 percent hold for Japan and Sweden (Fukao *et al.*, 2009; Edquist, 2011). Utilizing INNODRIVE data and analyzing 13 EU countries with the help of an econometric cross-country growth accounting methodological approach, Roth and Thum (2013) find that 50 percent of labour productivity can be explained. Using INTAN-Invest (NACE1) data for an EU-15 country sample over the time period 1995–2009, Corrado *et al.* (2013) find a value of 24 percent. In their most recent study, using INTAN-Invest data (NACE2), Corrado *et al.* (2018) differentiate between a pre-crisis and a crisis period. They find that intangible capital contributes 30 percent over the time period 2000–2013, and 19 and 43 percent in times of pre-crisis and crisis respectively, for an EU-14 country sample.

Third, the capitalization of intangibles accelerates productivity growth.

5. Model specification, research design and data

5.1 Model specification

We estimate a slightly revised model specification as developed in the existing econometric literature (Roth and Thum, 2013, p. 495). Following this literature, the slightly revised model specification takes the following form:

Table I. Overview of existing empirical studies, 2009–2018

Authors	Country	Investment (in GDP) in %	Contribution to LPG in %†	Growth acceleration in %	Article	Harmonized cross-country dataset	Metho-dology
Corrado *et al.* (2009)	US	~ 13* (03)	27 (95–03)	11.2 (95–03)	RoIW	–	GA
Fukao *et al.* (2009)	JAP	11.1 (00–05)	27; 16 (95–00); (00–05)	17.3; −1.4 (95–00); (00–05)	RoIW	–	GA
Marrano *et al.* (2009)	UK	13** (04)	20 (95–03)	13.1 (95–03)	RoIW	–	GA
Nakamura (2010)	US	Intangible = Tangible (00–07)	/	/	RoIW	–	GA
Edquist (2011)	SE	10/~16*** (04)	41; 24 (95–00); (00–06)	16; −2.3 (95–00); (00–06)	RoIW	–	GA
Roth and Thum (2013)	EU-13	9.9**** (98–05)	50 (98–05)	4.4 (98–05)	RoIW	INNODRIVE	CCGA
Corrado *et al.* (2013)	EU-15	6.6 (95–09)	24 (95–07)	/	OREP	INTAN-Invest (NACE1)	GA
Corrado *et al.* (2018)	EU-14, NMS-4	7.2, 6.4 (00–13)	30, 10; 19, 8; 43‡, 17 (00–13); (00–07); (07–13)	/	JIPD	INTAN-Invest (NACE2)	GA

Note(s): †LPG = Labour Productivity Growth. *The measure here is non-farm business output. **The measure here is adjusted market sector gross value added (MGVA). ***The measure here is gross value added (GVA). ****The measure is GVA (c – k + o excluding k70). ‡Capital share. US = United States, UK = United Kingdom, JAP = Japan, SE = Sweden, EU = European Union, NMS = New Member States, RoIW = Review of Income and Wealth, OREP = Oxford Review of Economic Policy, JIPD = Journal of Infrastructure, Policy and Development, GA = Growth Accounting, CCGA = Cross Country Growth Accounting. The numbers in brackets refer to the relevant time periods

$$(lnq_{i,t} - lnq_{i,t-1}) = c + gH_{i,t} + mH_{i,t}\frac{(q_{max,t} - q_{i,t})}{q_{i,t}} + n(1 - ur_{i,t}) + p\sum_{j=1}^{k} X_{j,i,t} + yd_{i,t} + \alpha(lnk_{i,t} - lnk_{i,t-1}) + \beta(lnr_{i,t} - lnr_{i,t-1}) + u_{i,t} \quad (1)$$

Where $(lnq_{i,t} - lnq_{i,t-1})$ is labour productivity growth (GVA expanded by intangibles and divided by total hours worked) for the non-farm business sectors $b–n + r–s$ excluding real estate activities expanded by the investment flows of business intangible capital in country i and period t. The constant term c represents exogenous technological progress; the level of human capital $(H_{i,t})$ reflects the capacity of a country to innovate domestically; and the term $H_{i,t}(q_{max,t} - q_{i,t})/q_{i,t}$ proxies a catch-up process, with $q_{max,t}$ using a purchasing power parity-weighted GVA measure divided by total hours worked and representing the country with the highest level of labour productivity at period t. The term $(1 - ur_{i,t})$ takes into account the business-cycle effect proxied by 1 minus the unemployment rate (ur); the term $\sum_{j=1}^{k} X_{jit}$ is the sum of k extra policy variables, which could possibly explain TFP (total factor productivity) growth and $yd_{i,t}$ are year dummies to control amongst others for the economic downturn in 2001, in the wake of the bursting of the information-technology bubble in the previous year and the 9/11 attack in 2001, as well as the pronounced economic downturn since 2008. $(lnk_{i,t} - lnk_{i,t-1})$ and $(lnr_{i,t} - lnr_{i,t-1})$ represent the growth of tangible and intangible capital services, and $u_{i,t}$ represents the error term.

5.2 Research design

The econometric analysis covers 16 out of 27 EU countries from 2000 to 2015. The countries included are Austria, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Slovakia, Slovenia, Sweden and the United Kingdom[5]. With 16 EU countries and 16 time periods from 2000 to 2015, this leaves the econometric analysis with an overall number of 256 observations. Following the approach by Roth and Thum (2013, p. 496), annual growth rates from 2000 to 2015 were estimated. The econometric analysis was restricted to a period of 2000–2015, due to the valid calculation of capital stock data. Equation (1) is estimated with the help of an econometric cross-country growth accounting approach. This approach differs from traditional single-growth accounting in two ways. First, the output elasticities are estimated rather than imposed. And second, the model can be designed to explain the international variance in TFP (total factor productivity) growth. The whole research design applies to non-farm business sectors $b–n + r–s$ excluding real estate activities. For Greece, Ireland and Portugal, measures for the total economy were adjusted to the non-farm business sectors. For Greece, disproportionately high levels of organizational capital investment were adjusted to an average EU-16 level. Measurement errors and missing values in the latest releases of the EU KLEMS (Jäger, 2017) and the INTAN-Invest (NACE2) dataset (Corrado *et al.*, 2018) were dealt with when necessary[6].

5.3 Data sources

The data were retrieved from the sources specified below:

(1) Data on the single components of intangible capital were taken from the INTAN-Invest (NACE2) dataset (Corrado *et al.*, 2018), which provides information on gross fixed capital formation (GFCF) and intangibles adjusted GVA. The data cover 19 EU

countries + the US over the period 1995–2015, for 21 NACE2 economic sectors. The INTAN-Invest (NACE2) dataset does not provide intangible capital stocks.

(2) Data on the single components of tangible capital were taken from the EU KLEMS database (Jäger, 2017). The database provides data on GFCF, tangible capital stocks, GVA, labour compensation, capital compensation and number of hours worked per employee. The data cover the EU-28 countries and the US, over the period 1995–2015, for 21 NACE2 economic sectors.

(3) Human capital is measured as the percentage of the population aged 15+ that has attained at least upper-secondary education, which is taken as a proxy for the stock of human capital. The data were obtained from Eurostat.

(4) Data on unemployment, power purchasing parity (PPP), inflation (HICP), government expenditures on education (percent of GDP), total government expenditures (percent of GDP), social expenditure (percent of GDP) and stock of foreign direct investment (FDI) (percent of GDP) were obtained from Eurostat.

(5) Data on income tax (as a percent of GDP) were obtained from the OECD. The variables rule of law (Kaufmann *et al.*, 2010), data on market capitalization (percent of GDP) and openness to trade were retrieved from the World Bank.

5.4 A note on the construction of intangible capital stocks

In line with the literature (Niebel *et al.*, 2017, p. 55; Roth and Thum, 2013, p. 497; Timmer *et al.*, 2007, pp. 32 and 39), intangible capital stocks for the selected 16 EU-27 countries for the time period 2000–2015 were constructed by applying the perpetual inventory method (PIM) to a series of intangible capital investment going back to 1995 and using the depreciation rates (δ_R) as suggested by Corrado *et al.* (2009): 20 percent for R&D, design and new product development in the financial services industry; 35 percent for software; 40 percent for organizational capital and firm-specific human capital; 60 percent for brand names and 13.75 percent for entertainment, artistic and literary originals and mineral exploration. For the calculation of the intangible capital stock R_t, the PIM takes the following form:

$$R_t = N_t + (1 - \delta_R)R_{t-1} \tag{2}$$

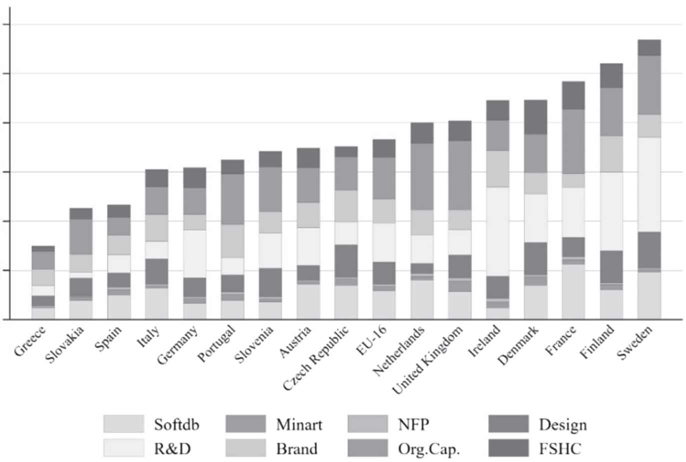
which assumes that (1) geometric depreciation, (2) constant depreciation rates over time and (3) depreciation rates for each type of asset are the same for all countries. The real investment series for (N_t) uses a GVA price deflator which is the same for all intangibles.

5.5 A note on the construction of intangible and tangible capital services

Data on intangible capital service services were generated according to the work by Oulton and Srinivasan (2003) and Marrano *et al.* (2009) and are consistent with the EU KLEMS approach (Timmer *et al.*, 2007). This work contends that rather than using a wealth measure (such as the capital stock), it is vital to ascertain the flow of services a capital stock can provide to production. The technical steps of the construction of intangible and tangible capital services are in line with Roth and Thum (2013) and are explained in detail in Appendix 1.

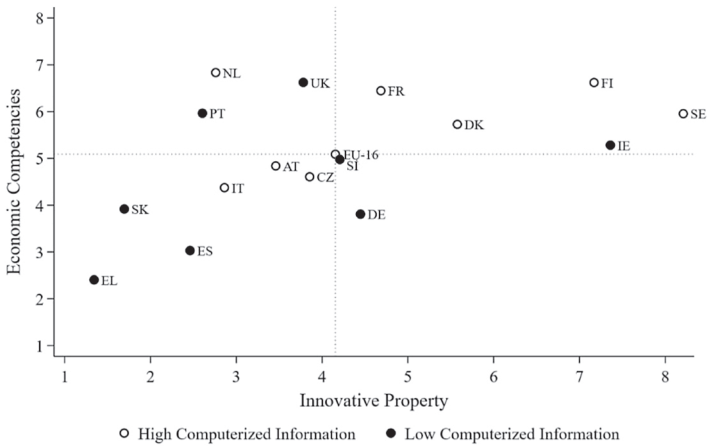
6. Descriptive analysis

Table AI in Appendix 2 shows the descriptive statistics of the analyzed dataset. Labour productivity growth increased by 0.1 percentage points (from 1.5 to 1.6), or by 6.7 percent, a slightly higher value than the value of 4.4 percent detected in previous work (Roth and Thum, 2013, p. 498). Figure 1 shows the business intangible capital investment over GVA for the



Note(s): Investments are compared to GVA (non-farm business sector b-n + r-s excluding real estate activity). Softdb=Software and Databases. Minart=Entertainment, artistic and literary originals and mineral exploration. NFP=New product development costs in the financial industry. Design=Design. R&D=Research and Development. Brand=Brand Names. Org.Cap.=Organizational Capital. FSHC=Firm-Specific Human Capital
Source(s): INTAN-Invest (NACE2) data (Corrado *et al.*, 2018)

Figure 1.
Business intangible investment (as a percentage of GVA) in 16 EU countries, 2000–2015



Note(s): The dashed lines indicate the EU16 average values. AT = Austria, CZ = Czech Republic, DE = Germany, DK = Denmark, EL = Greece, ES = Spain, FI = Finland, FR = France, IE = Ireland, IT = Italy, NL = the Netherlands, PT= Portugal, SE = Sweden, SI = Slovenia, SK = Slovakia, UK = United Kingdom
Source(s): INTAN-Invest (NACE2) data (Corrado *et al.*, 2018)

Figure 2.
Scatterplot between innovative property and economic competencies (as a percentage of GVA), 2000–2015

eight intangible capital indicators for the 16 EU countries over the 16-year average time period 2000–2015. The figure shows that overall business intangible capital investments vary considerably across the 16 EU countries. Sweden ranks first with an investment of 17.1 percent. This is similar to the findings by Edquist (2011), who reports an investment rate of 16, but higher than the findings by Roth and Thum (2013), who report an investment rate of 13.6 percent over business GVA. Sweden is followed by Finland, France, Denmark and Ireland with investment rates of 15.6, 14.5, 13.4 and 13.4 percent over GVA, respectively. Such values are again higher than those found by Roth and Thum (2013). In particular, the Irish case seems noteworthy, given its low values in the literature (Roth and Thum, 2013, p. 498). Most countries' investment rates are positioned between 9 and 12 percent, and therefore fall near the EU-16 average investment rate of 11 percent. This is in the range of the value of 9.9 percent, as reported in earlier econometric work (Roth and Thum, 2013, p. 498). The lowest investment levels can be detected in Spain, Slovakia and Greece, with values of 7.0, 6.8 and 4.5, respectively. Overall, it is noteworthy that the equal investment levels for Germany and Italy – with values of 9.3 and 9.2 percent – as well as the pronounced difference between Germany and France by 5.2 percentage points, were not detected in the earlier literature using INNODRIVE data (Roth and Thum, 2013, p. 498)[7].

In order to analyze the distribution of the three intangible dimensions, Figure 2 displays a scatterplot between the innovative property and economic competencies. The five countries located in the upper-right corner – Sweden, Ireland, Finland, Denmark and France – can be classified as highly innovative and strong investors in economic competencies. In addition, four out of these five countries score high on computerized information. There are some economies, however, that are highly innovative, but which invest less in economic competencies and computerized information, such as Germany[8]. The third category includes countries that score low on innovative property but high on economic competencies, namely the UK, the Netherlands and Portugal, of which only the Netherlands scores high on promoting computerized information. The fourth category contains countries that score low on both dimensions: Italy, Spain, Slovakia and Greece. Three out of these four countries also score low on computerized information.

Figure 3 compares business investments in intangible and tangible capital as used in the econometric estimation. Once intangibles are included in the asset boundary of the national accounts, the average level of investment of the 16 EU countries is 25.1 percent. This value is significantly higher than the value produced if one only considers tangible capital investment, which would be at 14.1 percent. Among the 16 EU countries, seven countries (Finland, France, Sweden, the Netherlands, the United Kingdom, Ireland and Denmark) invest more in intangibles than in tangibles – their share of intangible/tangible investment is already greater than one percent. This is in line with the finding by Nakamura (2010), who detected this pattern for the US as early as the year 2000, but contrasts with an earlier analysis for the time period 1998–2005 (Roth and Thum, 2013, p. 500), which did not find such a pronounced pattern[9].

Figure 4 shows the time series pattern for intangible and tangible capital investment and labour productivity growth for the 16 individual EU countries and the average EU-16 pattern. Three findings are especially noteworthy. First, in line with earlier literature (Corrado *et al.*, 2018), when analyzing an average EU-16 time series pattern, the crisis has led to a slight decline in intangible capital investment but a more pronounced decline in tangible capital. Whereas intangible capital investments have swiftly recovered, tangible capital investments have not yet recovered to pre-crisis levels. Second, the decline in investment in tangible capital has been pronounced in EA countries due to the sovereign debt crisis, particularly in Greece, Spain, Italy, Portugal and Slovenia. Conversely, with the exception of Greece, intangible capital investment has even increased in these countries in times of crisis and economic recovery. Third, the Irish case is exceptional. In times of economic recovery, Ireland

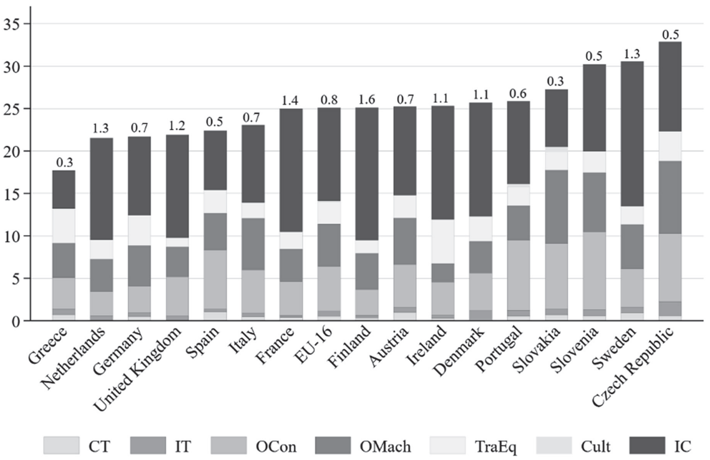


Figure 3.
Business tangible and intangible capital investments (as a percentage of GVA), EU16, 2000–2015

Note(s): CT=communications technology; IT=information technology; OCon=total non-residential capital investment; OMach=other machinery and equipment; TraEq=transport equipment; Cult=cultivated assets; IC=intangible capital. Residential Structure has been excluded. Values on top of the bars depict the intangible/tangible capital investment ratio
Source(s): INTAN-Invest (NACE2) data (Corrado *et al*., 2018) and EUKLEMS data (Jäger, 2017)

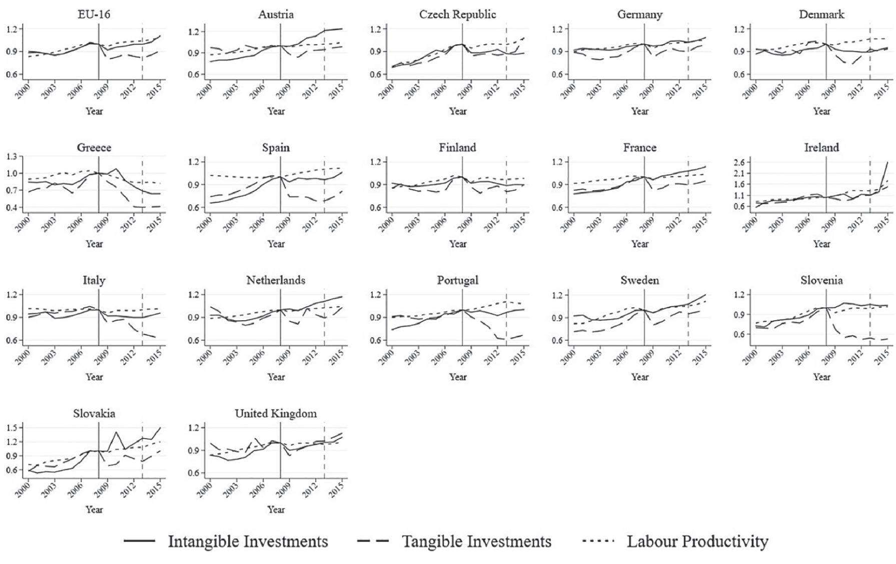


Figure 4.
Investments in intangibles and tangibles and labour productivity in 16 EU countries (2000–2015)

Note(s): Investment in intangibles, tangibles and labour productivity are given in millions of national currencies and are standardized to 1 in the year 2008. The continuous line indicates the start of the financial crisis in September 2008. The dashed line indicates the start of the economic recovery at the end of 2013. Adapted y-scales are applied to Greece, Ireland and Slovakia. EU-16 average is based on PPP-adjusted values
Source(s): INTAN-Invest (NACE2) data (Corrado *et al*., 2018)

has managed to more than double its intangible capital investments – largely due to significant investments in R&D.

7. Econometric estimation

We estimate equation (1) with the help of a pooled panel (PP) estimation approach[10]. To control for panel heteroscedasticity, a panel-corrected standard error estimation procedure (PCSE) was used[11]. It should be noted that the PP-PCSE estimation yields the same coefficients as a random-effects estimator (see row 27 in Table III). This property permits us to compare our results directly with the econometric findings of the existing literature (Roth and Thum, 2013, pp. 501–505). Regression 1 in Table II shows the results when estimating a traditional production function without the inclusion of intangibles (excluding software, R&D, and entertainment, artistic and literary originals and mineral exploration from the tangible capital investment). Growth in tangible capital services is positively associated with labour productivity growth and has a coefficient of 0.31, which explains a 64 percent share of labour productivity growth[12]. Regression 2 includes intangibles. Growth in intangible capital services positively relates to labour productivity growth with a coefficient of a magnitude of 0.38, explaining 66 percent of labour productivity growth. As can be inferred from Table I, this value is higher than the figure of 50 percent reported in earlier work (Roth and Thum, 2013, p. 502). Once intangibles are included, the impact of tangible capital diminishes to 34 percent, which is a slightly lower value than previously reported in the literature (Roth and Thum, 2013, p. 503)[13]. This finding clarifies that intangible capital investments have become the dominant source of growth in EU countries.

Regression 3 in Table II analyses the relationship between intangible capital and labour productivity during times of crisis by adding a crisis (2008–2013) interaction effect to the specification of regression 2. Regression 3 clarifies that while the relationship between tangible capital services growth and labour productivity growth actually turns negative in times of crisis, with a coefficient of −0.04 (0.28–0.32), the relationship between intangible capital services growth and labour productivity growth remains positive with a coefficient of 0.20 (0.48–0.28). To analyze this novel finding in more detail, regression 4 adds a recovery interaction effect (2014–2015) to a crisis-recovery sub-sample (2008–2015). Regression 4 clarifies that in times of economic recovery, intangible capital services growth have a strong positive relationship to labour productivity growth. This finding is particularly evident in Ireland in 2015, where a large intangible service growth (20 percent) is related to a large labour productivity growth of (25.8 percent) (see rows 2 and 3 in Table III and Figure 4).

Regression 5 assesses which dimensions of intangible capital services are the key drivers for the positive relationship between intangible capital and labour productivity growth. It includes (1) computerized information, (2) innovative property and (3) economic competencies. In contrast to earlier work (Roth and Thum, 2013, p. 503), which finds economic competencies to be the main driver, we now find innovative property to be a strong driver (0.37) of labour productivity growth. This relationship describes the evidence in the Irish case in 2015, in which a large share of innovative property services growth is related to a large labour productivity growth. Excluding Ireland in rows 23–25 in Table III renders innovative property insignificant and re-establishes economic competencies with a coefficient of 0.17 as the main driver. In order to control for potential endogeneity, regression 6 estimates equation (1) with the help of a 2SLS estimation approach and 208 overall observations. Following earlier econometric work by Roth and Thum (2013, p. 503), lagged levels of intangible and tangible capital as instruments were chosen[14]. The results clarify that while the relationship between tangible capital and labour productivity growth is

Estimation method Time sample Equation	PP-PCSE 2000–2015 (1)	PP-PCSE 2000–2015 (2)	PP-PCSE 2000–2015 (3)	PP-PCSE 2008–2015 (4)	PP-PCSE 2000–2015 (5)	2SLS 2000–2015 (6)
Tangible services growth	0.31*** (0.08)	0.19** (0.08)	0.28*** (0.08)	−0.13 (0.15)	0.18** (0.07)	0.58 (0.42)
Tangible services growth*crisis	–	–	−0.32** (0.13)	–	–	–
Tangible services growth*recovery	–	–	–	0.47 (0.30)	–	–
Intangible services growth	–	0.38*** (0.07)	0.48*** (0.09)	0.32*** (0.11)	–	0.50*** (0.16)
Intangible services growth*crisis	–	–	−0.28** (0.13)	–	–	–
Intangible services growth*recovery	–	–	–	0.42* (0.23)	–	–
Innovative property services growth	–	–	–	–	0.37*** (0.07)	–
Computerized information services growth	–	–	–	–	−0.01 (0.04)	–
Economic competencies services growth	–	–	–	–	0.02 (0.06)	–
Upper secondary education 15+	0.07*** (0.02)	0.05*** (0.01)	0.05*** (0.01)	0.02 (0.02)	0.06*** (0.01)	0.07*** (0.02)
Catch-up	−0.02** (0.01)	−0.02*** (0.01)	−0.02*** (0.01)	−0.01 (0.01)	−0.02** (0.01)	−0.02* (0.01)
Business cycle	−0.11* (0.06)	−0.12* (0.06)	−0.13** (0.06)	−0.13* (0.07)	−0.12* (0.06)	−0.11** (0.05)
R-squared	0.40	0.50	0.54	0.63	0.54	0.46
Observations	256	256	256	128	256	208
Number of countries	16	16	16	16	16	16

Note(s): In regression (1), tangible services growth, labour productivity growth and the catch-up term exclude software, R&D, and entertainment, artistic and literary originals and mineral exploration. In regressions, (2–6) labour productivity growth and the catch-up term are expanded with intangible capital. Tangible capital excludes residential capital. Labour productivity growth was calculated based on the GVA of the non-farm business sectors $b-n+r-s$ (excluding real estate activities). ***p < 0.01, **p < 0,05, *p < 0.1

Table II.
Intangibles and labour productivity growth, 2000–2015, PP-PCSE estimation

rendered insignificant after controlling for endogeneity, the coefficient for intangible capital services growth remains highly significant, yielding a further increase in magnitude (0.50). The sensitivity analysis in Table III further explores the robustness of the coefficient of intangible capital on labour productivity growth, from regression 2, permitting us to conduct an analysis with a maximum of 256 observations.

Table III displays a sensitivity analysis of regression 2 in Table II. The first row shows the coefficient for the *Baseline regression*, regression 2 in Table II. Rows 2–6 analyze the sensitivity due to influential cases[15]. When controlling for Ireland in 2015, as expected, the intangible capital coefficient declines (0.26), explaining a 46 percent share of labour productivity growth. A similar decline in magnitude (0.24 and 0.28) is found when excluding Ireland or Ireland and Greece from the country sample in rows 3 and 5. Excluding Greece in row 4 yields a higher coefficient (0.44). Excluding the three new member states in row 6 yields a slight reduction of the coefficient (0.37). Rows 7–12 restructure the country sample and analyze five distinct European regime dummies. When analyzing the 13 EU countries from 2000 to 2015 from earlier work (Roth and Thum, 2013), the relationship remains highly significant and reveals an increase in magnitude (0.52). Neither controlling for the five European regime dummies in rows 8–12, nor altering the model specifications in rows 13–22, nor using alternative estimation

Row	Specification change	Coefficient on intangibles	Countries	Obs.	R-Squared
Baseline regression					
(1)	Baseline-regression	0.38***	16	256	0.50
Influential cases					
(2)	Including Irish 2015 dummy	0.26***	16	256	0.59
(3)	Excluding Ireland	0.24***	15	240	0.48
(4)	Excluding Greece	0.44***	15	240	0.56
(5)	Excluding Greece and Ireland	0.28***	14	224	0.56
(6)	Excluding new member states	0.37***	13	208	0.53
Restructuring of country sample					
(7)	13 EU countries, 2000–2015	0.52***	13	208	0.65
(8)	Dummy for coordinated economies	0.37***	16	256	0.51
(9)	Dummy for Mediterranean countries	0.37***	16	256	0.50
(10)	Dummy for new member states	0.33***	16	256	0.53
(11)	Dummy for Scandinavian countries	0.37***	16	256	0.50
(12)	Dummy for liberal economies	0.37***	16	256	0.50
Specifications					
(13)	Rule of law	0.37***	16	240	0.51
(14)	Openness to trade	0.33***	16	256	0.53
(15)	FDI	0.39***	16	241	0.54
(16)	Government expenditures	0.35***	16	256	0.52
(17)	Social expenditures	0.31***	16	256	0.54
(18)	Education expenditures	0.41***	16	241	0.57
(19)	Inflation	0.38***	16	256	0.53
(20)	Income tax	0.36***	16	256	0.50
(21)	Stock market capitalization	0.38***	16	204	0.50
(22)	Alternative Business cycle	0.38***	16	256	0.50
Other independent variables					
(23)	Without Ireland (Innovative property)	0.11			
(24)	Without Ireland (Computerized information)	−0.01	16	240	0.50
(25)	Without Ireland (Economic competencies)	0.17***			
Methods					
(26)	Panel autocorrelation-order 1	0.40***	16	256	0.58
(27)	Random-effects	0.38***	16	256	0.51

Note(s): The random-effects estimator depicts an overall R-Square value. $^{***}p < 0.01$, $^{**}p < 0,05$, $^{*}p < 0.1$. Obs. = Observations

Table III. Sensitivity analysis for the baseline PP-PCSE estimator

approaches in rows 26–27 alters the significance of the relationship between intangible capital and labour productivity in any appreciable manner, although the magnitude of the relationship varies slightly.

8. Conclusions

This paper analyses the relationship between intangible capital investment by businesses and labour productivity growth by analyzing an EU-16 country sample over the time period 2000–2015, with the help of a cross-country growth accounting estimation approach. By matching the most recent release of the INTAN-Invest (NACE2) dataset (Corrado *et al.*, 2018) with the latest data available from the EU KLEMS dataset (Jäger, 2017) alongside a wide range of growth-relevant policy variables from Eurostat, the OECD and the World Bank, the paper generates the largest and most up-to-date panel dataset developed on intangible capital at the macro-level, based on a total of 256 country observations.

The paper reaches three major findings. First, in line with previous growth econometric literature (Roth and Thum, 2013), the paper confirms that once intangibles are factored into the calculations, they become the dominant source – up to 66 percent – of labour productivity growth in the EU. Second, when focussing on times of crisis (2008–2013), the paper finds that whereas the relationship between tangible capital and labour productivity turned negative, the impact of intangibles on growth remained solidly positive throughout this period. Thirdly, when accounting for the economic recovery (2014–2015), the paper establishes a highly significant and remarkably strong relationship between intangible capital and labour productivity growth.

In light of these novel empirical results, four main policy conclusions can be drawn from our analysis of European economies. First, given the paucity of econometric findings in the literature analyzing the relationship between intangible capital and labour productivity growth at the macro level, additional research should be devoted in future to further econometrically corroborate the positive relationship between intangible capital and labour productivity. This future research should examine in more detail the evolutionary changes in existing cross-country intangible capital datasets, by country and by asset type. Second, as developed economies transition into knowledge societies, it is essential to incorporate a complete set of intangibles – including branding, firm-specific human capital and organizational capital – into today's national accounting framework in order to acknowledge the pronounced shift in investment patterns from tangible to intangible investment in contemporary national accounting frameworks. The current frameworks are inadequate, as they under-represent actual levels of capital investment in European economies. Their reported levels of capital investment would undoubtedly be greater once the full range of investment in intangible capital is incorporated into the accounting framework. Third, the incorporation of a broader dimension of innovation investment seems to be an important first step in revising today's national accounting framework, particularly when focussing on the business sector. Moreover, a follow-up step consists of broadly adapting the national accounting framework to reflect environmental, health and public intangible capital investment. Fourth, government policies that actively support the accumulation of business intangibles should be designed and implemented as soon as possible. This will foremost require government investment in public intangibles, such as enhancing the quantity and quality of a highly-skilled labour force, well-functioning formal and informal institutions and a well-designed policy framework that includes credible financial conditions and an effective scheme offering intangible tax incentives at the member state and EU level[16].

Notes

1. Accessible at www.intaninvest.net (Corrado *et al.*, 2018).
2. Accessible at www.euklems (Jäger, 2017).
3. Accessible at www.innodrive.org (INNODRIVE, 2011).
4. Accessible at www.intan-invest.net (Corrado *et al.*, 2013).
5. The cases for Belgium and Hungary were excluded due to missing data in the EU KLEMS dataset. Luxembourg was excluded due to significant inconsistencies in the intangible capital data.
6. Details on the exact procedure followed for each country and asset type can be obtained from the author upon request.
7. A first comparison of the time series patterns of the INNODRIVE and INTAN-Invest (NACE2 rev.) in Figure A1 in Appendix 3 reveals that total intangible capital investment has strongly increased in the case of Italy, moderately increased in the case of France and has not increased at all in the case of Germany, compared to the original INNODRIVE data. Future research should analyze these differences in more detail, by country and asset type.
8. Germany's position might be related to the altered methodology in the INTAN-Invest (NACE2) dataset (Corrado *et al.*, 2018) (see Figure A1 in Appendix 3).

9. Such contrasting findings might be related to the overall increase in total intangible capital investment in the INTAN- Invest dataset (NACE2), as displayed in Figure A1 in Appendix 3.
10. Without a lagged initial income term on the left-hand side, the baseline model specification in equation (1) may be estimated without the complexities of a dynamic panel analysis. When replicating the random-effects estimation by Roth and Thum (2013, pp. 501–505), a Breusch and Pagan LM test for random effects was performed via the post-estimation command "xttest0" (Stata Corporation, 2017). With a χ^2 value of 0, the rejection of the null hypothesis fails. This validates the usage of a pooled panel estimation approach.
11. The PCSE calculation was performed via the "xtpcse" command (Stata Corporation, 2017).
12. Taking equation (1) as our reference, with the mean value of $(lnq_{i,t} - lnq_{i,t-1})$ being 1.5, the mean value of $(lnk_{i,t} - lnk_{i,t-1})$ being 3.1, and α being 0.31, the calculation can be set up as follows: (0.31*3.1)/1.5 = 0.64.
13. When controlling for Ireland in 2015 (see row 2 in Table III and Figure 4), intangible capital services explain 46 percent of labour productivity growth. This value is closer to the 50 percent finding by Roth and Thum (2013, p. 502). Growth in tangible capital services and TFP then explains 31 and 23 percent, respectively.
14. To be precise, the first two lagged levels were used. A Wooldridge robust score test of overidentifying restrictions was performed via the 2SLS post-estimation command "estat overid" (Stata Corporation, 2017). With a χ^2 (2) value of 0.4, the rejection of the null hypothesis fails. This indicates that the instruments used are valid.
15. The influential cases of Ireland and Greece have been detected via the "avplot" command (Stata Corporation, 2017), as well as from Figure 4.
16. See here Gros and Roth (2012); Haskel and Westlake (2018); Roth (2019) and Thum-Thysen *et al.* (2019).

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Appendix 1

Construction of intangible and tangible capital services growth

Following Oulton and Srinivasan (2003), Marrano *et al.* (2009) and the EU KLEMS approach (Timmer *et al.*, 2007) and consistent with Roth and Thum (2013), tangible and intangible capital services growth ($lnk_{i,t} - lnk_{i,t-1}$) and ($lnr_{i,t} - lnr_{i,t-1}$) or respectively, $\Delta lnk_{i,t}$, and $\Delta lnr_{i,t}$, are defined as:

$$\Delta ln\, k_{i,t} = \sum_{i=1}^{m} \bar{v}_{i,t} \Delta lna_{i,t} \quad \text{(A1)}$$

$$\Delta ln\, r_{i,t} = \sum_{i=m+1}^{n} \bar{v}_{i,t} \Delta lna_{i,t} \quad \text{(A2)}$$

where $a_{i,t}$ is the asset-specific capital stock, as calculated with the PIM, assets from 1 to m are tangible assets, and assets from $m+1$ to n are intangible. Lower case $k_{i,t}$, $r_{i,t}$ and $a_{i,t}$ indicate that the variables are scaled on hours worked. $\bar{v}_{i,t}$, is a two-year average weighting term defined as:

$$\bar{v}_{i,t} = \frac{1}{2}[v_{i,t} + v_{i,t-1}] \quad \text{(A3)}$$

The term $v_{i,t}$ is computed as:

$$v_{i,t} = \left(\frac{p^a_{i,t} a_{i,t}}{\sum_{i=1}^{n} p^a_{i,t} a_{i,t}} \right) \quad \text{(A4)}$$

From (A4), $a_{i,t}$ is the asset-specific capital stock and $p^a_{i,t}$ is the asset-specific (tangible or intangible) user cost. The latter user cost is defined as:

$$p^a_{i,t} = p^I_{i,t-1} i_t + \delta_{i,t} p^I_{i,t} - \left[p^I_{i,t} - p^I_{i,t-1} \right] \quad \text{(A5)}$$

Where $p^I_{i,t-1}$ is the investment price, constructed from the price index of the GFCF series at chained prices, i_t is the time-specific rate of return (common to all tangible and intangible assets) and $\delta_{i,t}$ is the time variant and asset-specific depreciation rate. The depreciation rate that varies over time reflects the varying contribution over time of industries to the total non-farm business sector (b-n+r-s excluding real estate activities). The time-varying depreciation rate used here is defined as:

$$\delta_{i,t} = \frac{A_{i,t-1} + I_{i,t} - A_{i,t}}{A_{i,t-1}} \quad \text{(A6)}$$

The last term in (A5) is the capital gain term $[p^I_{i,t} - p^I_{i,t-1}]$; following Niebel and Saam (2011), it is computed considering the price indices of three consecutive periods using the formula:

$$\left[p^I_{i,t} - p^I_{i,t-1} \right] = \frac{1}{2} \left(ln(p_{i,t}) - ln(p_{i,t-2}) \right) p_{i,t-1} \quad \text{(A7)}$$

The rate of return i_t is common to all the tangible and intangible assets and represents the overall return on the investment under the profit maximization assumption, as explained in Oulton and Srinivasan (2003). Following Timmer *et al.* (2007), the common rate of return is computed here using an ex-post approach that accounts for the rental payments of each asset:

$$i_t = \frac{p^a_t a_t + \sum_i \left[p^I_{i,t} - p^I_{i,t-1} \right] a_{i,t} - \sum_i p^I_{i,t} \delta_{i,t} a_{i,t}}{\sum_i p^I_{i,t-1} a_{i,t}} \quad \text{(A8)}$$

Where $p_t^a a_t$ is the total nominal capital compensation, obtained by subtracting the labour compensation from the GVA.

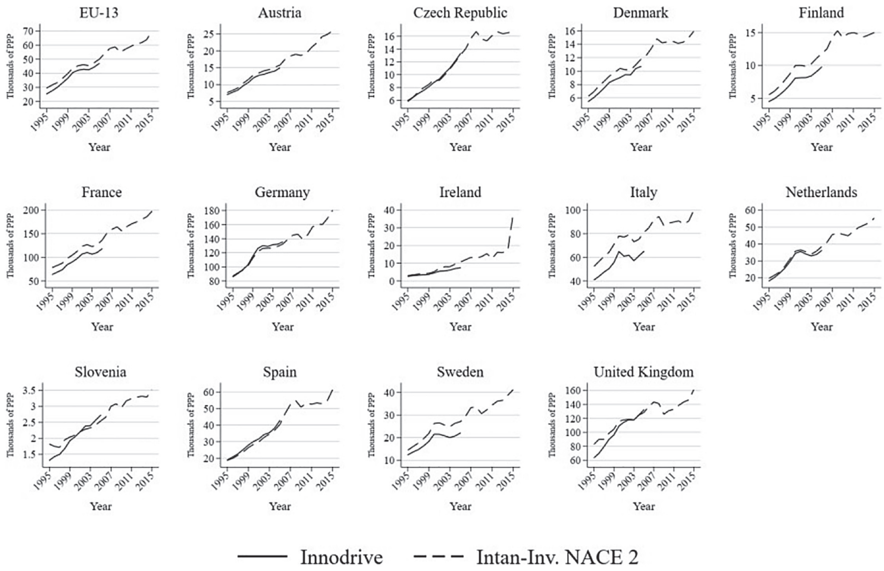
Appendix 2

	Obs.	Mean	Standard deviation	Min.	Max.
LPG-expanded by intangibles (in %)	256	1.6	3.1	−7.6	25.8
LPG-excluding all intangibles (in %)	256	1.5	3.0	−8.7	16.7
Intangible services growth (in %)	256	2.8	3.4	−7.9	20.0
Tangible services growth (in %)	256	3.1	2.9	−4.4	13.8
Tangible services growth-expanded by intangibles (in %)	256	2.9	3.0	−5.8	13.3
Innovative property services growth (in %)	256	4.0	4.3	−8.2	33.5
Economic competencies services growth (in %)	256	1.4	3.8	−13.0	17.0
Computerized information services growth (in %)	256	3.9	6.4	−18.4	40.1
Upper secondary education 15+ (in %)	256	67.8	14.2	21.0	87.6
Interaction education and catch-up – expanded by intangibles	256	34.7	35.0	0.0	197.2
Interaction education and catch-up – excluding all intangibles	256	31.8	30.4	0.0	158.1
Business cycle (in %)	256	91.2	4.5	72.5	96.9
Rule of law	240	1.4	0.5	0.3	2.1
Openness (in %)	256	92.3	39.0	45.6	215.4
FDI (main balance of payments as a % of GDP)	241	−0.4	5.2	−15.2	10.2
Government expenditure (as a % of GDP)	256	47.1	5.9	29.0	65.1
Social expenditure (as a % of GDP)	256	25.3	4.7	14.8	34.5
Education expenditure (as a % of GDP)	241	5.3	1.2	3.0	8.8
Inflation (in %)	256	2.2	1.7	−1.7	12.2
Income tax (as a % of GDP)	256	8.9	5.0	2.6	26.3
Stock market capitalization (as a % of GDP)	204	52.8	36.2	1.5	233.9

Note(s): LPG = Labour Productivity Growth, Obs. = Observations, Min. = Minimum, Max. = Maximum

Table AI. Descriptive statistics, EU16, 2000–2015

Appendix 3



Note(s): PPP Adjusted time series were used. The 13 EU countries are: Austria, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Slovenia, Spain, Sweden and the United Kingdom. "Total Intangible Investments" is the sum of Computerized Information, Innovative Properties and Economic Competencies. Economic sectors for INNODRIVE (NACE1) dataset include c-k+o (excluding k70) and for INTAN-Invest (NACE2) dataset include b-n + r-s (excluding l)
Source(s): INNODRIVE data (INNODRIVE, 2011) and INTAN-Invest (NACE2) dataset (Corrado *et al.*, 2018)

Figure A1. Intangible investments in 13 EU countries, 1995–2015: a comparison of INNODRIVE and INTAN-Invest (NACE2) datasets

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