Company productivity increases with more knowledge-based capital

By Heike Belitz, Marie Le Mouel, and Alexander Schiersch

In Germany, around 200 billion euros are invested every year in knowledge-based capital, which encompasses assets such as research and development, software and databases, organizational capital, marketing and advertising, and technical design. Yet investments in traditional capital (such as machinery and non-residential buildings) still significantly outweigh knowledge investments, standing at over 320 billion euros across the whole economy. Nevertheless, at the sector level, manufacturing, information and communication services, professional services, and financial services stand out: Investments there are dominated by knowledge-based capital. More importantly, in the years since the financial crisis, there has been no increase in the investment intensity in knowledge-based assets. DIW Berlin compiled a novel dataset on company investments in knowledge-based capital covering almost 2 million records to explore the relationship between investments and company productivity. Initial results show that knowledge-based capital has a positive effect on productivity of comparable magnitude for all the different assets measured. Furthermore, intangible assets complement material assets—therefore, investments in traditional capital goods should always be accompanied by investments in intangible assets. An economic policy to increase investment needs to take these interdependencies into account and emphasize the importance of strengthening intangible assets.

Businesses in developed economies are facing enormous pressure to be innovative and competitive. To face these challenges, it is necessary for them to invest both in modern machinery as well as knowledge-based capital. This kind of capital includes a number of intangible assets such as research and development (R&D), design, and organizational capital.[1] When companies invest in these items, they expect to reap benefits for a number of years, similarly to when investing in more traditional capital, such as machinery, equipment, vehicles, or buildings.

Empirical studies based on macroeconomic data show that investments in intangible assets increase the value added at both the country and economic sector level.[2] However, there have been few studies on the effects of knowledge-based capital at the company level.[3]

As part of a study for the Federal Ministry of Economics and Energy (*Bundesministerium für Wirtschaft und Energie*, BMWi), DIW Berlin measured the extent to which

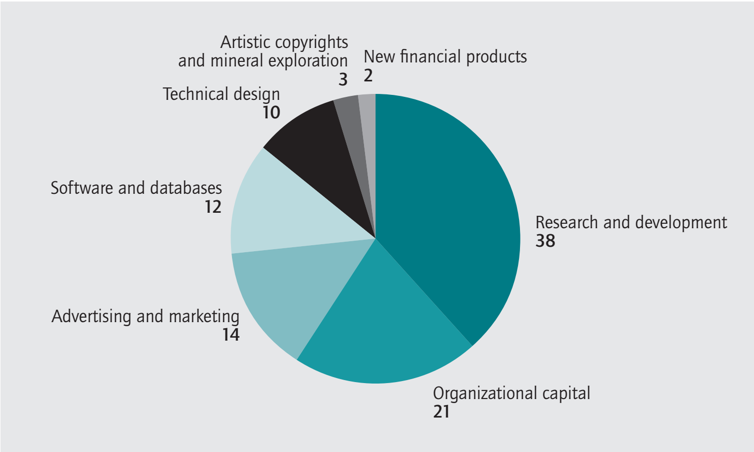
1 There is no conclusive definition for the components of knowledge-based capital. The OECD counts the following elements as a part of knowledge-based capital: software, databases, private sector R&D, mineral exploration, trademarks and copyrights, licenses and artistic originals, new products in the financial sector, new architectural and technical designs, R&D in the social sciences and humanities, marketing and advertising, education and training to develop firm-specific human capital, and organizational capital. See OECD, *Supporting Investment in Knowledge Capital, Growth, and Innovation* (Paris, 2013).

2 Thomas Niebel, Mary O'Mahony, and Marianne Saam, "The Contribution of Intangible Assets to Sectoral Productivity Growth in the EU," *Review of Income and Wealth* 63 (2017): 49-67; Carolina Hintzmann-Colominas, Josep Lladós-Masllorens, and Raúl Ramos-Lobo, "Intangible assets and labour productivity growth" (Working Paper Series WP15-004, Open University of Catalonia, 2016); Wen Chen, Thomas Niebel, and Marianne Saam, "Are intangibles more productive in ICT-intensive industries? Evidence from EU countries," ZEW Discussion Papers, no. 14-070 (2014); Felix Roth and Anna-Elisabeth Thum, "Intangible Capital and Labour Productivity Growth: Panel Evidence for the EU from 1998–2005," *Review of Income and Wealth* 59, no. 3 (2013): 486–508; Emanuela Marrocu, Raffaele Paci, and Marco Pontis, "Intangible capital and firms' productivity," *Industrial and Corporate Change* 21, no. 2 (2012): 377–402.

3 Dirk Crass and Bettina Peters, "Intangible assets and firm-level productivity," ZEW Discussion Papers, no. 14-120; Christian Rammer and Bettina Peters, "Investitionsschwäche oder Strukturverschiebung der Investitionstätigkeit? Zur Rolle immaterieller Investitionen für die Wettbewerbsfähigkeit von Unternehmen," ZEW Discussion Paper, no. 16-037 (in German).

Figure 1

Gross investment in knowledge-based capital in Germany in 2015
In percentages

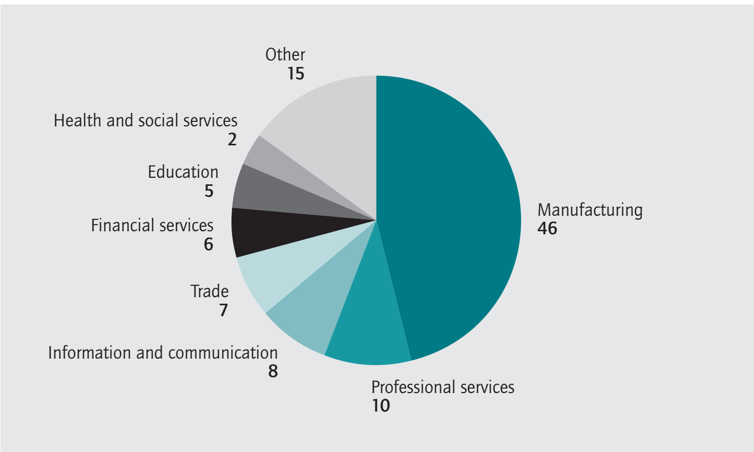


Source: Authors' own calculations and estimates.

The majority of investment in knowledge-based capital is done in research and development followed by organizational capital.

Figure 2

Distribution of gross investment in knowledge-based capital across economic sectors in Germany in 2015
In percentages



Source: Authors' own calculations and estimates.

Nearly half of all investment in knowledge-based capital is concentrated in the manufacturing sector.

individual economic sectors in Germany invest in knowledge-based capital.[4] Additionally, company data was used to examine how different elements of knowledge-based capital influence company productivity.

Investments in physical assets are still dominant

Intangible assets are becoming increasingly important in a number of countries. For example, studies in the United States conclude that investments in knowledge-based capital have been surpassing those in physical capital since the turn of the millennium.[5]

The DIW Berlin study provides an overview of the total magnitude of investments in knowledge-based capital for Germany, supplementing official statistics to cover additional assets. The system of national accounts already includes information on investments in R&D, software, artistic copyrights, and mineral exploration, which are classified as intellectual property investments. Investments in organizational capital, advertising and marketing, architecture and engineering design (technical design), and new financial products are added to these official numbers. They are approximated by applying an internationally recognized measurement methodology to publicly available data for Germany (Overview).[6]

According to DIW Berlin's estimates, overall gross investment in knowledge-based capital in 2015 totaled around 202 billion euros, representing 7.4 percent of gross value added. In comparison, gross investment in machinery and non-residential buildings[7] was 323 billion euros, or 11.8 percent of gross value added. Thus, investments in physical capital remained the predominant type of investment in Germany.

Of the total investments in knowledge-based capital in 2015, the majority were in R&D (38.5 percent) and organ-

4 Heike Belitz, Alexander Eickelpasch, Marie Le Mouel, and Alexander Schiersch, "Wissenbasiertes Kapital in Deutschland: Analyse zu Produktivitäts- und Wachstumeffekten und Erstellung eines Indikatorensystems," Study commissioned by the Federal Ministry of Economic Affairs and Energy (BMWi), *DIW Berlin: Politikberatung kompakt*, no. 126 (in German; available online; accessed on January 19, 2018. This applies to all other online sources in this report unless stated otherwise).

5 OECD, *Supporting Investment in Knowledge Capital, Growth and Innovation* (Paris: 2013).

6 Investments in worker training and continuing education were excluded as they could not be divided into the economic sectors on the basis of publicly available information. The German Economic Institute (*Institut der deutschen Wirtschaft Köln*, IW) estimates that German companies invested around 33 billion euros in 2016 in worker training. See Susanne Seya and Beate Placke, "Lernen 4.0," *IW Trends* 4. The BIBB estimates the net costs of company-based training (gross costs minus productive work) for the training year 2012/2013 to be 7.7 billion euros (in German; available online).

7 Gross investments in tangible assets, excluding the real estate sector.

Overview

Methodology for construction of indicators of investment in knowledge-based capital by economic sectors

Element	Description	Data sources
Research & development	Gross fixed capital formation	System of National Accounts (SNA)
Software and databases	Gross fixed capital formation	SNA
Artistic copyrights	Gross fixed capital formation	SNA
Mineral exploration	Gross fixed capital formation	SNA
Advertising	60 percent of total revenue of the advertising and market research (M73) sector Distributed across economic sectors using the input-output tables for 2013 Doubled to include internal investments	Sales tax statistics Input-output tables 2013 *DIW Berlin calculations*
Organizational capital		
External	80 percent of total revenue of the management consulting (M70.22) sector Distributed across economic sectors using the input-output tables for 2013	Sales tax statistics Input-output tables 2013 *DIW Berlin calculations*
Internal	20 percent of employee compensation for supervisors and managers	Statistics on employees subject to social insurance contributions Structure of Earnings Survey 2014 Employee compensation SNA *DIW Berlin calculations*
Architectural and engineering design	50 percent of total revenue of the architecture and engineering offices (M71) sector Distributed across economic sectors using the input-output tables for 2013	Sales tax statistics Input-output tables 2013 *DIW Berlin calculations*
New financial products	Current expenditure on innovations in the financial services sector (K)	Mannheim Innovation Panel (ZEW)

izational capital (20.8 percent). These elements were followed by advertising and marketing (14.3 percent), software and databases (12.4 percent), and architectural and engineering design (9.5 percent). Smaller investments were made in copyrights, mineral exploration, and new financial products (Figure 1).

Investments in knowledge-based capital are concentrated in the manufacturing industry

The manufacturing industry accounted for almost half (46 percent) of total investments in knowledge-based capital made in Germany in 2015 (Figure 2). The next five largest sectors individually account for between 5 percent and 10 percent of total intangible investments and collectively for 36 percent. These are sectors providing professional services (such as R&D, legal services, market research, tax consulting and auditing, and engineering offices), information and communication, trade, financial services, and education.

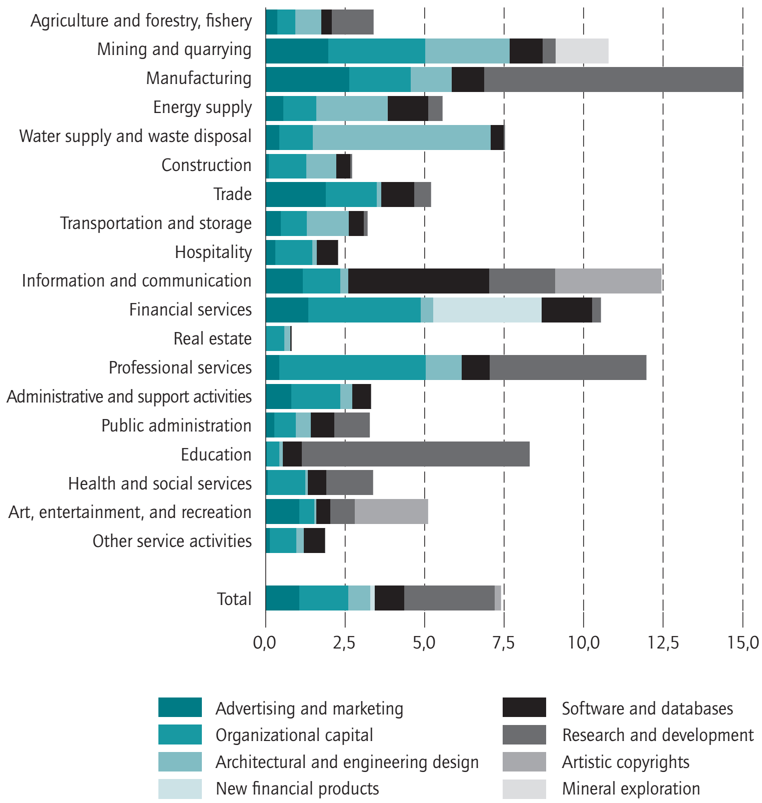
This sectoral distribution of investments is not affected by the size of the respective sectors. On the contrary, the sectors that represent the largest share of total investment in knowledge-based capital are also those that have the highest investment intensity, measured as investment relative to gross value added.[8] The manufacturing industry is again at the top of the ranking with 15 percent of value added being invested in knowledge-based capital. It is followed by information and communication, professional services, mining and quarrying, and financial services, each investing over 10 percent of value added (Figure 3). In the manufacturing, professional services, and education sectors, the asset that drives this share is R&D, whereas in the information and communication sector, the primary assets are software and copyrights.

Taking into account the broad bundle of all elements of knowledge-based capital, some sectors can be classified as “knowledge intensive” although their investments in R&D are minimal. For example, the high investment rate (10 percent of value added) in the mining and quarrying sector is mainly driven by investments in organizational capital and technical design. Large investments in tech-

8 The mining and quarrying industry is a notable exception: While the sector invests a high share of value added into knowledge-based capital, its small size in the total economy means that it also represents a small share of total investments in knowledge-based capital.

Figure 3

Investment in elements of knowledge-based capital as a share of gross value added by economic sector in Germany in 2015
In percentages



Source: Authors' own calculations and estimates.

The investment rate in knowledge-based capital is highest in the manufacturing sector.

nical design contribute to the high knowledge intensity in the water supply and waste disposal industry, and likewise with investments in organizational capital and financial products in the financial services sector.

Knowledge intensification is stagnating in all economic sectors

While the investment rate for knowledge-based capital is still lower than that of physical capital for the entire German economy, this is not the case in some knowledge-intensive sectors, such as manufacturing, information and communication, professional services, and financial services (Figure 4). Companies in these key sectors of the German economy have already been investing more in intangible assets than in machines and equipment for years.

The total volume of nominal investments in knowledge-based capital rose from around 163 billion euros in 2009 to around 202 billion euros in 2015, an increase of 23 percent. However, this growth has only kept up with overall economic growth and has not led to a general knowledge intensification of the national economy. The investment rates of both physical and intangible capital have been largely stable since 2009 (Figure 4). However, there have been slight increases in the investment rates of particular elements of knowledge-based capital, such as technical design, R&D, and organizational capital.

Growth in knowledge-based capital increases overall factor productivity

Firm and establishment data from official statistics of the Federal Statistical Office and of the Federal Labor Office (*Bundesagentur für Arbeit*, BA) were used to analyze the effect of knowledge-based capital on company productivity. The econometric analysis was carried out on the largest company database to date, permitting an in-depth look at detailed economic sectors. However, only some elements of knowledge-based capital are measured at such level of detail: R&D, software,[9] licenses and patents,[10] and organizational capital. The company data thus covers around 60 percent of all investments in knowledge-based capital.[11]

The effect of the elements of knowledge-based capital on the total factor productivity (TFP)[12] of companies is analyzed in this study. Total factor productivity is a measure of the efficiency of production. When two companies with the same amount and combination of inputs, such as labor and machinery, produce different amounts of output, the company that produces more output will have a higher measure of TFP. Total factor productivity is often viewed as a measure of technical progress, which is not directly measurable. It is also highly correlated with labor productivity, but unlike labor productivity, it already takes into account the possibility to substitute labor for capital (Box).

Estimates are made both for broad economic sectors, such as manufacturing or information and communication, as well as for the detailed divisions, such as metal

9 Only software purchased and accounted for in the time period considered by the analysis is included in the Statistical Offices' investment survey.

10 In the official statistics used here, only the expenses for acquired and recognized rights are recorded, but not for internally developed patents, etc., because they have no market price. Accordingly, patent applications resulting from in-house R&D and unsuccessful applications are not included in the data.

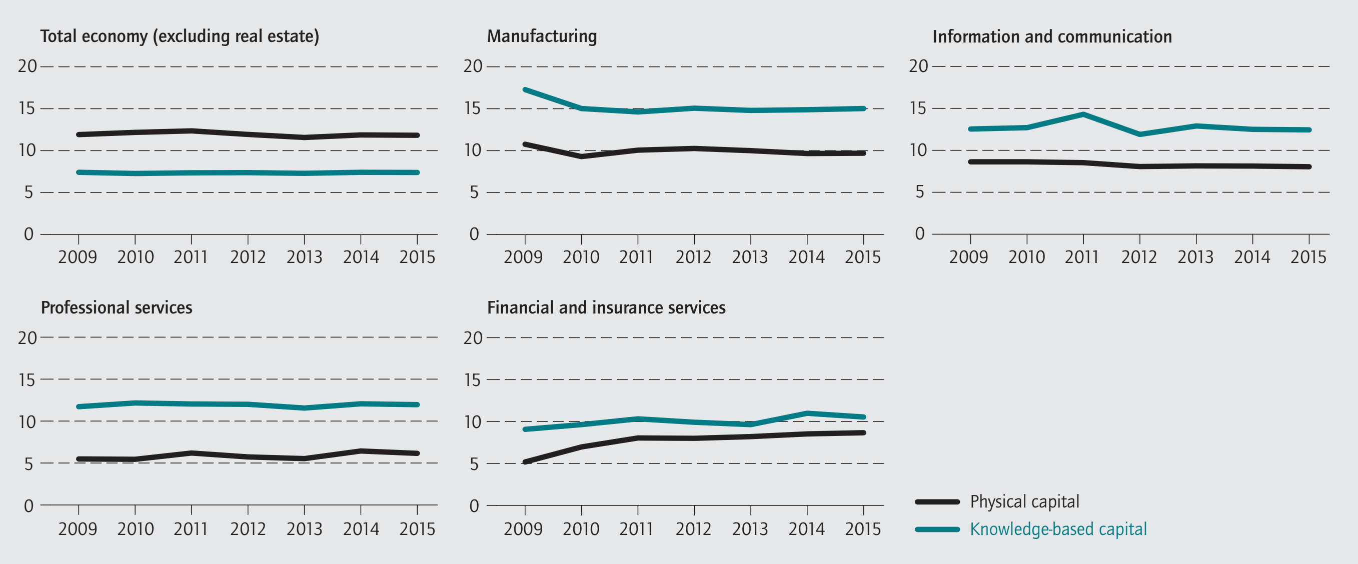
11 Investments in new financial products, new architectural and technical designs, advertising, and company-specific training are not included.

12 See the entry on total factor productivity in the DIW Glossary here (in German only).

Figure 4

Investment rates for knowledge-based and physical capital in selected economic sectors, 2009–2015

In percentages



Source: Authors' own calculations and estimates.

While more is invested in physical capital than in knowledge-based capital in the total economy, this is reversed in specific sectors of the economy.

production and processing or information services.[13] The coefficients resulting from the estimations, or elasticities, indicate in percentages by how much productivity increases when one variable, such as organizational capital, increases by one percent while all other variables remain unchanged. The elasticities of the various knowledge-based assets are all positive and significant across economic sectors (Table).[14] Thus, increasing the stock of R&D, software, licenses and patents, and organizational capital increases company productivity.

Comparing elasticities across the economic sectors is also interesting. For example, in the manufacturing sector, it is R&D and software that have the highest coefficients and thus most influence TFP. In contrast, the elasticity of R&D in the transport and logistics industry is substantially smaller than the elasticities of software and organizational capital. Individual elements of knowledge-based capital affect the various economic sectors to differing degrees. Software often has a relatively high coefficient compared to the other elements of knowledge-based capital across all sectors.

Additional results for each of the 48 economic divisions (two-digit level) confirm this picture: knowledge-based capital increases productivity in many sectors. This applies particularly to R&D and software, for which positive elasticities are found in 41 and 44 sectors of the 48, respectively. The strong effect of software combined with its relatively low level of capital stock suggests that there are still productivity gains to be had in this area.[15]

A significant positive effect on TFP is documented in 33 and 40 sectors out of 48 for the capital stock from licenses and patents and organizational capital, respectively. The elasticities are within the scope of previously published results.[16] Overall, the elasticities of licenses

13 In official statistics, a distinction is made between "sectors" and "divisions" for the classification of economic activities. The "sectors" (one-digit) are subdivided into "divisions," each of which is coded with two numbers (two-digit).

14 The missing coefficient for R&D in the real estate sector is due to the fact that companies in this sector did not report any R&D.

15 Michael Ebnet and Christina Timiliotis come to a similar conclusion in *ifo Schnelldienst* 1 (Vol. 71, 2018), where they argue that Germany invests little compared to other countries in areas such as cloud computing, big data analytics, and e-invoicing.

16 For a literature review, see Belitz et al. (2017), Wissenbasiertes Kapital in Deutschland.

Box

Total Factor Productivity (TFP): Model and the relationship between TFP and labor productivity

Within the framework of the microeconomic analysis, a production function is assumed in which the individual elements of knowledge-based capital directly affect total factor productivity:

$$Y_{ijt} = \omega_{ijt} L_{ijt}^{\beta_{l,j}} K_{ijt}^{\beta_{k,j}} \text{ and } \omega_{ijt} = G(R_{ijt}, S_{ijt}, Z_{ijt}, O_{ijt}, \omega_{ijt-1}; \boldsymbol{\gamma})$$

where Y_{ijt} is gross value added, K_{ijt} physical capital stock, L_{ijt} labor input, ω_{ijt} total factor productivity (TFP), and $\beta_{l,j}$ and $\beta_{k,j}$ the production elasticity of the labor and capital inputs, respectively. In this model, the TFP (ω_{ijt}) is determined by the function $G(\cdot)$, which contains the stocks of R&D capital (R_{ijt}), organizational capital (O_{ijt}), software capital (S_{ijt}), and licenses and patents (Z_{ijt}), as well as the past productivity developments. The vector $\boldsymbol{\gamma}$ contains the elasticity of the elements of the function $G(\cdot)$ regarding the TFP.[1] The indices define the company i, the sector j, and the observation time t.

In the model used here, knowledge-based capital directly affects company productivity (TFP). This contrasts with other similar analyses where an extended Cobb-Douglas production function is used. In these cases, the elements of the knowledge-based capital are treated like another input—they influence the output of the companies as opposed to their productivity. For example, the Griliches production function, which is dominant in the literature, extends the Cobb-Douglas production function with the input R, (which can stand for R&D capital or for knowledge-based capital more generally), as such:[2]

1 Here we assume that $G(\cdot)$ is a linear function.

2 For purposes of simplicity, the sector index j is omitted. See Zvi Griliches, "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *The Bell Journal of Economics* 10, no. 1 (1979): 92-116.

$$Y_{it} = \omega_{it} L_{it}^{\beta_l} K_{it}^{\beta_k} R_{it}^{\beta_r}$$

A commonly used measure of productivity is labor productivity, which is the ratio of output to labor input:

$$\frac{Y_{it}}{L_{it}} = \omega_{it} L_{it}^{\beta_l - 1} K_{it}^{\beta_k} R_{it}^{\beta_r}$$

As the equation above shows, the coefficients on physical and knowledge-based capital (β_k,β_r) remain unaffected by using this alternative measure. The coefficients will continue to measure the change in output due to a one percent change in either input.

More generally, in the context of a Cobb-Douglas production function, all inputs are substitutable for each other. The proportion of L_{it} and K_{it} can be changed without affecting the amount of output Y_{it} produced. For example, a company can reduce its use of L_{it} and increase its use of K_{it} and still produce the same amount of Y_{it}. Its labor productivity will thus increase without the company producing more efficiently—it is simply using another input mix.

The above equation also illustrates that an increase in total factor productivity (ω_{it}) automatically increases labor productivity. However, total factor productivity itself remains uninfluenced by the possibility to substitute inputs for each other. The analysis focuses on TFP in order to estimate the effect of the different elements of knowledge-based capital without distortions due to substitution patterns.

and patents are generally lower than those of the other knowledge-based assets. This could be explained by the fact that the data only record expenses for externally acquired and recognized patents and do not cover those developed internally.

The complementarity and substitutability of elements of knowledge-based capital were also examined in the analysis.[17] Although the number of sectors about which unambiguous conclusions can be drawn is limited due to methodological constraints, it can be seen that software and organizational capital are often substitutable. This means that when companies use more of one, they can use less of the other and still achieve the same level of output. The substitution relationship implies that software solutions can be used to simplify organizational structures. Complementary relationships dominate the remaining combinations of elements of knowledge-based capital, especially in the manufacturing sector. Hence, increasing productivity demands not just an expansion of investments in a single element, such as R&D, but also of investments in complementary elements of knowledge-based capital, such as software. There are also complementary relationships between the various intangible assets and physical capital, mainly in the manufacturing industry.

17 The methodology is taken from Martin Carree, Boris Lokshin, and René Belderbos, "A note on testing for complementarity and substitutability in the case of multiple practices," *Journal of Productivity Analysis* 35, no. 3 (2011): 263–269.

Table

Elasticities of knowledge-based capital stock in relation to total factor productivity by economic sector, 2003 to 2013

Capital stock of	Manufacturing industry[1]	Transport & storage	Information & communication	Real estate	Professional, scientific, and technical services	Administrative and support activities
R&D (R)	0.013***	0.005***	0.012***		0.026***	0.027***
Software (S)	0.012***	0.035***	0.041***	0.097***	0.038***	0.049***
Licenses & patents (Z)	0.005***	0.006***	0.019***	0.047***	0.016***	0.023***
Organizational capital (O)	0.010***	0.030***	0.053***	0.024***	0.010***	0.025***
N	67,936	144,258	97,812	100,367	314,117	156,489

*Note: *** p<0.01, ** p<0.05, * p<0.1*

1 Estimations for the years 2010-2014 due to missing data for software (S) and licenses and patents (Z).

Year, sector, legal status, and regional dummies are taken into account in the first stage of the estimations.

Interpretation aid: A one percent increase in the stock of software capital increases the productivity in the information and communication sector by 0.041 percent when keeping all other variables unchanged.

Sources: German Statistical Offices (AfiD Panels on industrial companies and services); authors' own calculations.

More knowledge-based capital increases the productivity of enterprises across economic sectors.

Conclusion

Businesses in Germany are investing heavily in knowledge-based capital, such as research and development, organization, software, design, and advertising. In 2015, total investments in knowledge-based capital amounted to around 202 billion euros. Currently, only in certain highly competitive industries such as manufacturing, are investments in intangible assets outpacing those in tangible capital. The most important knowledge-based asset in Germany is R&D, followed by organizational capital and marketing. During the period from 2009 to 2015, the national economy did not become more knowledge intensive; rather, intangible investment simply kept up with economic growth.

The analysis using extensive company data confirms the well-established fact that the growth of R&D capital stock increases productivity and further shows that increases in organizational and software capital have similarly strong positive effects in many sectors.

The results of the analysis presented here therefore suggest that productivity improvements can be obtained by increasing knowledge-based capital. The stocks of organizational capital and of software and databases are still comparatively low in many sectors, and ramping up investments in these assets can yield potential efficiency gains. Economic policy should support businesses to invest in as many elements of knowledge-based capital as are relevant to them. To this end, more awareness needs to be raised regarding the significance of intangible assets for the competitiveness of companies in politics and business. It is also necessary to analyze in more detail what barriers exist to companies investing in intangible assets.

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