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THE CONTRIBUTION OF INTANGIBLE ASSETS TO SECTORAL PRODUCTIVITY GROWTH IN THE EU

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Abstract

In this paper, we report on new data on intangible investment at the level of one-digit NACE industries of ten European Union (EU) countries. The data are constructed as a sectoral breakdown by using as control totals the INTAN-Invest database, which contains measures of intangible investment at the level of the aggregate business sector. With the sectoral data, we assess the contribution of intangibles to productivity growth based on growth accounting and econometric estimation of production functions. The growth accounting contribution of intangibles to labor productivity growth is generally highest in manufacturing and finance. The estimated output elasticity of intangibles lies between 0.1 and 0.2, above factor shares but considerably below values found in previous research using aggregate data.

JEL Codes: E22, J24, O47

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1. INTRODUCTION

During the past two decades, growth in aggregate productivity has been quite unevenly distributed across the advanced economies. While earlier research explored the effect of differences in ICT investment and in multifactor

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productivity, more recent work considers the role that investment in intangible assets plays in explaining cross-country differences in labor productivity growth. A small part of intangible investments such as software are included in standard national accounts data and in international data provided, for example, by the EU KLEMS project (O'Mahony and Timmer, 2009). Most intangible assets, however, such as research and development (R&D), organizational capital, and training are to date not treated as investment in national accounts (although R&D has been added according to the new 2008 System of National Accounts). Following the pioneering work by Corrado *et al*. (2005, 2009) in estimating total intangible investments for the U.S., estimates of intangible assets at the aggregate level of European countries have recently become available through the INTAN-Invest platform (Corrado *et al*., 2012). To date, there are few estimates available at the sector level.

In this paper, we make a first attempt to quantify the importance of intangible assets, defined from the perspective of national accounting, at the sector level for European countries. We provide a better understanding of the contribution of intangible assets to sectoral productivity growth in three ways. First, we construct a new sectoral breakdown of intangible assets at the level of NACE[1] one-digit industries for ten European countries (Section 3).[2] Second, we present descriptive and growth accounting evidence for ten countries on the magnitude of intangible investment and its contribution to labor productivity growth across sectors (Section 4). Third, we estimate the output elasticity of intangibles econometrically and compare the results with those obtained in growth accounting (Section 5).

The growth accounting calculations presented below reveal a non-negligible contribution of intangible assets to productivity growth, but with significant variation across sectors and countries. The econometric estimates suggest values for the output elasticity of intangibles that are greater than factor shares, suggesting the possibility of spillovers from investing in intangible assets. However, the coefficients are much lower than previous results found using aggregate measures of intangibles.

2. Related Research

While the concept of intangible capital has been used in economic research for a long time, the explicit attempt to quantify it in a way that can be integrated into national accounts was undertaken only recently. Corrado *et al*. (2005) made the main contribution setting out the approach for categorizing and quantifying intangible capital at the level of the national economy. In particular, they set out criteria for treating some expenditures as investment rather than as intermediate inputs and adjust output to be consistent with this changed treatment of inputs. Corrado *et al*. (2009) construct intangible capital estimates for the U.S. and use them in a growth accounting framework. Including previously unmeasured inputs

[1]Nomenclature statistique des activités économiques dans la Communauté européenne—statistical classification of economic activities in the European Community.

[2]Measures of intangibles assets at the industry level were also constructed for Belgium, Hungary, Ireland, and Sweden, but complete growth accounting data are not available for these countries.

generally lowers the measured growth in multifactor productivity (MFP) and raises the measured contribution of capital inputs to growth in labor productivity. With their data, Corrado *et al*. (2009) find that the contribution of intangible capital to growth in labor productivity is about equal to the contribution of tangibles. After accounting for intangibles, capital instead of MFP constitutes the dominant source of growth. Internationally comparable data on intangibles for aggregate economic activity have been constructed based on the approach by Corrado *et al*. (2005) in the projects INNODRIVE (Piekkola, 2011) and COINVEST, funded by the European Commission, and by The Conference Board.[3] Recently, the three teams published harmonized data on intangibles at the country level on the platform INTAN-Invest (Corrado *et al*., 2012). This platform initially presented data on intangible investments and capital stocks for all EU25 countries, Norway, and the U.S. for the aggregate market sector for the period 1995–2005. These data have been extended in some countries to 2009. Sectoral estimates were only produced by these projects for a few EU countries (see Haskel *et al*., 2010; Haskel and Pesole, 2011; Crass *et al*., 2015). Some sector estimates have also been developed for non-EU countries; for example, Baldwin *et al*. (2012) for Canada and Fukao *et al*. (2009) for Japan. In this paper, we provide a first sectoral breakdown of intangible assets data for a larger set of European countries, using internationally consistent data. The approach follows that of Corrado *et al*. (2012) and uses the INTAN-Invest aggregate numbers as control totals, thus maintaining consistency with this previous work. The paper also constructs estimates of sectoral intangible capital stocks and uses these to gauge their impact on growth at the sector level.

The idea that organizational changes and other forms of intangible investment such as workforce training are necessary to gain significant productivity benefits from adopting new technology has been in the literature for some time (in the context of the information technology revolution, see, e.g., Black and Lynch, 2001; Bresnahan, 2002; Bertschek and Kaiser, 2004). However, the econometric literature on the relationship between intangibles and labor productivity at the macroeconomic level is just beginning to emerge. Roth and Thum (2013) use INNODRIVE data for the aggregate of the non-farm business sector of 13 European countries to estimate a production function including intangibles. When accounting for intangibles, investment instead of multifactor productivity becomes the dominant source of growth. The coefficient of intangible investment of about one quarter turns out to be much higher than the coefficient identified by this asset's factor share in growth accounting. Using the INTAN-Invest data, Corrado *et al*. (2014) find a coefficient of similar—in some specifications, even larger—magnitude. They formally investigate the presence of spillovers that are suspected if the estimated marginal product of a factor exceeds the marginal product implied by the factor remuneration under competitive markets. Their results strongly support the possibility of spillovers. Moreover, they find evidence of a complementarity between intangible assets at the aggregate level and ICT capital at the sectoral level. The main limitations of this previous work using aggregate measures of intangibles are the small number of observations available

[3]See http://www.conference-board.org/data/intangibles/.

for econometric estimation and the lack of information on heterogeneity of intangible assets across industries. O'Mahony and Peng (2011) was one of the first papers to investigate the impact of intangible assets using industry data. Their analysis is limited to investment in firm-specific human capital accumulated by training. In line with the work at the country level, the authors find evidence of an output elasticity of firm-specific human capital exceeding its factor share. The construction of broad measures of intangible capital stocks at the sector level allows us to go beyond the previous literature in both measuring the contributions of these assets to output growth using a growth accounting method and investigating the presence of spillovers through more robust econometric estimation that takes account of variations across sectors.

3. Data Construction

3.1 *Sources and Methods*

The data for our analysis cover ten European countries and 11 sectors (listed in Table 1) for the period 1995–2007.

The sectoral data on intangible assets were compiled by the authors within the INDICSER project and cover eight types of assets, listed in Table 2. The aggregate business-sector control totals for computing the sectoral measures of intangible investment were taken from the INTAN-Invest database described by Corrado *et al*. (2012), supplemented by data from the INNODRIVE project database. We then apply sectoral information to these control data to obtain estimates for investment in individual assets at the level of one-digit industries of the NACE rev. 1.1 classification (listed in Table 1). Aggregate scientific R&D is broken down by sector based on information from the OECD (ANalytical) Business Enterprise Research and Development databases (OECD ANBERD and BERD). The R&D producing sector (NACE group *K*73) provides research activities for firms situated in other industries of the business sector (purchased R&D). A considerable amount of R&D intangibles in K73 thus ought to be counted as purchased and not as own-account intangible R&D capital. To avoid double counting, R&D in

TABLE 1
Industry and Country Coverage

Industry code	Description	Country code	Country
A–B	Agriculture, hunting, forestry and fishing	AUT	Austria
C	Mining and quarrying	CZE	Czech Republic
D	Total manufacturing	DNK	Denmark
E	Electricity, gas and water supply	ESP	Spain
F	Construction	FIN	Finland
G	Wholesale and retail trade	FRA	France
H	Hotels and restaurants	GER	Germany
I	Transport and storage and communications	ITA	Italy
J	Financial intermediation	NLD	Netherlands
K71–74	Renting of machinery and equipment and other business activities	U.K.	United Kingdom
O	Other community, social and personal services		

TABLE 2
List of Assets

Acronym	Description	Depreciation rate
INT	**New intangibles**	
R&D	Scientific research and development	0.150
FSHK	Firm-specific human capital	0.400
NFP	New product development costs in the financial industry	0.200
Arch	New architectural and engineering designs	0.200
MKTR	Market research	0.550
ADV	Advertising expenditure	0.550
OKo	Own-account development of organizational structures	0.400
OKp	Purchased organizational structures	0.400
ICT	**ICT assets**	
IT	Computing equipment	0.315
CT	Communications equipment	0.115
Soft	Software	0.315
NonICT	**Non-ICT assets**	
TraEq	Transport equipment	0.092–0.229
OMach	Other machinery and equipment	0.094–0.149
OCon	Total non-residential investment	0.023–0.051
RStruc	Residential structures	0.011
Other	Other sssets	0.094–0.149

Notes: Depreciation rates for new intangible assets are taken from Corrado *et al.* (2012, p. 25). “New” intangibles are those not yet included in national accounts. ICT and Non-ICT assets are those covered by national accounts data in the EU KLEMS database.

K73 is split up by proportions from use tables at purchasers’ prices from the World Input–Output Database (WIOD). Investment in firm-specific human capital (FSHK) is split up among sectors using data on training costs, time spent on training and opportunity cost of training (for details, see O’Mahony, 2012). New product development costs in the financial industry (NFP) from INTAN-Invest can be entirely allocated to sector *J*. We consider as purchased assets investments in purchased new architectural and engineering designs (Arch), market research (MKTR), advertising expenditure (ADV), and organizational structures (OKp). We employ proportions from use tables at purchasers’ prices from the World Input–Output Database (WIOD) described by Timmer (2012) and Dietzenbacher *et al*. (2013) to construct the sectoral breakdown of the aggregate values for these assets. We assume that for every category, the weight of an industry in the total purchase of assets of a particular category equals the weight of that industry in the purchase of services from industry *K*74, other business services, which includes marketing, architecture advertising, and consulting. Since *K*74 includes other sub-industries not relevant for intangibles, we have conducted sensitivity analysis with more precise NACE rev. 1.1 matrices, and we show that the impact of this assumption is generally quite small. However, these more detailed matrices are not available across all sample countries (see the supplementary online Appendix). No sectoral information exists to independently calculate the own-account part of designs, marketing, and advertising investment. We therefore assume that the industry breakdown of own-account expenditure for these three assets equals their proportion of purchased assets. In line with the principles used in INTAN-Invest, 20 percent of managers’ wages are counted as own-account development of organizational structures (OKo).

TABLE 3

Summary Statistics: Share of Industry *j* in Total Intangible Investment—Mean of Years 1995–2007

Industry	AUT	CZE	DNK	ESP	FIN	FRA	GER	ITA	NLD	U.K.
A–B	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
C	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
D	0.39	0.30	0.34	0.39	0.61	0.34	0.57	0.35	0.32	0.23
E	0.01	0.02	0.01	0.03	0.02	0.02	0.02	0.01	0.02	0.01
F	0.05	0.08	0.10	0.07	0.03	0.05	0.03	0.05	0.04	0.05
G	0.16	0.16	0.18	0.12	0.08	0.13	0.09	0.21	0.14	0.14
H	0.02	0.03	0.01	0.03	0.01	0.01	0.01	0.02	0.02	0.03
I	0.05	0.05	0.06	0.08	0.06	0.06	0.03	0.07	0.09	0.09
J	0.09	0.09	0.07	0.11	0.06	0.10	0.10	0.07	0.09	0.15
K71–74	0.17	0.22	0.16	0.12	0.09	0.25	0.13	0.16	0.22	0.22
O	0.04	0.04	0.05	0.04	0.03	0.03	0.02	0.04	0.04	0.06
BS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: EU KLEMS Release 2009, INTAN-Invest, and INDICSER—own calculations.

For the construction of real intangible capital, investments are in general deflated with an index based on the deflator for value added from the EU KLEMS database. This follows the convention in the previous studies mentioned above, as no explicit deflators for intangible assets exist to date. There are initial efforts to estimate specific investment price indices for intangibles—for example, R&D investment price indices by Corrado *et al*. (2011) for the U.K. and by Copeland and Fixler (2012) for the U.S.—but no estimates exist yet for the set of countries covered in this paper. The one exception employed here is training capital, which is partly constructed using estimates of opportunity costs (wages) of workers being trained and hence uses an earnings deflator (see O'Mahony, 2012). The detailed methodology for the construction of the sectoral intangible measures and the resulting adaptation of output and capital is described in the

TABLE 4

Summary Statistics: Share of Intangible Investment in Adjusted Value Added—Mean of Years 1995–2007

Industry	AUT	CZE	DNK	ESP	FIN	FRA	GER	ITA	NLD	U.K.
A–B	0.01	0.02	0.03	0.01	0.01	0.01	0.03	0.00	0.03	0.04
C	0.05	0.04	0.00	0.04	0.08	0.05	0.08	0.03	0.02	0.03
D	0.09	0.06	0.11	0.07	0.13	0.12	0.12	0.06	0.12	0.11
E	0.03	0.02	0.03	0.04	0.05	0.07	0.04	0.02	0.06	0.06
F	0.03	0.07	0.09	0.03	0.03	0.05	0.03	0.03	0.05	0.07
G	0.06	0.06	0.07	0.04	0.05	0.06	0.04	0.06	0.06	0.09
H	0.02	0.06	0.03	0.01	0.06	0.03	0.03	0.02	0.05	0.07
I	0.04	0.03	0.04	0.03	0.04	0.05	0.03	0.03	0.07	0.09
J	0.08	0.13	0.07	0.07	0.11	0.11	0.10	0.05	0.08	0.17
K71–74	0.10	0.14	0.10	0.06	0.07	0.10	0.06	0.06	0.10	0.13
O	0.05	0.07	0.06	0.04	0.04	0.05	0.03	0.05	0.06	0.11
BS	0.07	0.06	0.07	0.04	0.08	0.08	0.07	0.05	0.08	0.10

Source: EU KLEMS Release 2009, INTAN-Invest, and INDICSER—own calculations.

supplementary online Appendix. Tables 3 and 4 present descriptive statistics for the sectoral intangible data, which are discussed further below.

For the growth accounting and econometric analysis, the data on output, non-ICT tangible capital, ICT capital, and labor input are taken from the EU KLEMS database (O'Mahony and Timmer, 2009). In this analysis, we follow the convention of including software as part of ICT capital, so this broad category includes some intangibles as well as the tangible assets computer hardware and communications equipment. In addition, two other intangible assets currently included in national accounts, mineral oil exploration and artistic originals, are included as part of non-ICT capital (other assets in Table 2). This is to facilitate comparisons with previous work originating from the EU KLEMS project.

3.2 *Computation of Input and Output Measures*

The industry-specific intangible capital stock series A_t are constructed using the well-known perpetual inventory method (PIM):

$$A_{k,j,t}=(1-\delta_k)A_{k,j,t-1}+I_{k,j,t}/Ip_t, \tag{1}$$

where $I_{k,j,t}$ is nominal investment in intangible capital. Nominal investment is deflated by Ip_t, which is the same for all industries j and intangible assets k (except training). It is based on the value added price index for the total business sector (BS). δ_k is the time- and industry-invariant depreciation rate of asset k taken from Corrado *et al*. (2012)—these depreciation rates are listed in Table 2. The initial capital stock in year 1995 is derived from the formula

$$A_{k,j,1995}=Iq_{k,j,1995}/(\delta_k+\bar{g}), \tag{2}$$

where $Iq_{k,j,1995}$ is the real investment in 1995 in intangible asset k, $\bar{g}$ is the average growth rate of real value added in the total business sector between 1991 and 1999 (1995–1999 for the Czech Republic and Hungary), and δ_k is again the depreciation rate of asset k.[4]

Because of the inclusion of intangible investment, we have to adjust several EU KLEMS input and output variables. We adjust nominal value added as follows:

$$VA_{\text{adj}j,t}=VA_{j,t}+\sum_{k\in INT}I_{k,j,t}\,. \tag{3}$$

An adjusted value added deflator $VA\_P_{\text{adj}j,t}$ is calculated as:

$$\Delta\ln VA\_P_{\text{adj}j,t}=\bar{v}_{VA,j,t}\Delta\ln VA\_P_{j,t}+\bar{v}_{INT,j,t}\Delta\ln Ip\_INT_t, \tag{4}$$

where $\bar{v}_{VA,j,t}$ is the two-period average share of nominal value added *VA* in adjusted value added and $\bar{v}_{INT,j,t}$ the two-period average share of nominal intangible

[4]The estimates are not overly sensitive to the growth rates of real value added, as previous growth is small relative to the high depreciation rates of intangibles.

investment I_{INT} in adjusted value added. The purchased intangibles (OKp, Arch, MKTR, and ADV) increase value added in industry j due to the reduced amount of intermediate inputs. Gross output remains the same. The own-account intangibles (OKo, FSHK, NFP, and R&D) increase gross output and therefore value added of industry j (for an elaborate discussion see, e.g., Statistisches Bundesamt, 2009, p. 60). We also have to recalculate the internal rate of return. First, we compute the industry-specific adjusted total capital compensation:

$$CAP_{\text{adj}j,t} = VA_{\text{adj}j,t} - LAB_{j,t}, \tag{5}$$

where VA_{adj} denotes adjusted value added and LAB labor compensation. The nominal rate of return[5] i for industry j is then defined as follows:

$$i_{j,t} = \frac{CAP_{\text{adj}j,t} + \sum_k (p^I_{k,j,t} - p^I_{k,j,t-1}) A_{k,j,t} - \sum_k p^I_{k,j,t} \delta_{j,k} A_{k,j,t}}{\sum_k p_{k,j,t-1} A_{k,j,t}}, \tag{6}$$

where $p^I_{k,j,t}$, $\delta_{k,j}$, and $A_{k,j,t}$ are the investment price index, the depreciation rate, and the real stock of all tangible and intangible assets k, respectively. Table 2 gives a list of the 16 assets covered. Based on this internal rate of return $i_{j,t}$, we calculate the asset-specific user costs of capital $q_{k,j,t}$ for all tangible and intangible assets:

$$q_{k,j,t} = p^I_{k,j,t-1} i_{j,t} + p^I_{k,j,t} \delta_{k,i} - \left[p^I_{k,j,t} - p^I_{k,j,t-1} \right]. \tag{7}$$

The compensation of all assets is derived according to the following relation:

$$CAP_{\text{adj}\,k,j,t} = q_{k,j,t} A_{k,j,t}. \tag{8}$$

The industry-specific growth rate of new intangible capital services (*Kint*) is calculated as follows:[6]

$$\Delta \ln Kint_{j,t} = \ln Kint_{j,t} - \ln Kint_{j,t-1} = \sum_{k \in INT} \bar{w}^{INT}_{k,j,t} \Delta \ln A_{k,j,t}, \tag{9}$$

with $\bar{w}^{INT}_{k,j,t}$ denoting the two-period average share of intangible asset k in total intangible capital compensation:

$$w^{INT}_{k,j,t} = \frac{q_{k,j,t} A_{k,j,t}}{\sum_{k \in INT} q_{k,j,t} A_{k,j,t}}. \tag{10}$$

[5]We also recalculate the standard EU KLEMS internal rate of return for industries *D*, *G*, and *I* as their numbers are based on sub-industries.

[6]Similar calculations are used for ICT and non-ICT capital.

The aggregation of input and output volumes to the total business sector (BS) is based on the Törnquist quantity index described in O'Mahony and Timmer (2009):

$$\Delta \ln Kint_{BS,t} = \bar{\mu}^{INT}_{j,t} \sum_{j} \Delta \ln Kint_{j,t}, \qquad (11)$$

with $\bar{\mu}^{INT}_{j,t}$ being the two-period average share of industry j in business-sector intangible capital compensation.

3.3 *Descriptive Statistics*

A first way to evaluate our breakdown of the INTAN-Invest data is to see how the aggregate values of new intangible assets are distributed across sectors (Table 3). In most countries, the largest part of overall intangible investment is concentrated in the manufacturing sector (*D*). In Germany and Finland, the share exceeds 50 percent. However, it is lower in the other countries and only 23 percent in the U.K. The business service sector (K71-74) and wholesale and retail trade (*G*) exhibit higher shares than the remaining sectors. Looking at industry investment in intangibles relative to value added (Table 4) allows us to control for the effect of industry size. We observe that the share of manufacturing (*D*) and business services (K71-74) remains high. In contrast, the high share of total intangibles attributed to the wholesale and retail trade industry (*G*) is close to average when considered relative to value added. All countries except the Czech Republic and Germany display an above-average share of intangible investment in manufacturing and business services. In seven countries, financial intermediation *J* also exhibits a share that exceeds the average.

Looking at the shares of intangible investment per category (supplementary online Appendix Tables B1–B10) in each industry reveals that the high overall intangible investment in manufacturing is mainly driven by R&D, which has the lowest depreciation rate. Financial services have a category of intangible investment unique to that industry, which accounts for 10–30 percent of its total intangible investment and is also assumed to have a comparatively low depreciation rate. High contributions to growth in other sectors show little systematic relation to investment into particular assets. In the U.K., we observe a high share of investment in own-account organizational capital in several industries. Since the occupational classification in the U.K. tends to label more workers as managers than observed in other countries, we cannot completely exclude the possibility of measurement error here, which has to be addressed by future data construction (for alternative measures of own-account organizational capital, see also Squicciarini and Le Mouel, 2012). Business services in the U.K. also exhibit a higher share of R&D investment than observed in other countries.

Previous research has shown that growth accounting data, including those from the EU KLEMS database, exhibit high variation in the internal rates of return as calculated by equations such as (6) above. Oulton and Rincón–Aznar (2012) point out that variation is particularly implausible across sectors. When recalculating internal rates with intangibles, we observe that the variation is reduced somewhat, but not in any substantial way. In an overall sample of 1,430 observations, the mean internal rate of return falls from 12.4 percent to 11.8 percent, with the standard deviation being reduced from 15.2 percent to 12.0 percent. Some outlier values are reduced. The maximal rates observed in Finland, Spain, and the U.K. decline by more than ten percentage points. The strongest decline in average rates of return is observed in those sectors with the highest averages, which are the construction sector (with the average declining from 20.9% to 17.9%) and the financial sector (with the average declining from 32.4% to 25.0%). Including intangibles indeed reduces implausible variation, but the effect remains moderate (see Inklaar, 2010, for similar results for the U.S.). External rates of return should be considered as an alternative in future work on intangibles. Still, the sensitivity of growth accounting results on intangible capital to different rates of return might be limited because of the large part of user cost accruing to depreciation. Niebel and Saam (2016) find similar results for ICT capital, for which asset price decline and depreciation represent a large part of user cost.

4. Growth Accounting

4.1. *Method*

We use the established growth accounting methodology (see, e.g., Inklaar *et al.*, 2005) decomposing growth in value added (*VA*) per hour worked in industry *j* in country *c* at time *t* into the contributions of inputs per hour worked and multifactor productivity. We use the value added measure that is augmented by intangible assets. Inputs per hour worked are ICT capital per hour worked, non-ICT capital per hour worked, new intangible assets per hour worked, and labor services *H* divided by the number of hours worked *L*, which represents a measure of labor quality (*LQ*). The factor income shares of inputs are represented by $\pi^{input}_{c,j,t}$. In the empirical implementation, we use two-period averages to measure them. By definition, they sum up to one: $\pi^{ict}_{c,j,t}+\pi^{nict}_{c,j,t}+\pi^{int}_{c,j,t}+\pi^{H}_{c,j,t}=1$. Growth accounting then decomposes growth in value added per hour worked, in the following way:

$$\Delta\ln\left(\frac{VA}{L}\right)_{c,j,t}=\pi^{ict}_{c,j,t}\Delta\ln\left(\frac{Kict}{L}\right)_{c,j,t}+\pi^{nict}_{c,j,t}\Delta\ln\left(\frac{Knict}{L}\right)_{c,j,t}+\pi^{int}_{c,j,t}\Delta\ln\left(\frac{Kint}{L}\right)_{c,j,t}+\pi^{H}_{c,j,t}\Delta\ln LQ_{jit}+\Delta\ln MFP_{c,j,t}. \tag{12}$$

4.2. *Results at the Sectoral Level*

We present growth accounting results for the ten EU countries in Figure 1—detailed tables are available in the supplementary online Appendix (Tables B11–B20). In all tables, we represent growth accounting results including intangibles in output and inputs and, for comparison, growth in labor productivity that is not adjusted for intangibles (LP*).

First comparing across countries, Italy and Spain have relatively low contributions of intangible assets to labor productivity growth, and these are also the two countries that display the lowest average annual growth in labor productivity

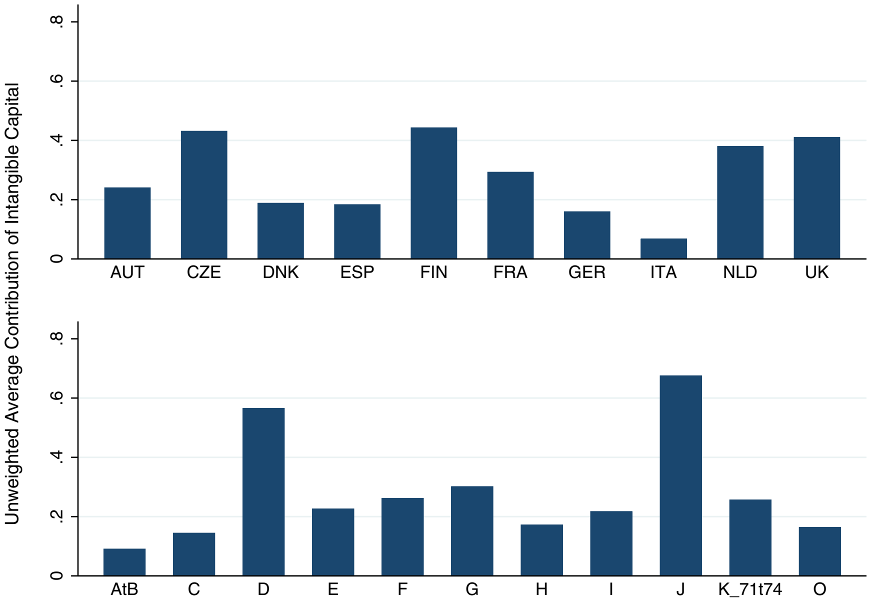

Figure 1. Average Contribution of Intangible Capital to Labor Productivity Growth—Unweighted Average Across Industries Countries and Across Countries, 1995–2007

Source: EU KLEMS Release 2009, INTAN-Invest, and INDICSER—own calculations.

between 1995 and 2007. In France, the Netherlands, and Austria, the contribution of intangibles is higher and labor productivity also shows medium growth over the period. In contrast, Germany and Denmark show lower contributions of intangible assets, although their growth in labor productivity is about average for the sample. High growth in labor productivity is observed in the U.K. (2.8 percent), Finland (3.6 percent), and the Czech Republic (4.0 percent), and the first two also show the highest values of the aggregate contribution of intangibles to labor productivity growth, with 0.5 percentage points in the U.K. and 0.6 percentage points in Finland. Thus it appears that slow-growing countries were less likely than fast-growing ones to invest in intangible assets.

When looking across industries, financial intermediation and manufacturing stand out as those with the largest contributions of intangible assets to labor productivity growth. These sectors have high contributions in many countries, and in Spain and Germany other sectors show very small contributions. However, financial intermediation and manufacturing do not dominate everywhere. In Italy, the low contribution in the manufacturing sector (0.1 percentage points) is particularly striking. In the Czech Republic, the contribution of intangibles turns out to be low in manufacturing and unusually high in construction. The data also show a high contribution for business services in several countries, most notably in the Netherlands and the U.K. In the U.K., wholesale and retail trade (*G*) and hotels and restaurants (*H*) achieve values that are larger than in other countries. Finland also shows relatively high contributions in sector *G*, as does Spain relative to its aggregate business-sector contributions.

Overall, the results show important variation in the contribution of intangibles to labor productivity growth both at the level of industries and at the level of countries. In order to compare the strength of variation in these two dimensions, we compute coefficients of variation of the average contribution of intangibles to labor productivity growth at both levels. We first average over industries and consider variation at the country level. The coefficient of variation amounts to 0.46. If we take the average contribution at the level of the business sector, instead of the unweighted mean, the coefficient of variation changes only marginally (0.47). We compare the country variation to the coefficient of variation at the industry level, where the average contribution of intangibles for each industry is computed as an unweighted mean across countries. Here, the coefficient of variation amounts to 0.65. Overall, then, these simple calculations suggest that variation in the contribution of intangibles to labor productivity growth is higher at the industry than at the country level. But with the standard deviation being nearly half as large as the mean, variation at the country level plays an important role too.

The estimates in Table B11–B20 also tentatively suggest that countries/industries with high contributions from other knowledge inputs (ICT, labor quality, and MFP) also appear to show high intangibles contributions. The correlation between the contributions of ICT capital and intangible capital across countries and industries is high at 0.44, and there is also a significant correlation between labor quality and intangibles (0.27). The correlation between MFP and intangibles, at 0.13, is positive but not large. Recent work by Chen *et al*. (2016) investigates the extent to which the effect of intangibles varies with the ICT intensity of the industries, thus looking at a source of complementarities. They find that the output elasticity of intangible assets varies between 2 percent for the industries at the lowest quartile of ICT intensities and 15 percent at the highest quartile.

Overall, the growth accounting results suggest that intangible assets make a substantial contribution to labor productivity growth, although the extent of this varies by industry and country. Note also that when estimating the impact of intangibles, value added growth is adjusted to take account of the transfer of intangible expenditures from intermediates to investment. The final columns of Tables B11–B20 suggest this has a small positive impact on labor productivity growth, of the order of 0.1–0.2 percentage points.

5. Econometric Analysis

5.1. *Econometric Specification*

Growth accounting assesses the contribution of inputs to labor productivity growth under the assumptions of factor payment at marginal productivity and constant returns to scale. In econometric estimations of the production function, we assess marginal productivity without tying it to the value of factor shares. There may be several reasons why the output elasticity of a factor deviates from its income share: errors in the measurement of output and inputs, non-constant returns to scale, imperfect competition, or effects of unmeasured complementarities or spillovers (for a discussion concerning the output elasticity of ICT, see

Stiroh, 2002). While it goes beyond the scope of the present paper to discriminate between these drivers, our results can at least give an indication of whether intangible assets are a plausible candidate for complementarities and spillovers at the industry level. The few papers that have previously estimated the coefficient of intangible assets in a production function using aggregate data have found surprisingly high values for the output elasticity of intangibles, exceeding the factor share twofold or more (Roth and Thum, 2013; Corrado *et al.*, 2014). We investigate to what extent this result carries over to the industry level.

If the marginal productivities of inputs do not coincide with factor shares, there are no *a priori* reasons to assume constant returns to scale. Therefore we estimate a sectoral Cobb–Douglas production function for value added with three types of assets and labor services as inputs, allowing for variation in the neutral technology parameter $A_{c,j,t}$ across countries c, industries j, and time t as well as for non-constant returns to scale. Taking logs and first differences, we obtain the following equation in growth rates:

$$\Delta\ln VA_{c,j,t}=\mu_t+\mu_{c,j}+\beta^{ict}\Delta\ln Kict_{c,j,t}+\beta^{nict}\Delta\ln Knict_{c,j,t}+\beta^{int}\Delta\ln Kint_{c,j,t} + \beta^{H}\Delta\ln H_{c,j,t}+\epsilon_{c,j,t}. \tag{13}$$

Since the equation is written in first differences, country–industry dummies or fixed effects reflect neutral productivity trends that are specific to the single industries in particular countries. Time dummies μ_t allow for a non-constant component in technical change. The error term is denoted as $\epsilon_{c,j,t}$. The coefficients for the different inputs (in logarithms) correspond to their output elasticities. Under constant returns to scale, they would sum up to one: $\beta^{ict}+\beta^{nict}+\beta^{int}+\beta^{H}=1$.

An equivalent formulation of equation (13) is useful in testing if the output elasticity of intangible assets significantly exceeds their factor shares. Solving equation (12) for MFP growth and replacing growth in value added by the specification of the production function (equation (13)) yields:

$$\Delta\ln MFP_{c,j,t}=\mu_t+\mu_{c,j}+(\beta^{ict}-\pi^{ict})\Delta\ln Kict_{c,j,t}+(\beta^{nict}-\pi^{nict})\Delta\ln Knict_{c,j,t} + (\beta^{int}-\pi^{int})\Delta\ln Kint_{c,j,t}+(\beta^{H}-\pi^{H})\Delta\ln H_{c,j,t}+v_{c,j,t}\ , \tag{14}$$

where the π^x are averages across country, industry, and time for input x. The error term is denoted as $v_{c,j,t}$. This specification has been used previously to estimate potential spillovers from ICT and intangibles (Stiroh, 2002; Corrado *et al.*, 2014). If the regression coefficients of inputs significantly differ from zero, the output elasticities significantly differ from factor shares. Here, we just report the results for equation (13)—the results using (14) are reported in the supplementary online Appendix.

We use four different estimators to estimate the production function (and, equivalently, the MFP equation). This follows a standard approach of starting from a general specification and then relaxing some assumptions to check for robustness of the estimated coefficients controlling for country and industry heterogeneity. Differences in productivity levels across countries and industries are eliminated in all specifications since the equations are expressed in first differences. A specification in first differences rather than in levels was chosen in order to estimate roughly the same relationship as is analyzed by the growth accounting method. As a baseline specification, we consider a pooled OLS regression. With the least squares dummy variable specification (LSDV), we control independently for country-specific and industry-specific rates of technical change. In addition, we use fixed-effects (FE) panel regressions with each country–industry combination as panel identifiers, giving more weight to growth patterns specific to industries within particular countries. Finally, we attempt to control for endogeneity by employing a system-GMM dynamic panel regression, commonly used in production function estimations. With this approach, we aim at controlling for the endogeneity of inputs. It uses second-order ($t-2$) and third-order ($t-3$) lags as instruments for all input growth variables and again country–industry combinations as panel identifiers (see, e.g. Dobbelaere *et al.*, 2013). Following Kahn and Lim (1998), all regressions are weighted by the average number of hours worked between 1995 and 2007 in countries and industries. This approach seems to be appropriate as we expect the data from smaller industries to be noisier. When estimating the Cobb–Douglas function, we test for constant returns to scale (CRS).

5.2. *Results*

Estimates of the production function (13) are presented in Tables 5 and 6, with the equivalent MFP equation (14) results reported in the supplementary online Appendix. The coefficient of intangible assets is positive and significant in all regressions. The returns to scale implied by the estimated production function are decreasing (In the MFP regressions, the coefficients on non-ICT capital and labor services are negative—see supplementary online Appendix). As Stiroh (2005) notes (referring to own results and to Griliches and Mairesse, 1998), low estimates of returns to scale and occasionally insignificant coefficients for capital inputs are typical for panel estimations of production functions. Decreasing returns are a feature of the production function both including and excluding intangible capital.

Since inputs are highly correlated with time, allowing for time-varying technical progress may result in over-controlling, so time dummies were not included in these regressions. If progress does not follow any smooth pattern over time, there is a risk that it eliminates a part of the dynamic effects that should be attributed to inputs. Since we estimate equations in first differences, these specifications still allow for neutral factor-augmenting technical change at a constant rate (Tables 5 and 6). In each table, we compare the estimation that includes intangibles in inputs and outputs with the estimation without intangibles.

With the inclusion of intangible assets, the coefficients on inputs decline in most specifications. In the MFP regressions (see the supplementary online Appendix), intangible assets now exhibit a significant coefficient in all but one specification. If we consider that the fixed effects and the system-GMM specification account best for sectoral heterogeneity, we obtain an output elasticity between 0.12 and 0.18 that exceeds the factor share by about half. While we thus find some indication that the output elasticity of intangible assets exceeds their factor share, the values that we observe lie below the values of 0.25–0.55 found in previous research using aggregate measures (Roth and Thum, 2013; Corrado *et al.*, 2014).

TABLE 5

Production Function Estimation, Full Sample—Dependent Variable: Growth Rate of Value Added

	With intangibles				Without intangibles			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	POLS	LSDV	FE	SGMM	POLS	LSDV	FE	SGMM
Δln (ICT Cap. Serv.)	0.052***	0.058***	0.054***	0.056***	0.060***	0.063***	0.060***	0.052**
	(0.015)	(0.016)	(0.016)	(0.021)	(0.017)	(0.016)	(0.017)	(0.021)
Δln (N.ICT Cap. Serv.)	0.089**	0.087**	0.085**	−0.042	0.105**	0.088**	0.090**	0.001
	(0.045)	(0.037)	(0.042)	(0.093)	(0.048)	(0.036)	(0.042)	(0.092)
Δln (Intan. Cap. Serv.)	0.137***	0.099***	0.120***	0.174***				
	(0.035)	(0.032)	(0.032)	(0.052)				
Δln (Labor Services)	0.317***	0.363***	0.309***	0.538***	0.359***	0.388***	0.334***	0.656***
	(0.045)	(0.060)	(0.057)	(0.115)	(0.051)	(0.062)	(0.060)	(0.119)
L.Δln (Value Added)				−0.048				−0.048
				(0.076)				(0.074)
Constant	0.007**	0.007	0.008***	0.008**	0.010***	0.010	0.011***	0.012***
	(0.003)	(0.006)	(0.002)	(0.003)	(0.003)	(0.006)	(0.002)	(0.004)
N	1,320	1,320	1,320	1,210	1,320	1,320	1,320	1,210
Adjusted R^2	0.216	0.289	0.119		0.173	0.256	0.087	
CRS	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.033

Source: EU KLEMS Release 2009, INTAN-Invest, and INDICSER—own calculations.

Notes: Clustered standard errors by country–industry combination in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. POLS = pooled OLS regression, LSDV = least squares dummy variable regression, FE = fixed-effects regression, SGMM = system-GMM regression, ICT Cap. Serv. = ICT capital services, N.ICT Cap. Serv. = non-ICT capital services, Intan. Cap. Serv. = intangible capital services.

In the growth accounting results, the contribution of intangibles to labor productivity growth varies notably across sectors. In order to account for sectoral heterogeneity in the econometric analysis, we estimate all specifications with intangibles separately for the goods-producing sector (industries *C* to *F*) and the service sector. The limited number of observations prevents us from estimating production functions for more disaggregated sectors.

In most specifications, the coefficients on intangible capital are similar across the two broad sectors. The GMM results show marginally higher coefficients in services, but even here there is no significant difference across the two sectors. In the MFP regressions, the coefficients on intangible capital, although positive, are only significant in the GMM specification. Assuming that this method correctly accounts for endogeneity, the coefficient of intangibles would exceed the factor shares by 0.10 in the goods-producing sectors and by 0.15 in services. The insignificant coefficient for conventional capital and the negative coefficient for labor are direct consequences of the decreasing returns to scale found in the production function estimation in Table 6, since decreasing returns imply that factor shares exceed output elasticities for at least some inputs. This feature of the production function should caution us against taking these results as more than preliminary evidence. Future work should investigate heterogeneity, complementarity, and lagged adjustments in more detail.

TABLE 6
Production Function Estimation, by Broad Sector—Dependent Variable: Growth Rate of Value Added Including Intangibles

	Goods-producing sector				Service sector			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	POLS	LSDV	FE	SGMM	POLS	LSDV	FE	SGMM
Δln (ICT Cap. Serv.)	0.033	0.019	0.020	0.035	0.073***	0.090***	0.085***	0.041*
	(0.028)	(0.033)	(0.029)	(0.036)	(0.019)	(0.018)	(0.020)	(0.021)
Δln (N.ICT Cap. Serv.)	0.032	0.135	−0.045	−0.058	0.074	0.019	0.067	0.054
	(0.123)	(0.087)	(0.111)	(0.120)	(0.056)	(0.048)	(0.046)	(0.085)
Δln (Intan. Cap. Serv.)	0.155***	0.110**	0.134***	0.183***	0.154***	0.099**	0.143***	0.228***
	(0.046)	(0.041)	(0.042)	(0.054)	(0.055)	(0.049)	(0.044)	(0.074)
Δln (Labor Services)	0.413***	0.535***	0.467***	0.372***	0.211***	0.219***	0.216***	0.276***
	(0.082)	(0.127)	(0.110)	(0.105)	(0.059)	(0.068)	(0.065)	(0.092)
L.Δln (Value Added)				0.106				0.152**
				(0.076)				(0.061)
Constant	0.007	0.014**	0.010***	0.007	0.009**	−0.011**	0.008***	0.003
	(0.006)	(0.006)	(0.004)	(0.005)	(0.003)	(0.005)	(0.002)	(0.003)
N	480	480	480	440	720	720	720	660
Adjusted R^2	0.258	0.350	0.160		0.207	0.327	0.188	
CRS	0.005	0.053	0.002	0.000	0.000	0.000	0.000	0.000

Source: EU KLEMS Release 2009, INTAN-Invest, and INDICSER—own calculations.
Notes: Clustered standard errors by country–industry combination in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. POLS = pooled OLS regression, LSDV = least squares dummy variable regression, FE = fixed-effects regression, SGMM = system-GMM regression, ICT Cap. Serv. = ICT capital services, N.ICT Cap. Serv. = non-ICT capital services, Intan. Cap. Serv. = intangible capital services.

The fact that there is little difference in the coefficients of intangibles across sectors is not necessarily at odds with the higher growth accounting contribution observed in manufacturing. The growth accounting contribution depends on both the output elasticity (measured by the factor share) and the increase in intangible assets. If net investment is higher, the contribution to growth is higher even at equal output elasticities. Overall, the results are suggestive of a significant contribution of intangible investment to growth, but at magnitudes much lower than found in the previous literature.

6. Conclusion

In this paper, we have investigated the importance of investment in intangible assets for labor productivity growth at the sectoral level, based on the construction of a sectoral breakdown of the INTAN-Invest data. Growth accounting for ten EU countries shows the contribution of intangibles to labor productivity growth to be higher in manufacturing than in services, in line with previous single-country findings at the sectoral level; for example, Chun *et al*. (2012) for Japan, Goodridge *et al*. (2012) for the U.K., and Crass *et al*. (2015) for Germany. The high contribution of manufacturing is associated with a high share of intangible investment in value added in this sector. A large part of its intangible investment falls into the R&D category. In addition to the investment being higher, the assumed relatively low depreciation rate of R&D capital may have an effect on the high contribution of intangibles to productivity growth in manufacturing. Meanwhile, services are responsible for the high contribution of intangibles observed in the U.K. The U.K. exhibits higher shares of intangible investment in value added in business services and financial intermediation than other countries.

Our results partly confirm evidence from previous studies using intangible measures at the country level or partial measures of intangibles at the sectoral level, which suggests that the output elasticity of intangibles exceeds its factor share. With values between 0.10 and 0.18, we find that the output elasticity of intangibles is, however, lower than the values of 0.25–0.55 found with country-level measures in Roth and Thum (2013) and Corrado *et al*. (2014). In some specifications (reported in the Online appendix), we do not find any significant difference between the output share of intangibles and their factor income share.

With the currently available data at the level of one-digit industries of the NACE rev. 1.1 classification, we consider that our sectoral breakdown reveals useful first insights on the sectoral distribution of intangible assets, the change in econometric results when using sectoral instead of aggregate data, and the measurement challenges lying ahead. While some further adjustments may be feasible with NACE rev. 2 data, which are not yet available for all necessary components, we expect that a major step beyond the limitations currently faced will only be possible by building up sectoral estimates directly from national accounts and micro data. A reference set of sectoral data will most likely emerge in the future from intertwined efforts by research teams at several institutions, as was the case with the aggregate data on the INTAN-Invest platform.

In addition, more work is needed on developing better methodologies to measure prices and service lives. An important challenge will be to find out whether the result that manufacturing industries have a higher contribution of intangibles to growth remains robust, or whether the assets typically used in service industries are currently just harder to capture. On the analytical side, future research should revisit the issue of spillovers and complementarities of intangible assets using sectoral data.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

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Table B.20: Average Contribution to Labor Productivity Growth - 1995-2007 - United Kingdom
Table B.21: Production Function Estimation, Full Sample - Dependent Variable: Growth Rate of MFP
Table B.22: Production Function Estimation, by Broad Sector - Dependent Variable: Growth Rate of MFP Including Intangibles