RESEARCH, INNOVATION
AND TECHNOLOGICAL
PERFORMANCE IN GERMANY

COMMISSION OF EXPERTS
FOR RESEARCH
AND INNOVATION

EFI

REPORT

2018

2019 2020
2021 2022 2023
2024 2025 2026

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C STRUCTURE AND TRENDS

Foreword

Germany is economically well positioned at the beginning of 2018. The federal budget shows a substantial surplus, and the German economy is regarded as an anchor of stability in the euro zone. Many factors have contributed to this success. One important cause is the high level of investment in research and innovation by the private and public sectors in recent years.

Expenditure on research and innovation is an investment in the future, especially in times of rapid technological and economic change. The Commission of Experts for Research and Innovation therefore recommends that the new Federal Government invest more in science, research and innovation in order to secure Germany's role as a leading economic nation in the future. In its 2018 report, the Commission of Experts sets out the aspects that should be taken into account in this context and points to the need to act quickly and decisively.

In chapter A1, the Commission of Experts formulates guidelines for R&I policy in the new legislative period. The Commission considers it essential to give digitalization a significantly higher priority than in the past. The framework conditions for the internet and internet-based technologies must be greatly improved; in particular, the Federal Government has an obligation to expand e-government and the digital infrastructure, and to promote broad-based digital education. A further key demand for the new legislative period is that the Federal Government should create effective incentives for innovation, and further improve growth opportunities for start-ups, by introducing tax incentives for R&D activities by small and medium-sized enterprises. In order to strengthen the science system, it is also necessary to initiate a follow-up programme for the Higher Education Pact (Hochschulpakt) that would last for several legislative periods. The Pact for Research and Innovation must be continued and, in future, geared more towards the transfer of knowledge and technology.

Innovations can lead to conflicts between different sustainability goals, e.g. environmental quality or social justice. In chapter A2, the Commission of Experts states that such conflicts of objectives must not lead to an overburdening of R&I policy with the problems of a systematic sustainability assessment. Also in the future, R&I policy must remain open to funding R&I activities irrespective of certain technologies.

In chapter A3, the Commission of Experts marks the 50th anniversary of the establishment of the universities of applied sciences (UASs) with a critical appraisal of this independent type of tertiary education institution. The Commission underlines that the UASs play an important role in the German higher-education and innovation system. It recommends that the UASs and universities retain their respective distinct profiles and continue to develop in their own specific way in line with changing requirements.

Chapter A4 focuses on the strengthening of digital education in Germany. The Commission of Experts emphasizes that key digital skills are an important prerequisite for productivity growth and innovation in both established and new industries. It is therefore of the utmost importance to teach key digital skills from primary school onwards. This requires excellent IT equipment and highly qualified teaching staff. In Germany, neither is available to a sufficient extent.

In chapter B1, the Commission of Experts analyses the long-term development of productivity and innovation. This analysis looks at fears that productivity growth has been slowing down in many countries, including Germany, for several decades and especially since the mid-1990s, and will not develop any long-term dynamics. The Commission of Experts comes to the conclusion that the slowdown in productivity growth cannot be attributed to a single cause. However, the Commission is confident that strong basic research in particular, combined with an effective transfer of knowledge, can support further productivity growth. It is also important to take appropriate measures to support the rapid diffusion of radical innovations and their follow-on innovations. This currently applies in particular to the digital transformation, which is yet to be universally implemented. Furthermore, a regulatory environment must be created in which economic actors can make agile use of new technological opportunities, and generate and market radical innovations.

In chapter B2, the Commission of Experts analyses the challenges of European R&I policy. A central problem in the European Union is the so-called innovation divide between innovation leaders in northern and central Europe and less innovative Member States in southern and eastern Europe. More effective use of the European Structural and Investment Fund is urgently needed for progress to be made here. At the same time, it must be ensured that research funding in the Framework Programmes remains geared to the excellence criterion. The European Commission plans to set up a European Innovation Council, for which the Commission of Experts currently sees insufficient justification. Tackling Brexit is a further major task. The complex structures of European R&I policy make it more difficult to deal with these challenges. The Commission of Experts therefore regards the consolidation and simplification of European R&I policy structures as an important task that takes precedence over the creation of new institutions in the field of R&I policy.

In chapter B3, the Commission of Experts examines so-called autonomous systems, a significant technology for the future. Autonomous systems have enormous potential benefits for the economy and society. In order to better exploit this potential, it is important not only to respond to complex technological challenges, but also – and in particular – to promptly adapt and reshape the legal framework. Germany has strengths in basic research and some areas of application, but is lagging behind the world leaders in other application fields of autonomous systems. The Commission of Experts recommends inter alia the establishment of a Bundestag Committee of Inquiry (Enquete-Kommission) in order to embed government action in a societal discourse and to take technological and societal challenges into account.

The Commission of Experts is concerned that, due to the delayed formation of the government and the lack of agility shown hitherto by policy-makers, the challenges it has identified will not be addressed with sufficient resolve and speed. The current strength of the German economy opens up an opportunity for policy-makers to introduce structural enhancements to the F&I system and to undertake urgent investments for the future. It would be regrettable if these opportunities were missed in the new legislative period.

Berlin, February 2018

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EXECUTIVE SUMMARY

Executive summary

A Current developments and challenges

A 1 Central guidelines for R&I policy in the new legislative period

In the new legislative period, German R&I policy must be systematically developed further to meet the challenges it faces, which have continued to grow in recent years. The target should be to spend 3.5 percent of gross domestic product on R&D by the year 2025.

Better use must be made of the opportunities offered by digitization. The skills needed in the use of digital technologies should be widely promoted in all areas of education and training. Ambitious broadband-expansion targets well in excess of 50 Mbit/s must be laid down and implemented.

The quality of services provided by public authorities for citizens and businesses should be improved by expanding e-government. In addition, start-ups and other companies must be given access to public-sector data in order to open up new potential sources of value creation.

In the new legislative period, tax incentives for R&D activities should finally be introduced and focused on SMEs. For the practical implementation of tax incentives for R&D activities, the Commission of Experts recommends a tax credit for R&D personnel expenditure that can be offset against payroll tax.

A 2 Sustainability and innovation policy

The concept of sustainability encompasses economic, social and ecological dimensions. In its 2030 Agenda, the United Nations agreed on 17 sustainability goals with a total of 169 subtargets, to which the Federal Government has also committed itself. Innovations can make an important contribution to achieving the sustainability goals. Since it is unclear how to deal with conflicting goals, sustainability assessment represents an overarching socio-political challenge.

Innovations can lead to conflicts between different sustainability goals. Such conflicts of objectives should be cushioned by coordinating with other policy areas such as labour-market or environmental policy. In addition to supporting basic research, R&I policy must be able to focus on funding R&I activities that are relevant to the great societal challenges, keeping the door open to all technologies in this context.

The careful involvement of different social groups to identify and confirm important societal challenges is useful as a guideline for R&I policy.

A 3 Universities of applied sciences in transition

Fifty years ago, universities of applied sciences (UASs; originally called Fachhochschulen (FHs), today often referred to as Hochschulen für angewandte Wissenschaften (HAWs)), were established as an independent type of tertiary education institution. UASs are one important pillar of the German higher-education system and have made a significant contribution to the further development of the innovation system. Their specific tasks include, in particular, application-oriented teaching and application-oriented research. Furthermore, UASs offer important career opportunities for graduates of apprenticeship training.

In the course of educational expansion, the percentage of students attending UASs has risen. In the future, an even larger percentage of Bachelor students should study at UASs. UASs need better basic financing to ensure that they can carry out their tasks.

The number of doctoral degrees granted in cooperation between UASs and universities is increasing. Different organizational models are used in this context. In the Commission of Experts' view, experience gained with these models should be used to strengthen cooperative doctoral studies in the future. However, the actual right to grant doctoral degrees should remain exclusively with the universities.

A 4 Digital education

In the course of digitization, skills in software and algorithm development, and specialists with key forms of digital expertise, have become important prerequisites for productivity growth and innovation in both established and new industries.

Key digital skills should already be taught in primary schools nationwide. Schools need excellent IT equipment and facilities, as well as teachers who can communicate these skills. The Digital Pact for Schools (DigitalPakt Schule) must therefore be urgently implemented and given priority in financial planning.

In the dual system of vocational education and training, new professions should be developed in the IT field that reflect requirements. In addition, IT skills should become a fixed and integral part of all vocational training.

Tertiary education institutions across all disciplines should also be encouraged to teach programming skills and knowledge of software and web development, as well as data sciences and methods of machine learning. In this context, active use should be made of the new possibilities offered by Article 91b of the Basic Law.

B Core topics 2018

B 1 Long-term developments in productivity and innovation

The growth rate in overall economic productivity has been slowing down in many countries, including Germany, for several decades and increasingly since the mid-1990s. While some experts have expressed concern that this slowdown in productivity growth reflects a universal exhaustion of technological potential and innovative ideas, others blame delays in the diffusion process of digitalization.

The fact that the innovator rate has been decreasing in Germany and most other European industrialized countries for about 20 years is seen by some observers as an indication that, parallel to the slowdown in productivity growth, innovation activity, an important driver of productivity, is also declining. However, the decline in the innovator rate could also be due to a concentration of innovative activities on fewer and fewer economic actors operating in more concentrated markets with high barriers to market entry. It is currently too early to draw any final conclusions on whether innovation activities are in fact slowing down or simply becoming more concentrated. Further research and, above all, better indicators are needed to assess this.

The Commission of Experts emphasizes that ensuring long-term productivity growth also requires the use of radical innovations and, in particular, their rapid diffusion. Primarily due to its power to design the regulatory environment, the Federal Government has important influence here, which it should use.

- Basic research is an important source of radical innovations and should be strengthened. It should not be neglected in favour of applied research, even when the latter promises short-term contributions to innovation and growth.
- Innovations can only have a large-scale impact on productivity if they find widespread application. It is therefore important to take appropriate measures to support the diffusion of radical innovations and their follow-on innovations. This currently applies in particular to the digital transformation, which is yet to be universally implemented.
- The regulatory environment must ensure that the economic actors can agilely make use of new technological opportunities, and generate and market radical innovations. This requires a suitable regulatory framework, e. g. in competition law, to give new actors barrier-free market access and prevent the emergence of dominant companies; such conditions are also needed in the financial sector to support the founding and growth of innovative young companies.

B 2 Challenges of European R&I policy

The EU's R&I policy is a relatively young policy area that is characterized by the formulation of very ambitious goals. In the past, the EU has fallen short of these goals, in some cases by a long way. The Commission of Experts is concerned that the EU's repeated marked failure to meet self-proclaimed objectives will undermine the credibility of European R&I policy in the medium term.

The structures of European R&I policy are very complex, and responsibilities fragmented. The Commission of Experts therefore regards the consolidation and simplification of European R&I structures as a key task of national and European policy. This task must take precedence over the creation of new institutions and the development of additional funding instruments.

The current challenges for European R&I policy lie in overcoming the so-called innovation divide, while simultaneously ensuring the promotion of excellence in research in Europe, justifying the creation of the European Innovation Council (EIC), and coping with Brexit.

- Horizon 2020 is primarily geared to the promotion of excellence in research. This orientation must be maintained in the design of the 9th Framework Programme for Research and Innovation and should not be diluted by the inclusion of additional elements.
- At the same time, a governance structure must be created which ensures that the funds earmarked in the European Structural and Investment Funds for the promotion of research and innovation are used by the national governments in a more goal-oriented and effective way than in the past.
- The Commission of Experts is critical of the idea of setting up an EIC on the basis of the current pilot project, since its orientation is insufficiently substantiated and its integration into the institutional structure of European R&I policy unclear.
- The Commission of Experts advocates the establishment of an agency for radical innovations. However, it is sceptical about the idea of creating a new EU institution for the purpose. The Commission of Experts therefore recommends developing an institution for the promotion of radical innovations outside EU structures.
- In view of the importance of the United Kingdom as one of the most capable R&I systems in Europe, the Commission of Experts urgently advises forging the closest links possible between the United Kingdom and the European research landscape, as is currently the case with Norway.

B 3 Autonomous systems

The potential economic and societal benefits of autonomous systems are considerable. Their use can help improve road safety, support people in work processes, make life more pleasant for the individual, and improve societal participation. Autonomous systems independently solve complex tasks with the help of software and methods of artificial intelligence (AI). They learn on the basis of data, and are thus able to act without human intervention even in unfamiliar situations. However, at present the use of autonomous systems is still in its infancy in many fields.

Germany is in a good starting position for reaping the potential added value and benefits of autonomous systems. For example, the country has an internationally competitive basis for the development of autonomous vehicles. In other areas of application, however, Germany is lagging behind the market leaders in the development of autonomous systems. Furthermore, it is becoming apparent that other countries are giving high priority to AI research and industrial policy. In addition to designing a regulatory framework, therefore, German policy-makers must step up their funding of research in the field of both autonomous systems and AI.

- The Commission of Experts recommends setting up a Bundestag Committee of Inquiry (Enquete-Kommission) on “Autonomous Systems and Artificial Intelligence” to intensively examine questions of ethics, data protection, data privacy and competition.
- The Commission of Experts calls for the development of a national strategy for AI with the aim of boosting Germany’s scientific and technological competitiveness.
- The Federal Government must ensure that companies do not use data to build barriers to market entry that will obstruct the competitive process in the long term. In this case, data must be treated by the competition authorities as essential facilities.
- The fact that funding policy has hitherto been strongly focused on current strengths of the German economy could prove to be an obstacle to the development of new areas of

application. The Commission of Experts advises incorporating all application fields of autonomous systems into the funding.

- The Commission of Experts calls on the Federal Government to actively accompany and support the process initiated by the European Commission for the creation of a European internal market for data.

CURRENT DEVELOPMENTS AND CHALLENGES

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A 1 Central guidelines for R&I policy in the new legislative period

R&I policy has shown a positive dynamic in recent years. Against the background of the delayed formation of the government, the future Federal Government should follow this up swiftly and resolutely develop German R&I policy further. In this section, the Commission of Experts formulates the main tasks to be tackled.

Make the most of the opportunities offered by digitalization

– In order to meet the challenges of the digital transformation, it makes sense to broadly promote skills in handling digital technologies in all areas of education and training (cf. chapter A 4).[1] Strengthening digital education in German schools is an urgent task. The long-planned Digital Pact for Schools (DigitalPakt Schule) should finally be launched. Tertiary education institutions across all disciplines should teach students of all subjects not only programming skills and proficiency in software and web development, but also data sciences and methods of machine learning. In this context, the new possibilities offered by Article 91b of the Basic Law should be used in a joint effort by the Federal and Länder governments to implement suitable best-practice approaches in tertiary education institutions.
– Internet and internet-based technologies require new or adapted legal frameworks, e.g. in the fields of copyright, data protection, consumer protection and competition law.[2] As far as possible, these framework conditions should be adapted at the European level. The aim should be not to protect established business models, but to facilitate access for new market participants by making innovative offers.
– Germany is not competitive when it comes to the provision of broadband services with high-performance networks faster than 50 Mbit/s.[3] In the new legislative period, the government should lay down ambitious expansion targets and press ahead with their implementation.
– At the end of the last legislative period, the amendment of Article 91c (5) of the Basic Law made it possible to pass the Law for the Improvement of Online Access to Administration Services (Online-Zugangsgesetz); this cleared the way for the establishment and operation of effective central portals for e-government and public data stocks. The aim in the new legislative period must be to actively make the most of the opportunities thus created.[4] On the one hand, the quality of services provided by public authorities for citizens and businesses should be improved. On the other hand, start-ups and other companies should be given access to public-sector data in order to open up new potential sources of value creation.

Create innovation incentives for start-ups and SMEs

– Unlike most OECD countries, Germany has not used the instrument of tax incentives for R&D activities up to now.[5] The effectiveness of tax incentives for R&D activities has been proven in numerous international studies. The promotional effects are particularly marked in the case of SMEs. The Commission of Experts therefore again advises introducing such an instrument and focusing it on SMEs. As regards the specific design of tax incentives for R&D activities, the Commission of Experts recommends a tax credit for R&D personnel expenditure that can be offset against payroll tax.
– Venture capital represents an important source of financing for young, innovative companies.[6] However, only a limited amount of such capital is available in Germany. At the end of the last legislative period, the framework conditions

for venture-capital financing were improved; in the case of publicly financed funds providing venture capital, the organizational structures were adapted and the financial resources increased.[7] The new Federal Government should continue along these lines. The focus of policy should be on creating incentives for private players to invest in venture-capital funds and start-ups.[8] Efforts should continue to design the framework conditions for institutional investors in such a way that investments in venture-capital funds financing innovative growth businesses are supported, and recognized anchor investors can emerge.

– The concerns of start-ups and young companies are not yet sufficiently taken into account in R&D funding.[9] The Commission of Experts recommends adding a research component to complement the EXIST programme in the new legislative period. Recipients of EXIST start-up grants whose companies are in the start-up phase should be enabled to finance staff that might be required for short-term research needs. In addition, there should be a reduction in the formal hurdles for the participation of young companies that are already established in the market in the specialized programmes of the BMBF, BMWi and other ministries.
– The growth of innovative start-ups is hampered by the lack of a legal form for small businesses that is valid Europe-wide.[10] The new Federal Government should campaign at the European level for the creation of a European limited liability company, and this legal form should be made attractive for foreign investors – transaction costs for holdings should be minimized.

Strengthen the science system further

– In the new legislative period, decisions will have to be made about whether the Higher Education Pact (Hochschulpakt) is to be continued and, if so, in what form.[11] The Commission of Experts is in favour of the Federal and Länder governments initiating a follow-up programme to the Higher Education Pact over several legislative periods. The Federal Government should continue to support the Länder in financing teaching and overhead costs. Not only the number of students, but also the student/faculty ratios and other quality-relevant indicators should be taken into account in the allocation of resources. However, federal support must not lead to the Länder reducing their own contributions to the funding of tertiary education institutions. Furthermore, the universities and universities of applied sciences (cf. chapter A 3) require a substantial improvement in their basic funding.
– In addition, the Commission of Experts advocates a continuation of the Pact for Research and Innovation (Pakt für Forschung und Innovation). When the research-policy goals to be implemented by the non-university research institutions are updated, there should be greater emphasis on the transfer of knowledge and technology. The research institutions should develop and consistently implement a strategy for this.

Make R&I governance more innovation-friendly

– The establishment of the High-Tech Strategy (HTS) successfully strengthened interdepartmental cooperation in the shaping of R&I policy.[12] In the Commission of Experts' view, the HTS should be extended as quickly as possible. In this context, the key challenges – such as sustainability (cf. chapter A 2) or digitalization (cf. chapter A 4) – should be identified, clear target hierarchies formulated and milestones laid down.
– The Commission of Experts advises paying greater attention to important cross-cutting issues such as autonomous systems and artificial intelligence (cf. chapter B 3). The approaches to managing the digital transformation should not relate to individual industries or technological areas, but be comprehensive.
– The Commission of Experts is in favour of setting up an agency to promote radical innovations in the new legislative period.[13] It thus endorses a proposal drawn up in the summer of 2017 within the framework of the innovation dialogue (Innovationsdialog) between representatives from science, business and civil society.[14] The Commission of Experts believes that the existing research funding structures are unsuitable for creating sufficient incentives for implementing particularly high-risk and visionary projects. In this context, the new agency for the promotion of radical innovations should have considerable freedom and be able to act in its day-to-day business with a maximum degree of independence from political control (cf. also chapter B 2 on the European discussion).

- The new Federal Government should introduce an immigration law covering labour-related migration[15] that facilitates the immigration of people who are professionally qualified but have no academic degree, as well as people who would like to complete an in-company apprenticeship in Germany.[16]
- Innovation-oriented procurement can be used as an instrument of strategic R&I policy. The Commission of Experts advocates that the new Federal Government should aim to adapt the legal framework and practice of public procurement by giving ‚priority to the more innovative offer'. The considerable volume of public procurement should be used more to promote innovation than it has in the past.[17]

Targets for the year 2025

Concrete and verifiable targets must be formulated for the further development of the R&I policy. In doing so, the Federal Government should not restrict itself to the narrow time frame of one legislative period. In this context, the Commission of Experts reiterates its proposed targets for the year 2025:[18]

- Spend 3.5 percent of GDP on R&D,
- Establish at least three German universities among the world's 30 leaders,
- Double venture capital's share of gross domestic product to 0.06 percent,
- Catch up with the five leading nations in the field of digital infrastructure,
- Double the share of funding in the field of digitalization,
- Take on a pioneering role in e-government.

Sustainability and innovation policy

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Innovation policy and the sustainability postulate

Innovations can make an important contribution to achieving the ambitious Sustainable Development Goals (SDGs).[19] The discussion on how this contribution can be maximized has led to the demand for policy guidelines for R&I policy. For example, R&I policy should take its orientation from the great societal challenges of our time and support sustainable development.[20] In the process of deciding the main topics of R&I policy, this demand has found expression in the so-called ‚new mission orientation‘: for Germany, for example, in the funding priorities of the High-Tech Strategy (HTS), at the European level in the Horizon 2020 framework research programme.

The German Advisory Council on Global Change (WBGU) recommends even more strongly „a reorientation of innovation to make it possible to develop economies and prosperity within the guard rails of the Earth system.“[21] More specifically, the WBGU proposes aligning the HTS more closely to the objectives of sustainable development.[22] The High-Tech Forum also advocates gearing the research funding programmes to ecological, economic and social needs, and linking the Federal Government‘s sustainability and innovation strategies more closely to each other.[23] To ensure this, the government is requested to involve all societal groups in the process of shaping and/or aligning R&I policy.[24]

The Commission of Experts welcomes the orientation of R&I policy towards the great societal challenges. In particular, it regards the systematic involvement of different societal groups to identify or confirm important societal challenges for R&I policy guidelines as useful. That said, R&I policy should concentrate on funding research and innovation activities that are relevant to the great societal challenges, keeping the door open to all technologies.

Sustainability as a cross-cutting policy topic

The concept of sustainable development describes a development that meets the needs of today‘s generation without restricting the possibilities of future generations.[25] This general and vague definition is usually differentiated along three dimensions that must be reconciled for sustainable development: economic development, social justice and environmental compatibility. In its 2030 Agenda, the United Nations agreed in an integrated approach on 17 sustainability goals (SDGs) with a total of 169 sub-targets, to which the Federal Government has also committed itself in a reissue of its national sustainability strategy.[26]

Because the sustainability dimensions are highly complex and heterogeneous, different policy fields are responsible for specifying individual targets in greater detail, choosing instruments to achieve these targets, and monitoring progress. For example, social policy is responsible for poverty reduction, while improving water or air quality falls in the domain of environmental policy. In view of the scarcity of resources, there are significant conflicts of objectives here in political practice.

Impacts of innovation on sustainability targets are ambivalent

Innovations are important instruments for achieving the goals of sustainable development. Technological or social innovations can make the use of scarce resources more efficient, which not only boosts prosperity and eases the pressure on the natural environment, but also allows more scope for redistribution, as desired by social policy. Even so, innovation processes can have an ambivalent impact on the various dimensions of sustainability.

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Technological or social innovations do not necessarily have only positive ecological effects, e.g. as in the use of toxic substances in photovoltaic modules.[27] Furthermore, they can cause unwanted social frictions, for example if a new or improved product leads to another one becoming obsolete as a result of ‚creative destruction', leading to employment and income losses at the individual level.

An ex-ante quantification of sustainability is also often speculative. Innovation processes are inherently uncertain. As a result, not only their direct impact but also their indirect – and in some cases unintended – effects on humans and the environment are unpredictable.[28] Undesirable concomitant effects of innovations sometimes do not become evident until much later, e.g. the use of CFCs as coolants and their impact on the ozone layer. The specific implementation and use of innovations also plays an important role.[29] For example, the carbon footprint of an electric car depends on the power sources used for charging it.[30]

Sustainability evaluation of innovation: a normative challenge

Operationalizing sustainability makes it necessary to measure, evaluate and compare sustainability goals. In the past, science has made an important contribution to defining sustainability goals more precisely and to creating suitable indicators for measuring the degree of individual target achievement. However, comprehensive sustainability evaluation remains a normative challenge, since it is not clear how conflicts of objectives should be handled when an integrative assessment of different indicators is required. The sustainability indices used in practice[31] (e.g. Ecological Footprint, Index of Sustainable Economic Welfare, Happy Planet Index) do not solve the problem. On the contrary, they are highly inconsistent and therefore involve a considerable risk of misinformation or disorientation.[32]

Economic cost-benefit analysis provides at least a theoretically consistent framework for analysing or handling conflicts of objectives.[33] Yet this does not solve the fundamental problem of evaluation either, because there are diverging views on ethical standards beyond methodological and technical quantification problems (e.g. the monetary valuation of biodiversity).[34]

Approaches to a sustainability orientation of R&I policy

Some sustainability researchers propose subjecting the effects of innovation to an ongoing prediction and reflection process with the involvement of various societal groups.[35] The aim here is to be able to anticipate and evaluate these effects as early as possible. In the meantime, this approach is being promoted at the EU level under the term ‚Responsible Research and Innovation' (RRI)[36] in the Horizon 2020 research framework programme and is also being applied already in several European countries.[37] In Germany, the BMBF is providing support – for example within the framework of the funding policy Innovation and Technology Analysis (ITA) – for research into different impacts of future developments.[38] One advantage of this participatory approach is that it does not exclude any innovation projects a priori. However, there is a risk that the scope of research might be restricted too much or too soon.

R&I policy should not be overloaded with sustainability demands

The primary objective of R&I policy is to overcome different types of market failure in the innovation process, which arise as a result of knowledge and adoption externalities. Further-reaching side-effects of innovations are not the primary responsibility of R&I policy. Rather, corresponding policy areas (e.g. social policy, environmental policy) should deal with them according to the principle of the division of labour.[39]

A strict division of labour might not always be feasible in political practice. For example, an increase in the R&D promotion of environmentally friendly innovations is often called for to offset negative environmental externalities.[40] However, innovation policy must not be overburdened by having to compensate for policy failure in other regulatory areas.

Recommendations

The Commission of Experts warns against overburdening R&I policy with the problems of a systematic sustainability evaluation. The problem of assessing – and dealing with – conflicts of objectives among the many criteria for sustainable development remain an overarching socio-political challenge. Against this background, the Commission of Experts recommends the following:

- In addition to supporting basic research, R&I policy must be able to focus on funding R&I activities that are relevant to the great societal challenges, keeping the door open to all technologies.
- Innovations can lead to conflicts with specific sustainability goals – such as environmental quality or social justice. Such conflicts of objectives should be cushioned by coordinating with other policy areas such as environmental or social policy.
- The careful involvement of different societal groups to identify or confirm important societal challenges is a useful guideline for R&I policy. The Commission of Experts proposes a further examination of the theoretical principles and practical implementation possibilities of the Responsible Research and Innovation approach.

A

A 3 Universities of applied sciences in transition

Universities of applied sciences (UASs; originally called Fachhochschulen, FHs) were established fifty years ago as an independent type of tertiary education institution. In the meantime, they are often referred to as Hochschulen für angewandte Wissenschaften (HAWs) or given names such as Technology University of Applied Sciences or School of Economics and Law.

Alongside the universities, UASs are one of the two pillars of the German higher-education system (cf. box A 3-1).[41] They have a distinct profile and have made a significant contribution to the further development of the German innovation system.

The higher-education acts of the Länder define the UASs' specific tasks primarily as application-oriented teaching and application-oriented research.[42] Furthermore, UASs open up important career opportunities for graduates of apprenticeship training. This is not only important for making vocational education and training more attractive, it also ensures close links between qualified practical skills and knowledge on the one hand, and scientific findings and methods on the other.[43]

Box A 3-1

Review of UASs over the last 50 years

The ‚Agreement between the Länder of the Federal Republic of Germany on standardization in the field of universities of applied sciences' (Abkommen der Länder der Bundesrepublik Deutschland zur Vereinheitlichung auf dem Gebiet des Fachhochschulwesens), signed in October 1968, declared engineering schools and similar institutions such as Höhere Wirtschaftsfachschulen to be institutions of tertiary education. A number of new UASs were founded, especially in the early 1970s. After Germany's reunification, UASs were also set up in the former East German states, where predecessor institutions – such as engineering schools, art colleges and universities of agriculture – were turned into UASs. Many new UASs were established in the 1990s and after the turn of the millennium in both the new and old Länder.

By 2016, there were a total of 217 state-approved general UASs[44] in Germany with a total of 960,000 students.[45] About half of the UASs were state-run.[46] The three subject areas with most graduates were law, economics and social sciences; engineering; and mathematics/natural sciences. Furthermore, specialized professions were increasingly being catered for.[47]

The task of the UASs, as stated in the above-mentioned agreement, was to provide a scientifically based education that prepares students for final state examinations and enables them to work independently in their chosen professions.

In the 1990s at the latest, the Länder extended the range of tasks of the UASs towards the fields of research and development (R&D).[48] Today, the tasks specified in all Länder higher-education acts include not only the practice-oriented training of students, but also application-oriented and practical R&D, as well as the transfer of knowledge and technology.[49]

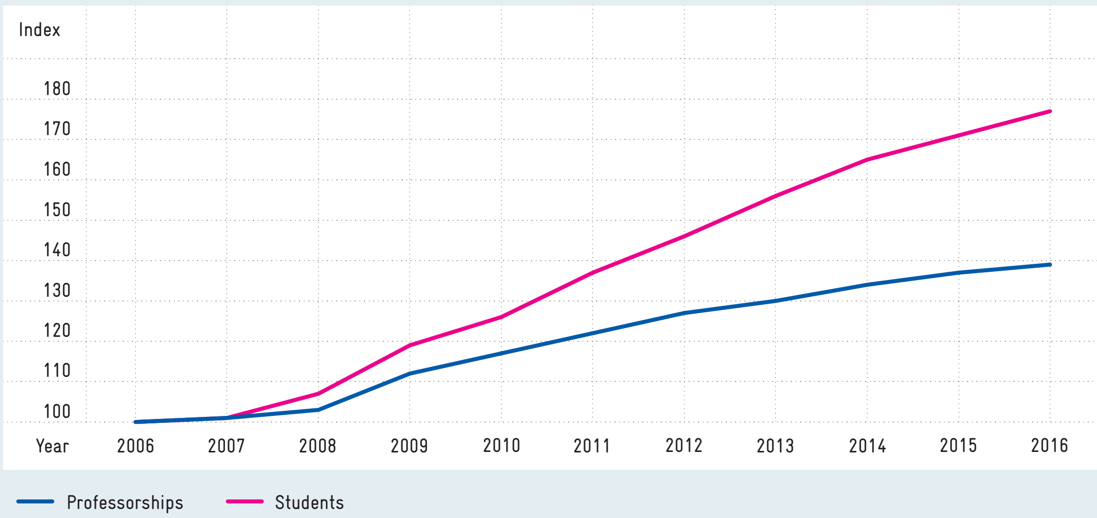
The training and qualification opportunities for students at UASs have expanded in the wake of the Bologna process initiated in the late 1990s.[50]

Fig. A 3-2

Download data

A

Development of the number of professors and the number of students at UASs



Index: 2006 = 100.
Source: own calculations on the basis of Statistisches Bundesamt (Federal Statistical Office), Fachserie 11, Reihe 4.1 and 4.4.

Current discussions revolve around the quality of teaching, potential in the field of applied research and in knowledge and technology transfer, as well as staff-recruiting difficulties at UASs. A particularly controversial debate focuses on the extent to which UASs with strong research divisions should be given the right to grant doctoral degrees.

Great importance of UASs for (regional) innovation systems

UASs play an important role in the R&I system.[51] An empirical analysis that was able to examine the causal effect of the staggered establishment of UASs in Switzerland in the 1990s, reveals an increase of up to 14 percent in the number of patent applications in the vicinity of the newly formed UASs relative to otherwise comparable regions. Furthermore, the quality of these patents – i.e. the frequency with which they were cited – also increased in the UAS regions by up to 4 percent.[52] Since students at UASs often study in the district where they acquire the higher-education entrance qualification, establishing UASs accordingly means that greater use can be made of regionally available human resources for R&I activities.[53]

A study conducted on behalf of the Commission of Experts using the microcensus surveys as its database shows that, in Germany,[54] the ratio of UAS graduates working in R&I activities is similar to the corresponding ratio of university graduates. During the study period from 2000 to 2011, approximately 24 percent of the UAS graduates were engaged in mostly R&I-related activities in their work – i.e. activities involving the „research, drafting, designing and developing of products, plans and programmes“.[55] In addition, a survey on scientific research staff showed that research-based companies were looking for UAS graduates for 46 percent of vacant scientific posts – 18 percent for people with a Bachelor‘s degree and 28 percent with a Master‘s degree.[56]

Increasing proportion of students at UASs

The UASs‘ key task in teaching is to provide training in the application of scientific findings and methods, or in artistic skills for professional practice.[57] By contrast, university teaching aims to empower the students more to generate new knowledge and develop new scientific methods. Since it can be assumed that the majority of all higher-education graduates will not engage in independent scientific activity, it seems in line with labour-market requirements if a larger percentage of students are enrolled at UASs that teach the practical application of scientific findings and methods. The increase in the percentage of students at UASs in the course of the educational expansion is plausible against this background.

The German Council of Science and Humanities (Wissenschaftsrat) notes that the above-average growth of the UAS sector during the expansion of the higher-education system is in line with its repeated recommendations, „although the expansion target – as measured in terms of demand and requirements – has evidently not been achieved yet“.[58] Against this background, the Commission of Experts advocates maintaining the increased capacity offered by UASs, or further raising the proportion of UAS students, while simultaneously reducing the proportion of students enrolled at universities, in the event of an expected demographic decline in the number of students beginning tertiary education.[59]

Teaching at UASs is characterized by smaller study groups than at universities; most teaching is carried out by professors.[60] This special feature of teaching should be maintained even if there is an increase in the number of students. However, in recent years the number of students has risen much more quickly than the number of professorships (cf. figure A 3-2). The student-faculty ratio at UASs has worsened from 39 students per professor in 2006 to 50 students per professor in 2016. Student drop-out rates have also risen at UASs in recent years – in both Bachelor‘s and Master‘s degree courses.[61]

Growing importance of applied research and the transfer of knowledge and technology

Alongside teaching, research and transfer activities are today also among the most important tasks of the UASs.[62] The amount of third-party funds raised – an indicator of research activities at UASs – has grown markedly in the last few years, although it has recently been stagnating.[63] The development of third-party funding provided by the Federal Government should be emphasized in this context (cf. also box A 3-3). At €246.2 million, it was almost five times as high in 2015 as in 2006. As a result, the Federal Government‘s share of total third-party funding raised by UASs went up from just under 25 percent in 2006 to 43 percent in 2015. The private sector‘s share declined in the same period from just under 34 percent to 22 percent. In absolute terms, however, there was also an increase here.

Most UASs have a central office that functions as a coordination and service unit for research.[64] Its job is to support professors who are active in research with setting up, applying for and implementing projects. Detailed information on the extent to which transfer services are a fixed part of the budgets of UASs was not available and could not be analysed by the Commission of Experts.

As part of the accompanying research on the programme ‚Research at universities of applied sciences‘ (Forschung an Fachhochschulen), UAS managements were asked what measures sustainably improve the framework conditions for research at UASs. This survey showed that, according to UAS managements, the intended results were most likely to be achieved by increasing basic funding for research, improving facilities for research, and reducing professors‘ teaching commitments.[65]

UAS professorships between the exigencies of practical work and science

In addition to pedagogical suitability and an ability to conduct scientific work, usually an applicant for an UAS professorship must have had several years of professional experience outside of higher education.[66] Especially in the fields of science, technology, engineering and mathematics (STEM), UASs therefore have to compete with private companies and in some cases with other public organizations in their recruitment efforts.[67] Whilst the UASs are restricted in terms of the salaries they can afford to pay, they can offer future professors a certain amount of freedom when it comes to the nature and composition of their tasks and working-time schedules, as well as opportunities for cooperation with the private sector. Recruitment problems[68] characterized by these competing priorities of scientific qualifications and professional experience must be resolved by weighing up these priorities when filling professorship vacancies. In this process, professional experience gained outside the higher-education sector – a unique selling point of UAS professors – should be regarded as the least negotiable aspect.

Box A 3-3

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Measures to promote research and the transfer of knowledge and technology at UASs

‚Research at universities of applied sciences'

On the basis of the ‚Federal/Länder agreement on the promotion of applied research and development at universities of applied sciences' dated June 2013, the BMBF is continuing the programme called ‚Research at universities of applied sciences', first introduced in 2006, in the period from 2014 to 2018.[69] According to the Federal/Länder agreement, the purpose of the programme is to "promote research at universities of applied sciences and young engineers, enabling the universities of applied sciences to sustainably develop their potential and specific profiles in applied research for the benefit of the economy, and to advance the research-oriented training of young engineers".[70] Key objectives are the advancement of knowledge and technology transfer through collaborations with partners in practical fields, and an intensified integration of teaching and research through research-oriented training in the R&D projects.[71] Within the framework of the programme, the BMBF supports applied research in the fields of engineering, the natural sciences and economics, as well as in social work, nursing and health sciences.[72]

The budget estimates for the ‚Research at universities of applied sciences' programme increased from €42 million for 2014 to €55 million for 2017.[73]

‚Innovative University'

In June 2016, on the basis of Article 91b (1) of the Basic Law, the Federal Government and the Länder signed an administrative agreement – entitled ‚Innovative University' (Innovative Hochschule) – to promote the research-based transfer of ideas, knowl-edge and technology at German tertiary education institutions. The programme is aimed primarily at UASs as well as small and medium-sized universities, enabling them to „continue the strategic development and implementation of their idea, knowledge and technology transfer profile".[74]

Funding is provided for „projects to implement the transfer strategy to enhance the profile of the tertiary education institution as a whole, or in thematic priority areas, in the transfer of ideas, knowledge and technology".[75] State-run tertiary education institutions are eligible to apply for funding; several institutions can file a joint application.[76] A total of up to €550 million has been made available for the funding initiative over ten years; 90 percent is financed by the Federal Government, 10 percent by the Länder where the institutions are located.[77] On the condition that applications of sufficiently high quality are received, at least half of the funding cases and half of the funding itself must go to UASs or to consortia coordinated by an UAS. One of two selection rounds was already carried out in 2017.[78] Predominantly UASs were selected for funding.[79]

‚Project academies'

The DFG funds project academies (Projektakademien) lasting for up to two years, whose purpose it is to enable UAS professors to launch DFG-funded research projects.[80] Applications for the establishment of a project academy can be filed by designated scientists at UASs, universities or other research institutions with experience in the acquisition of third-party funding. An application for a project academy can include up to two project-related workshops in which the participants enter into a scientific exchange and are prepared for the application to the DFG.

The coordinator issues public and national invitations to participate in the project academy. Applications can be made by UAS professors whose first appointment was no longer than six years prior to the application. They must describe and justify their research interest in the field of the project academy.[81] Building on the experience gained, the participants in a project academy can apply for funds to carry out pilot studies or initial preparatory work aimed at subsequently enabling them to apply for research-project funding according to the DFG's individual procedures.

In 2016, the German Council of Science and Humanities drew up measures aimed at getting more potential candidates interested in UAS professorships.[82] Among other things, it recommends designating more professorships as ‚special-focus professorships‘[83] with a reduced teaching load, enabling part-time professorships and shared professorships with non-university partners, and approaching potential candidates at an early stage to create a close relationship with the UAS. The German Council of Science and Humanities also proposes career-accompanying measures and support structures. These include, for example, tandem programmes,[84] preferably incorporated into cooperation platforms.[85]

In 2016, the Senate of the German Rectors‘ Conference (Hochschulrektorenkonferenz) came out in favour of launching a Federal/Länder programme to attract professors to UASs.[86] Decisions on the funding of UASs would be taken in a competitive procedure in which the individual UASs describe their strategies and detail the measures derived from them.

Opportunities for UAS graduates to study for a doctorate

All Länder higher-education laws in principal allow UAS graduates to access doctoral studies.[87] Cooperative doctoral studies – i.e. procedures in which universities and UASs cooperate but the right to grant doctoral degrees remains with the universities – are enshrined in all Länder higher-education laws in the meantime. Different models of cooperation are to be found both in the Länder higher-education laws and in practice. Furthermore, different measures have been developed to promote cooperative doctoral studies.[88] There is a consensus that cooperative doctoral studies must be further strengthened.[89]

In the last few years, there has been a controversial discussion on whether research-intensive departments at UASs should have an independent right to grant doctoral degrees.[90] Up to now, only universities have had this right. In some Länder, legislators have recently restricted this exclusivity to a certain extent;[91] however, up to now only Hesse has made use of the legal possibility to give UASs the right to grant doctoral degrees. Four doctoral centres had been approved by the end of 2017.[92] Of course, the consequences of this development cannot yet be examined and evaluated empirically.

Supporters of giving UASs an independent right to grant doctoral degrees believe this right gives the UASs an opportunity to „carry out their core tasks better in teaching, research and transfer in order to strengthen the innovative capability of society under reliable framework conditions“.[93] Critics of the proposal, by contrast, see the risk that giving UASs the right to grant doctoral degrees would lead to „a blurring of the different types of higher-education institution and their different tasks [...] and thus to a weakening of the German science system as a whole.“[94] There is also a fear that an independent right of UASs to grant doctoral degrees would have a negative effect on the quality and reputation of doctoral studies as a whole.[95] The Commission of Experts shares these concerns.

Recommendations

The Commission of Experts emphasizes that the UASs play a very important role both in the German higher-education system and in the innovation system. It recommends that both the UASs and the universities retain their distinct profiles, and that each of them continues to develop in its own specific way in line with changing requirements over time.

- The Commission of Experts believes the existing distribution of students between UASs and universities is currently not in line with labour-market requirements. The proportion of Bachelor‘s-degree students enrolled at universities is too high compared to the number of students enrolled at UASs, i.e. a larger proportion of Bachelor‘s-degree students should study at UASs in future. The UASs will need adequate staffing levels to manage this.
- UASs need better basic funding in general to enable them to perform their tasks appropriately in teaching, research and the transfer of knowledge and technology. This is primarily the responsibility of the Länder. Furthermore, the Commission of Experts again recommends that the Federal and Länder governments initiate a follow-up programme for the Higher Education Pact (Hochschulpakt), in which the Federal Government continues to support the Länder in financing university teaching, especially in the UASs.[96]
- The Commission of Experts supports the overall goal of the programmes ‚Research at universities of applied sciences‘ and ‚Innovative University‘ in order to boost the contribution

to innovation made by UASs. The Commission regards discussions on expanding or realigning the funding of application-oriented research and knowledge and technology transfer as premature at the present time.[97] The performance potential of the UASs can only be increased step by step. In the future, the UASs can also increasingly participate in the specialized programmes of the Federal Government.

– The Commission of Experts is convinced that the formal conditions for appointments to UAS professorships – i.e. combining pedagogical suitability and special skills for scientific work with experience from professional practice – should be maintained. The criterion of professional practice at UASs promotes the orientation towards applied teaching and research and offers starting points for knowledge and technology transfer.
– In order to counter current problems with the recruitment of UAS professors, appropriate measures compatible with the specific objectives of the UASs need to be taken in the field of personnel recruitment and development. The Commission of Experts is in favour of experimenting with the instruments proposed by the German Council of Science and Humanities and to systematically collect and evaluate the experience gained. It advocates launching a Federal/Länder programme to promote the creation of suitable structures for personnel recruitment and development at UASs, as well as the identification of best-practice examples.
– The Commission of Experts has repeatedly pointed out the advantages of a highly permeable two-tier education system and welcomes giving UAS graduates general access to doctoral studies. Against this background, however, it believes the solution lies not in giving the UASs the right to grant doctoral degrees, but in strengthening cooperative doctoral studies with universities. Strengthening cooperative doctoral studies simultaneously promotes interaction between the two pillars of the research system and contributes to increasing permeability in the education system. In the Commission of Experts‘ view, the right to grant doctoral degrees should therefore remain exclusively with the universities. It recommends continuously monitoring and evaluating the development of the increasing number of collaborations and the different models of cooperative doctoral studies and their funding. The Commission of Experts believes that the tried-and-tested division of labour between universities and UASs should be maintained and no further UASs should be given an independent right to grant doctoral degrees.

A

A 4 Digital education

Digital skills as a prerequisite for innovation and productivity growth

Digital technologies based on artificial intelligence, big data and cloud computing – and their associated disruptive business models – challenge Germany's previous specialization advantages (cf. chapter B 3). Examples of such business models include internet-based sharing and on-demand services like Netflix (video on demand), Spotify (music streaming) or Uber (driver-hiring service). In the course of this development, skills in software and algorithm development, or correspondingly qualified specialists, have become important prerequisites for productivity growth and innovation in both established and new industries.

Yet future demand for such specialists is only partially covered by the term IT professionals (cf. box A 4-1). One example is the occupational group of data scientists, which is rapidly establishing itself on the labour market; up to now, it has not been included in the official Classification of Occupations.[98] In the view of the Commission of Experts, therefore, a one-sided focus on IT professionals based on established definitions is not expedient in view of the developments of the internet economy.

The Commission of Experts has repeatedly urged an increase in the teaching of skills required to work with digital technologies – in short: digital education.[99] Key digital skills, i.e. all computer-, data- and IT-related skills (cf. box A 4-2), are an important basis for using digital technologies effectively. In addition, the ability to create software has meanwhile become a requirement in many professions. However, a focus on software alone is not sufficient – rather, interaction with other competences is necessary. In any case, the supply of qualified personnel needs to be increased through improved digital education

Box A 4-1

**Definitions:
IT professionals and data scientists**

An IT professional is an expert who practises a profession in IT. According to the Classification of Occupations (Klassifikation der Berufe, KldB)[100], the IT professions comprise all occupations in ‚computer science, information and communication technology'. These include the following professional groups:

- Computer science (among others: computer engineering, bioinformatics, and business, media and medical informatics); number of persons employed (2015): 192,200
- IT system analysis, IT application consulting and IT sales; number of persons employed (2015): 148,100
- IT network engineering, IT coordination, IT administration and IT organization; number of persons employed (2015): 144,500
- Software development and programming; number of persons employed (2015): 171,100[101]

Data scientists do not have a separate category in the KldB 2010. They generate information from large amounts of data and develop recommendations on ways to tap efficiency and innovation potential. The analytical tools and algorithms used are based on a fundamental knowledge of statistics and information technology, which must in turn be combined with domain-specific expertise in the respective areas of application.

Box A 4-2

A

Key digital skills

A binding definition of key digital skills does not exist. However, there is a useful definition in the ICILS (International Computer & Information Literacy Study)[102], an international comparative study of eighth-grade students. The study is based on the concept of technology-based problem-solving skills, as applied to adolescents and adults aged between 16 and 65 by the OECD's PIAAC study.[103] ICILS defines computer- and information-related skills on the basis of a functional literacy approach,[104] and describes the individual skills „that enable a person to use computers and new technologies to research, structure and communicate information, and to evaluate this information in order to successfully participate in life at home, at school, at work and in society".[105] Information-related skills are divided into two sections: Part I: Collecting and organizing information, and Part II: Generating and exchanging information.[106]

Part I: Collecting and organizing information

- Knowing how to use computers
- Accessing and evaluating information
- Processing and organizing information

Part II: Generating and exchanging information

- Converting information
- Generating information
- Communicating and exchanging information
- Using information safely

In the next survey in 2018, the ICILS will also survey skills in computational thinking as an additional option. Computational thinking is defined as a person's individual ability to identify and abstractly model a problem, dissect it into problem aspects or steps, draft and develop solution strategies, and describe them in a formalized way so that they can be understood and carried out by a human being or a computer.[107]

at schools and tertiary education institutions, in the dual vocational education system and in further training. Furthermore, digital education must enable students as early as possible to handle personal data responsibly.

High demand for skilled personnel for the digital transformation

There is a great demand for skilled personnel who can actively shape the digital transformation. The statistics on IT professionals in the narrower sense only allow a conservative estimate, since emerging professions such as data scientists have not been included in these statistics up to now. But even the figures on IT professionals in the narrower sense are unequivocal. According to a survey, 70 percent of German companies were already complaining of a growing shortage of IT professionals in late 2016. It stated that 51,000 posts for IT professionals were vacant, about 20 percent more than in the previous year and 35 percent more than the average for the previous nine years.[108] Furthermore, the number of advertised vacancies for IT professionals between August 2016 and August 2017 also rose by 20 percent.[109] According to an analysis conducted by an online job portal, one in three IT vacancies are advertised for longer than 60 days and are apparently difficult to fill.[110] The Federal Employment Agency (Bundesagentur für Arbeit) sees a shortage of skilled personnel especially in software development and IT application consulting.[111]

In a recent survey specifically among IT recruiters and HR managers from 200 companies in information and telecommunications technology, 41 percent of respondents indicated that they could not find enough candidates for vacant positions.[112] According to the survey results, the demand was especially high for web developers.

Digital education in German schools begins too late

The subject of computer science, if offered at all,[113] is not taught in Germany until the lower secondary education level. In addition, IT facilities, maintenance and internet access could be improved in many schools, despite a slightly positive trend in recent years.[114] Similarly, up to now there has been an insufficient focus on the didactical training of teachers with regard to the constantly changing content in the subject of computer science. Professional development of teachers in the use of digital media

A

in the classroom is below average by international comparison.[115]

By contrast, in the United Kingdom, for example, computing is already part of the curriculum in primary schools.[116] In 2014, it replaced ICT (Information & Communications Technology), which had been a compulsory subject for many years and focused primarily on teaching office applications (e.g. Microsoft Office applications such as Excel, Word, PowerPoint). The new subject in the UK is supported by economic actors like Google, which need technically trained young staff. Furthermore, the Royal Air Force funds programmable Lego robots, and the BBC distributes so-called micro:bit computers to schools with funding from Barclays Bank and Samsung. The UK has also promoted the use of cost-effective computer systems such as the Raspberry Pi, which can be used to make internet-capable computer systems for less than €30.[117] Educational materials for such systems are made available on open-access platforms.[118] Furthermore, competitions for pupils promote dissemination.

In Germany, on the other hand, there have hitherto only been hesitant and largely piecemeal efforts in this direction, primarily based on business initiatives. In the school subject Digital Studies, for example, primary school children learn how computers work using the ‚Calliope mini‘ micro-computer.[119] In February 2017, Saarland became the first German state where the Calliope mini is used across the board. Other Länder (Berlin, Mecklenburg-Western Pomerania and Lower Saxony) are equipping pilot schools with the devices. The Commission of Experts explicitly welcomes these efforts, but urges a significant increase in momentum. In addition, accompanying curricula must be quickly developed to help state ministries, teachers and learners.

Furthermore, micro-computers like the Calliope mini or the Raspberry Pi only represent one – albeit an important – part of the urgently necessary provision of IT equipment to schools, which also need powerful broadband internet access, special educational software, platforms and media, as well as a wide range of other internet-based services. A recent study[120] estimates that €2.8 billion per annum will be needed to provide adequate IT facilities in Germany‘s schools – which is likely to overburden Länder and municipal authorities. According to the study authors‘ estimates, even the five billion euros budgeted for the planned Digital Pact for Schools (DigitalPakt Schule)[121] (cf. p. 36) to develop digital infrastructures in schools and for the corresponding accompanying measures is far from sufficient. The Commission of Experts shares this view. It also points out that it is essential for the development of digital infrastructures in schools to go hand in hand with an increased commitment from teachers and more further training for teachers. Since the provision of qualified teachers via the regular system of teacher training or further training is very time-consuming, foreseeable bottlenecks among qualified teaching staff could be eased by recruiting more career changers.[122]

Programming skills are essential for IT training

The Commission of Experts has frequently praised Germany‘s dual system of vocational education and training. One of its most important advantages lies in the continuous adaptation of vocational content to technological change.[123] The Association of German Chambers of Industry and Commerce (Deutscher Industrie- und Handelskammertag, DIHK) last had the IT occupations[124] reviewed by the Federal Institute for Vocational Education and Training (Bundesinstitut für Berufsbildung, BIBB) in December 2016 to determine any need for modernization.[125] It suggested significantly expanding topics in the field of IT security (data security, availability, integrity and protection, including legal aspects) and incorporating more production-related content (e.g. robotics, sensor technology, 3D printing and virtualization) in the training syllabus. The BIBB also recommends reviewing and, if necessary, changing the IT occupational designations to make the profiles more attractive for female trainees.[126] New requirements in the fields of machine learning and artificial intelligence have not yet been taken up.

The fact that the content taught in vocational schools does not match operational requirements very well was regarded as potentially problematic. In a representative survey, only about 15 percent of trainees in IT occupations rated the vocational school content as good to very good in terms of how well it matched operational requirements.[127]

In the Commission of Experts‘ assessment, it is particularly important for both teachers and learners to develop programming and system skills at an early stage and in ways that are open to all technologies. Furthermore, further training – an area that is less well developed than initial training in Germany – is becoming more important.

In addition, a review is needed to determine which digital competences will be needed in all professions, not only in IT occupations, in the future. These skills must be integrated into the curricula as soon as possible. When drafting the curricula, it is particularly important to take into account the experience of companies that are technological leaders in the respective fields.[128]

Growing importance of computer science at tertiary education institutions

In the 2015/2016 academic year, almost 69,000 students enrolled in subjects relating to computer science (first-semester students, excluding teacher training).[129] This number corresponds to a 7 percent increase compared to the previous year. The percentage of women among the first-year students has been rising gradually, but continuously, since 2007. After 17 percent in 2007, it amounted to about 25 percent in 2015 – in the Commission of Experts' view a positive, but not yet sufficient development.[130] 51 percent of computer-science graduates took their examinations at universities of applied sciences, 49 percent at universities.

Apart from computer science itself, study subjects relating to computer science also include subjects that were introduced for the purpose of generating interaction between other disciplines with IT content. These subjects include, for example, business informatics, bioinformatics, computational engineering (often also referred to as computer engineering), as well as media informatics and medical informatics. About half of the graduates in the 2015/2016 academic year studied computer science without such a focus, almost a third specialized in business informatics. Media informatics came a distant third in terms of the number of graduates (making up 9 percent).

The relative importance of the subjects can be determined by dividing the number of first-year students in the respective subject by the number of all first-year students. The share of computer-science students rose from just under 2.9 percent in 2006 to 3.9 percent in 2016.[131] The share of business informatics also grew – from 1.4 to 2.1 percent.[132]

However, a general increase in the importance of IT content in other subjects cannot be extrapolated from the growing importance of study subjects relating to computer science. The Commission of Experts knows of examples of study subjects at German universities of excellence with no – not even subject-related – basic teaching in the use of software applications, databases or algorithm development. Unfortunately, there are no reliable statistics on this issue.

Examples of good practice can be found at the universities of Berkeley and Zurich. The University of California, Berkeley, offers students of all subjects a course in Foundations of Data Science, which is one of the prerequisites or compulsory courses in many departments. It familiarizes students with concepts of computer-aided calculation and statistics. No relevant prior knowledge is required for participation.[133] At the University of Zurich, the study courses in economics and computer science are being redesigned, so that they now leave room for a subsidiary subject. The range of subsidiary subjects comprises a selection of IT-related subjects for all non-computer-science students, such as computational sciences, data sciences and computer science for economists. Furthermore, a wide range of application-oriented subsidiary subjects are now available for computer-science students, e.g. in natural sciences and humanities.[134]

New further training opportunities in IT

In its 2015 report, the Commission of Experts drew attention to the increasing importance of further-training opportunities for a successful digital transformation.[135] Numerous public platforms – such as Coursera, Udacity, edX or iVersity – offer a constantly growing number of so-called MOOCs. Furthermore, microdegrees are increasingly being offered, which enable people to specifically update their knowledge; they build upon combinations of online courses and online examinations.

At the same time, private providers such as the US company Galvanize are increasingly specializing in establishing strongly application-oriented IT further-training courses – such as web development and data science – as quasi-standards in close consultation with both IT start-ups and established companies. The certificate courses, which take just a few weeks to complete, meet the economy's growing demand for continuous further training of employees in the latest digital skills. The course contents are continually being adapted to needs, and in many cases are directly based on companies' specific problems. In addition, special strategy courses on the value-creation potential of digitalization address the management level.

The Commission of Experts expressly welcomes new providers and forms of further training, especially since the need for further-training courses in IT seems to exceed supply. A survey among HR managers notes a marked discrepancy between the digital skills which respondents consider important to extremely important and current training opportunities.[136] German tertiary education institutions have not been particularly active in this segment to date.

Very few computer specialists in leadership positions

In large German companies, there are hardly any computer specialists in executive positions. According to a recent survey conducted by the Commission of Experts, in 100 German prime standard companies[137] with a total of 448 management board members, only 23 of the directors (5.1 percent) had completed a study programme or apprenticeship training in IT. Only one in five companies have any directors with an IT background at all.[138] In view of these figures, there are concerns that the digital transformation is still too rarely given top priority in German businesses. The question also arises of whether the required expertise is available at management levels in public institutions and administrations.

Federal measures in digital education could be expanded

Against the background of the problems in digital education mentioned above, the following section describes the measures taken by the Federal Government to overcome these deficits.[139]

From 2016 to 2019, in its umbrella initiative on vocational training (Berufsbildung 4.0), the BMBF is funding, among other things, inter-company vocational training facilities (IVTFs) and centres of competence by procuring digital equipment and drawing up new training concepts. The purpose of IVTFs is to complement training in companies and vocational schools by providing practical courses in digital skills.[140] The BMBF has budgeted approximately €84 million for this measure. In addition, a funding programme called ‚Digital Media in Vocational Education and Training‘ aims to support projects that try out new teaching and learning formats for media-based qualifications and to develop workable solutions for learning with digital media in an occupational context.[141] This includes, for example, learning with the help of mobile technologies such as smartphones or tablets, and improving the media skills of trainees and the training staff. Approximately €152 million, including co-financing from the European Social Fund (ESF), has been budgeted between 2012 and 2019.[142]

Further measures within the Berufsbildung 4.0 umbrella initiative include JOBSTARTER plus, which aims to support SMEs in continuing to develop their further training,[143] as well as a project called ‚Skilled labour qualifications and competencies for the digitalized workplace of tomorrow‘, which examines quantitative and qualitative effects of digitalization on qualification requirements.[144]

The Digital Pact for Schools proposed – but not yet implemented – by the BMBF plans to supply all schools (primary, secondary and vocational schools) with broadband connections and WLAN coverage, and to install internal data infrastructures and servers within the next five years.[145]

The School Cloud project, which is run in cooperation with the Hasso Plattner Institute and the ‚Excellence network of schools specializing in mathematics and the natural sciences‘ (Nationales Excellence-Netzwerk von Schulen mit Sekundarstufe II und ausgeprägtem Profil in Mathematik, Informatik, Naturwissenschaften und Technik, MINT-EC), aims to provide students and teachers with easy access to learning and teaching material.[146] To promote pupils‘ interest in computer science, the BMBF also launched the Youth Computer Science Competition in May 2017.[147]

The Commission of Experts welcomes the initiatives launched to date. The Digital Pact for Schools must urgently be given a sufficient funding framework and become a fixed part of the new Federal Government‘s programme.

Recommendations

The Commission of Experts welcomes the fact that the Federal Government expressly recognizes key digital skills as a qualification requirement in an increasingly digital world.[148] However, it still sees a considerable need for action and recommends the following measures by the Federal Government and the Länder to expand digital education:

- Key digital skills should already be taught in primary schools nationwide. Teachers in schools need not only excellent IT facilities, but also ongoing further training in order to lay the foundations for the digital knowledge-based society. The Digital Pact for Schools must therefore urgently be given a sufficient funding framework and become a fixed part of the new Federal Government's programme. In order to mitigate the foreseeable shortage of qualified teaching staff and accelerate development, the recruitment of career changers should be expedited. The provision of qualified teaching staff via the regular system of teacher education alone would take too long.
- In the dual system of vocational education and training, the range of courses offered in IT, especially in programming, as well as software and web development, should be significantly expanded across all occupations. In addition, IT skills should become a fixed part of all vocational training programmes.
- Tertiary education institutions should teach programming skills and knowledge of software and web development, as well as data sciences and methods of machine learning – also across all disciplines. In this context, the new possibilities offered by Article 91b of the Basic Law should be used in a joint effort by the Federal and Länder governments to implement suitable best-practice approaches in tertiary education institutions.
- Against the background of rapidly changing qualification requirements in IT, it is essential to expand the possibilities for further education (lifelong learning). In the Commission of Experts' view, novel training opportunities from the private sector are also required. They should be appropriately accompanied by R&I policy and continually evaluated with regard to their effects and significance for the education system.
- To be able to promote digital skills, they must be continuously monitored. The Commission of Experts therefore expressly welcomes Germany's participation in international comparison studies like ICILS or PIAAC to measure the key digital skills of both pupils and adults. Furthermore, the Federal Government should encourage the content-related further development of such studies.

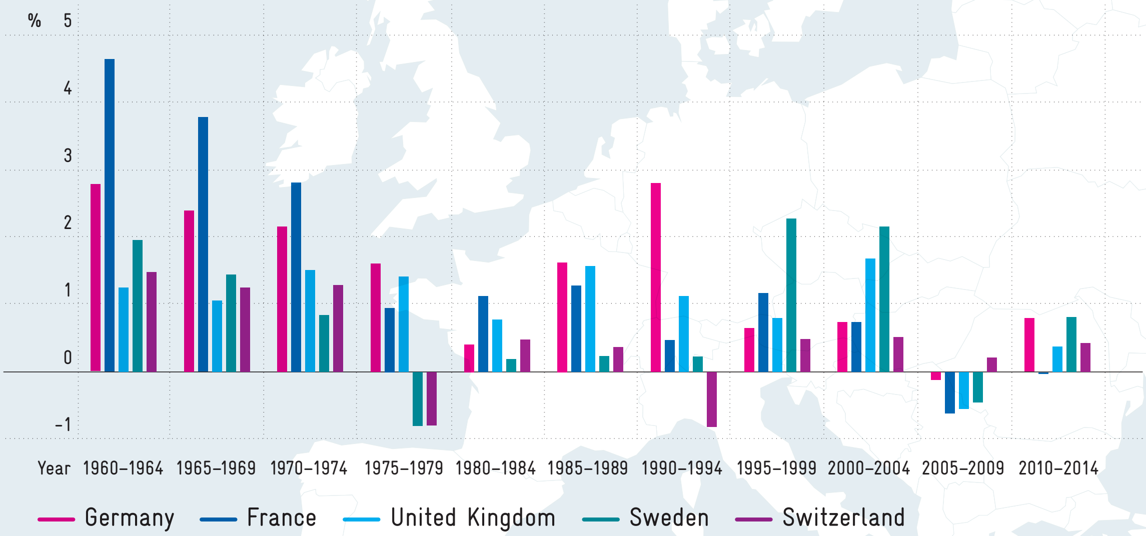
CORE TOPICS 2018

B

B 1 Long-term developments of productivity and innovation

The pace of growth of macroeconomic productivity indicators has slowed in many developed economies. Parallel to this, some indicators, e.g. the innovator rate, suggest a decline or focusing in innovation activities.

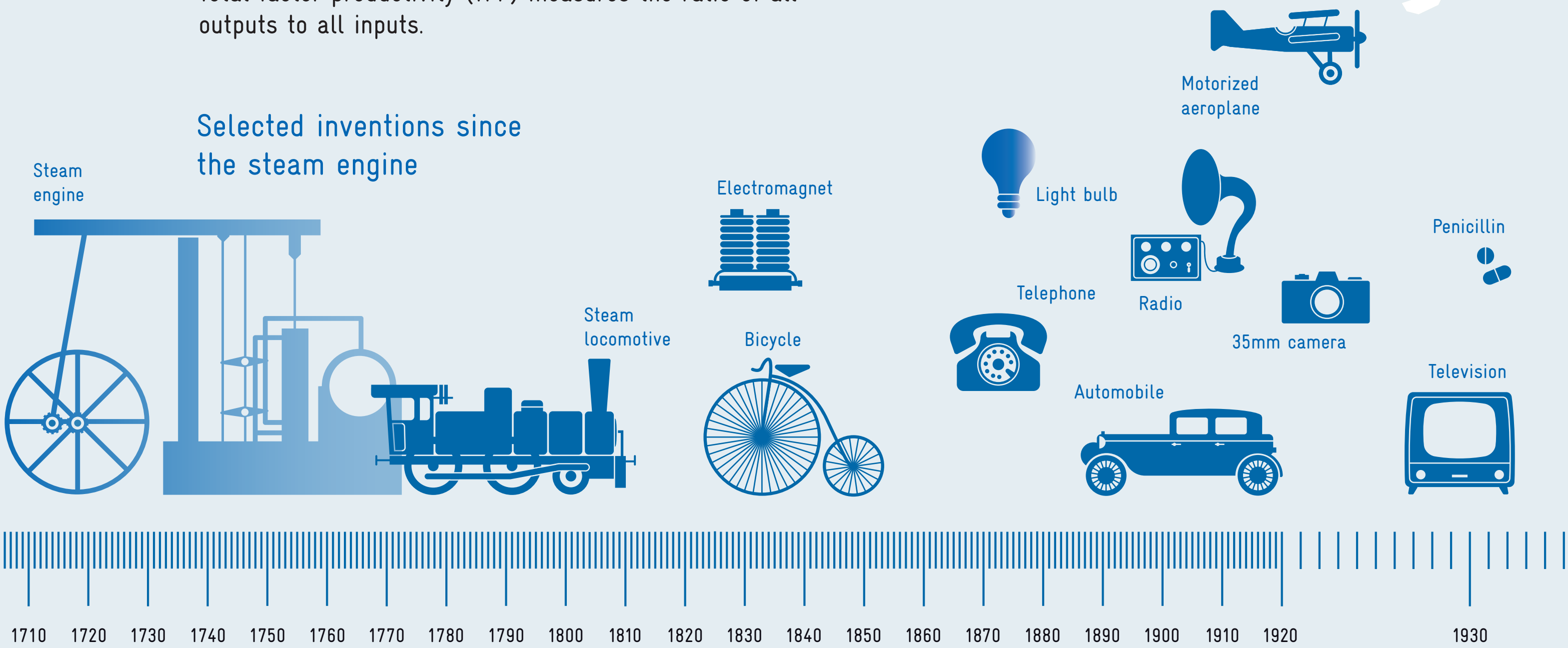
International comparison of TFP growth rates as percentages



Productivity

Total factor productivity (TFP) measures the ratio of all outputs to all inputs.

Selected inventions since the steam engine

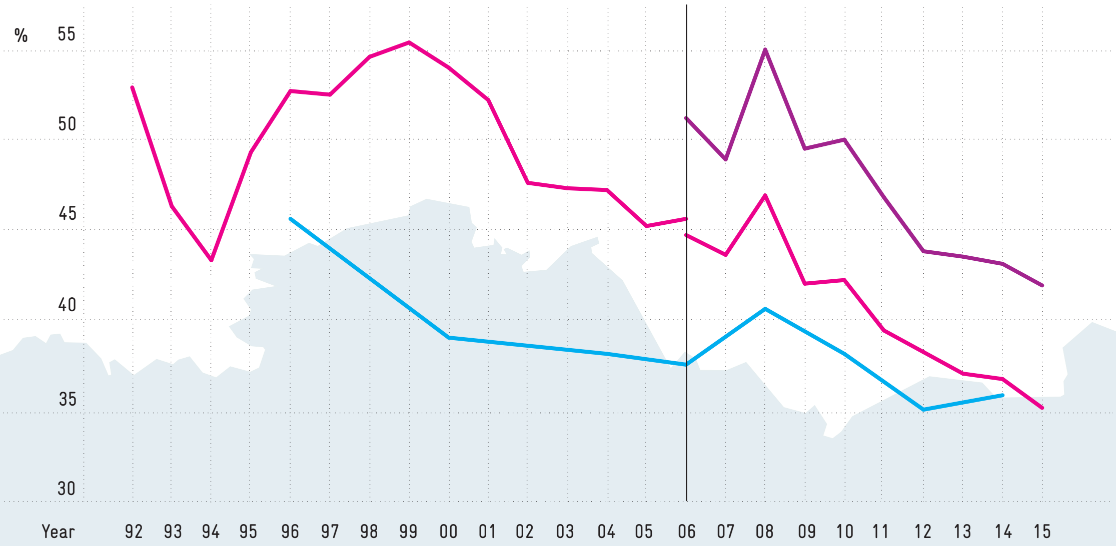


Source: Penn World Table 9.0. Cf. Peters et al. (2018). Own calculations.

Innovator rate

The innovator rate is the percentage of companies that have introduced at least one product or process innovation within a three-year reference period.

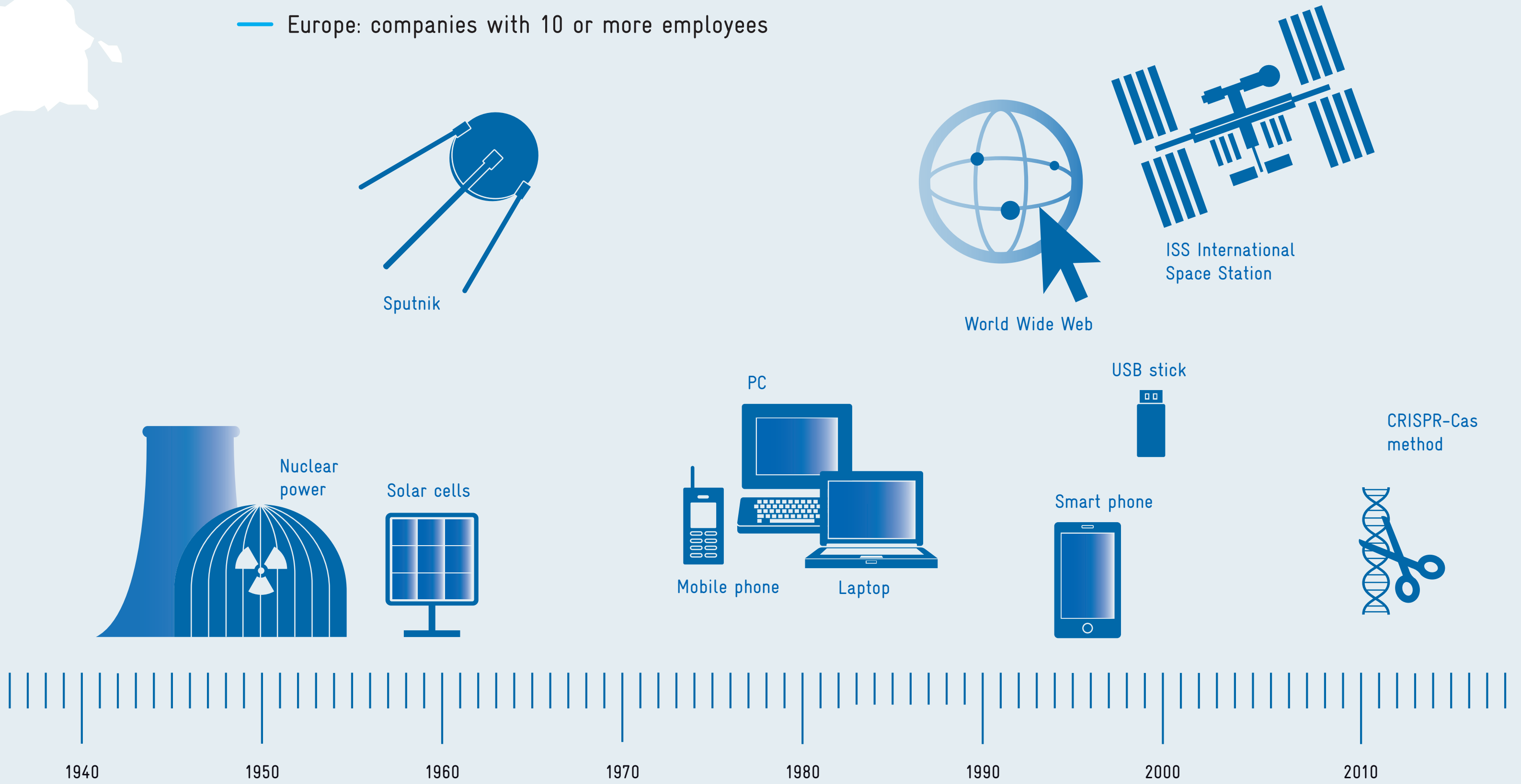
Development of the innovator rate in Germany and Europe as percentages



Germany: companies with 5 or more employees
2006: break in the time series following a change in the WZ reference base.

Germany: companies with 10 or more employees

Europe: companies with 10 or more employees



Source: Mannheim Innovation Panel and Eurostat, Community Innovation Surveys.
Calculations by ZEW (Centre for European Economic Research).

B 1 Long-term developments of productivity and innovation

B

B 1-1 Introduction

An economy's productivity is an important determinant of the development of its income and prosperity. In general terms, productivity measures the ratio of all outputs (goods and services) to inputs (factors of production) – for example, how much work is required in a year to produce a certain amount of goods. Productivity and prosperity have grown worldwide almost continuously since the Industrial Revolution. However, it has been observed for several decades, and especially since the mid-1990s, that this growth has slowed down.[149] This observation seems surprising in view of the advancing digitalization and networking of the global economy and the productivity gains this is expected to generate. It is discussed under the term 'productivity growth slowdown' and is regarded as a cause for concern by many.

The growth of overall economic productivity is highly dependent on innovation. Process innovations reduce production costs by making more efficient use of input factors, while product innovations raise the quality of the output or lead to entirely new products and services.[150]

Some indicators suggest that an innovation slowdown is also taking place in Germany and most other European industrial countries[151] parallel to the decline in productivity growth. In this chapter, the Commission of Experts discusses possible causes of these phenomena. It comes to the conclusion that the observed decline in the innovator rate could be interpreted as a concentration of innovation activities among a shrinking proportion of economic actors. Alongside other reasons, the resulting less broad-based generation and use of innovations could have led to a lower rate of productivity growth.

Slowdown in productivity growth as a worldwide phenomenon B 1-2

The prosperity of a society is often measured in a simplified fashion on the basis of its economic performance. Weak productivity growth in the economy as a whole, let alone an ongoing slowdown in productivity growth, is seen as a threat to rising prosperity.

The productivity of a country, industry or company can be measured in different ways.[152] The concept of Total Factor Productivity (TFP) has become established as the most important statistical tool for measuring it. Box B 1-1 explains technical details of TFP and its changes as a measure of the contributions that innovation makes to growth.

Figure B 1-2 illustrates the development of TFP from 1960 to 2014 in five-year averages in China, France, Germany, Japan, South Korea, Sweden, Switzerland, the United Kingdom and the USA. Over this long period, a trend towards a slowdown in productivity growth can be observed in many of the economies examined – for example in France, Switzerland and Sweden. In some countries, an intermediate increase in TFP growth up until around 2004 was followed by a renewed decline in growth – especially in the USA,[153] the United Kingdom and Japan. This decline in TFP growth has also been measurable in China in recent years.

Figure B 1-2 also shows the development of TFP[154] in Germany from 1960 to 2014 in five-year averages.[155] Here, a negative trend in TFP development since 1960 emerges over the long term. The annual growth rate of TFP fell from an average of 2.8 percent in the period from 1960 to 1964 to an average of 0.8 percent between 2010 and 2014. The effects of German Reunification[156] are clearly visible, as is the financial and economic crisis of 2007/2008.

Box B 1-1

Total Factor Productivity (TFP)

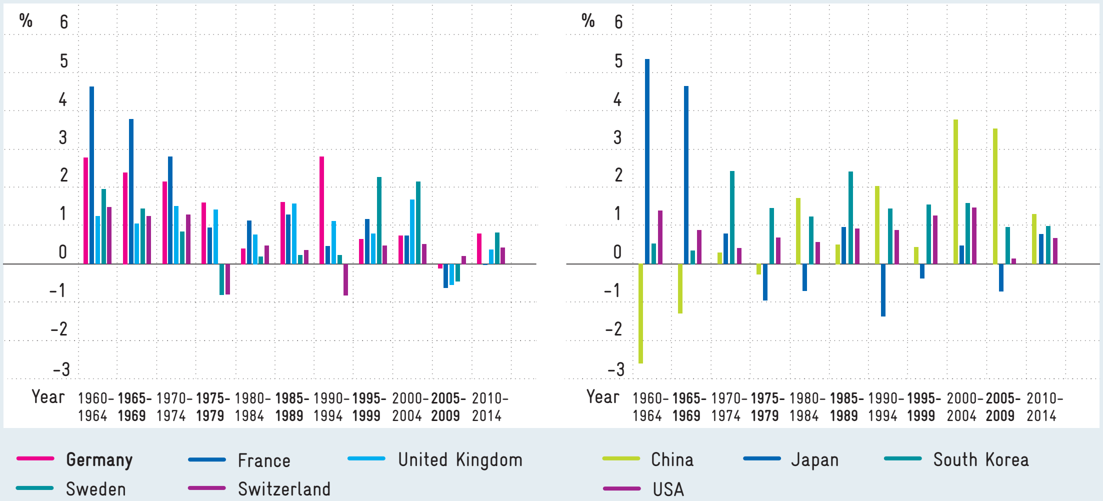
Total Factor Productivity is the most widespread measure of productivity; it relates overall economic output to a weighted combination of input factors (especially labour input, physical and intangible production capital, and energy).[157] The growth rates of the outputs and inputs are observed in order to determine the TFP growth rate. TFP growth in the observed economy is calculated from the difference between these growth rates.[158] Accordingly, TFP growth measures the part of output growth that cannot be directly explained by the use of the known input factors: in other words the unexplained part that is 'left over'.[159]

TFP growth can be an indication of a more efficient use of input factors and is often used as a measure of technical progress.[160] TFP is frequently interpreted as a further input and associated with an economy's knowledge base, which, like other input factors, changes over time. Labour productivity or other partial productivities – where total output is compared to a single input factor – are often used as additional measures of productivity. However, they only partially depict the production process, so that their informative content is significantly inferior to TFP.

Fig. B 1-2

Download data

International comparison of annual TFP growth rates as percentages



Total factor productivity (TFP) measures the ratio of all outputs to all inputs.
Shown as five-year averages.
Source: Penn World Table 9.0. Cf. Peters et al. (2018). Own calculations.

Disaggregated sectoral observations can provide further insights into productivity development. In view of the possibility that delays in the diffusion of IC technologies might be one reason for declining TFP growth, the recent development of ICT-intensive and ICT-producing industries in Germany is of particular interest. Box B 1-3 traces productivity growth in these industries between 1991 and 2013.

Innovation and productivity B 1–3

Innovation is an important determinant of productivity growth.[161] The evolution over time of such indicators as start-up rates, innovator rates, research productivities and patent developments is therefore of particular interest for R&I policy.

Box B 1-3

Download data

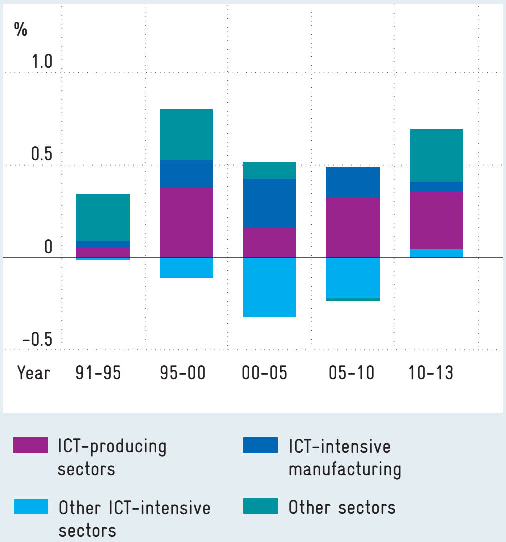
B

Productivity growth in ICT-using and ICT-producing sectors of the economy

A recent study takes a separate look at the contributions made to TFP growth in Germany by ICT-producing, ICT-intensive and other industries since 1991 (i.e. after Reunification).[162] Industries are considered ICT-intensive if they use a relatively large amount of ICT capital, but do not produce ICT themselves. The figure shows the average annual TFP growth contributions over five periods between 1991 and 2013.

The ICT-producing industries in Germany were thus responsible for about half of total TFP growth since 2005, although they only contributed less than 5 percent of the economy's gross value added. By contrast, TFP growth was recently weak in the ICT-intensive industries (manufacturing and the other ICT-intensive industries) – and their contributions to growth were even negative between 2000 and 2010. This difference in the productivity change between producers and users of ICT suggests a delay in the diffusion of new IC technologies.

Average annual TFP growth contributions in Germany as percentage points



Source: BEA and ifo. Presentation based on Elstner et al. (2016: 7).

Start-up rates and innovator rates declining

The start-up rate, i.e. the number of start-up businesses as a percentage of the total number of companies, is low in Germany by international comparison.[163] Furthermore, start-up rates in the knowledge-based economy[164] have been declining for years.[165] Figure C 5-2 (p. 109) illustrates this development. This is a cause for concern since innovative products, processes and business models are frequently developed and implemented especially in new companies. Moreover, start-ups secure the creation of jobs by generating local value added.

The innovator rate is defined as the number of companies with product and process innovations as a percentage of all companies.[166] Since the early 1990s, the so-called Oslo Manual published by the OECD and Eurostat has provided a conceptual framework – and the Community Innovation Surveys (CIS) an empirical basis – for comparing innovator rates internationally.[167] Marketing and organizational innovations are not taken into account; this is not a problem since new digital business models, for example, are usually reported as product innovations and not as marketing and organizational innovations.[168]

The development of the innovator rate in Germany since 1992 on the basis of national statistics (i.e. in companies with five employees or more and including additional service industries) has been characterized by an almost continuous decline – from just under 56 percent in 1999 to 35 percent in 2015 (cf. figure B 1-4).[169] The trend is the same for the period from 2006 to 2015 according to the CIS definition (companies with ten employees or more, fewer service industries) at an innovator rate that is about 6 to 8 percentage points higher.

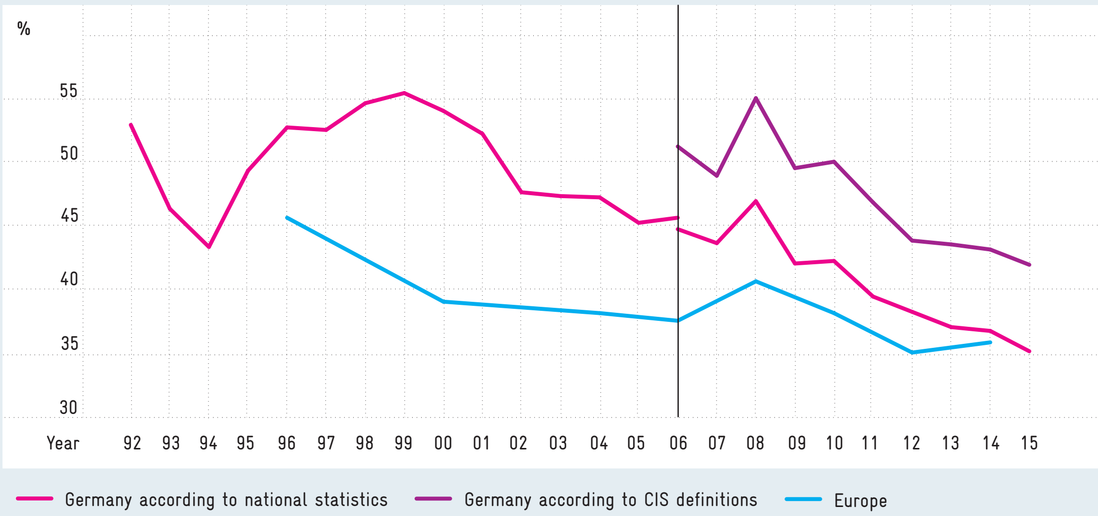
The trend towards declining innovator rates can be observed in the majority of EU countries examined by the CIS (cf. figure B 1-4). For example, the innovator rate fell from 46 percent in 1996 to 36 percent in 2014 in the European countries for which figures have been available since the second CIS survey (reference period 1992 to 1996)[170] – in the sectors included in the CIS (manufacturing, wholesale trade, transport, financial services, IT services, engineering offices).[171]

The decline in the innovator rate could be interpreted as innovation activity focusing on a decreasing percentage of companies. This development might

Fig. B 1-4

Download data

Development of the innovator rate in Germany and Europe as percentages



Reference basis according to national statistics: 1992–2006: divisions 10–37, 51, 60–64, 65–67, 72–74, 90 of 2003 WZ classification; 2006–2015: divisions 5–39, 46, 49–53, 58–66, 69–74, 78–82 of 2008 WZ classification. Companies with five or more employees. 2006: break in time series. Reference basis according to CIS definitions: divisions 5–39, 46, 49–53, 58–66, 71–73 of 2008 WZ classification. Companies with 10 or more employees. The data for Europe relate to the following countries: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, United Kingdom.
Sources: Mannheim Innovation Panel and Eurostat, Community Innovation Surveys. Calculations by ZEW (Centre for European Economic Research).

– but need not necessarily – involve a decline in the absolute number of innovations.

Development of research productivity and patent intensity not unequivocal

Another indicator that is currently the subject of much discussion is known as research productivity. It relates TFP growth to the number of researchers who provoke the growth via their knowledge production.

A recent study in the USA suggests a marked decline in research productivity of about 5 percent per annum.[172] One important criticism of the study looks at the way it measures research input, in particular the effective number of researchers in the years before 1960, when there was no uniform definition of R&D activities.[173] Another point of criticism is the measurement of research output: the growth rate of TFP is used as a measure of the number of new ideas.[174] This indicator is subject to a whole series of influencing factors, such as the quality of the traditional input factors – labour and capital – that are used. If this quality improves over time, there will be a decline in TFP, its growth and thus also the level of research productivity that is measured.[175] Another problem with this approach is that TFP growth alone is related to the research input. Other variables that can also influence the level of TFP growth are not taken into account, nor is their influence controlled for.[176]

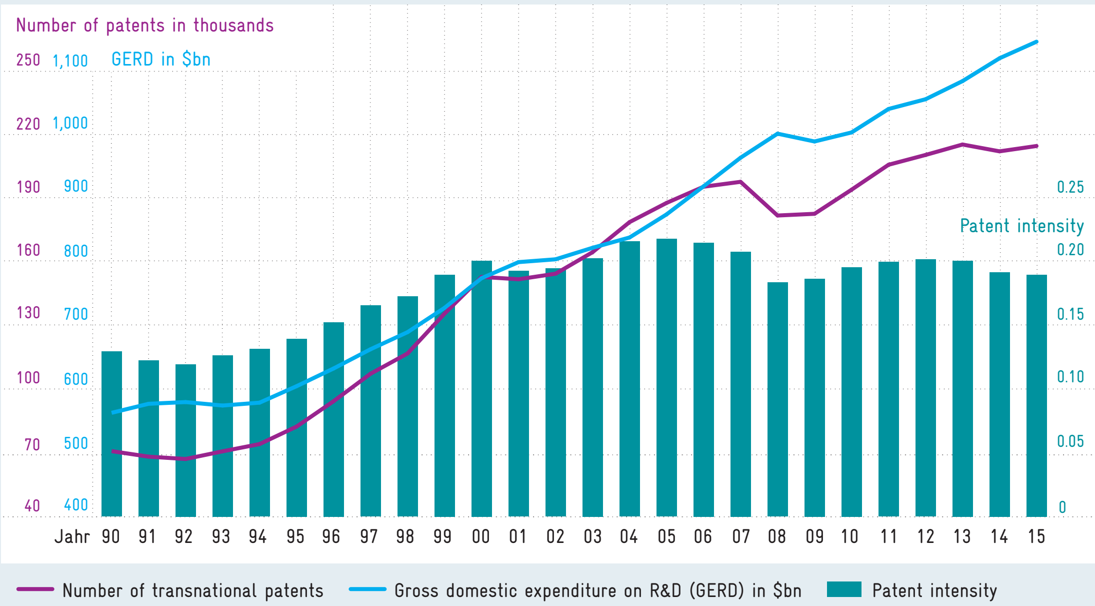
However, patents can also be used as a direct measure of new ideas. They are an important indicator of the potential exploitation of new ideas on the market. Transnational patent applications[177] have been stagnating both in Germany and in other major European economies since the international financial and economic crisis (cf. figure C 6-1). By contrast, particularly China, Japan and the USA have seen high rates of growth in patent applications, as shown in figure C 6-1 (left).

Average patent intensity – measured here as the ratio of transnational patent applications to GERD (Gross Domestic Expenditure on Research and Development, which is also an indicator of research productivity) – has declined slightly in the OECD countries since 2005.[178] Figure B 1-5 shows that the number of patent applications has been stagnating since then, while R&D expenditures continue to grow.

Fig. B1-5

Download data

Development of patent intensity in the OECD



GERD: Gross Domestic Expenditure on Research and Development.
GERD in $bn: constant prices and purchasing-power parity.
Transnational patents: fractional counting.
Sources: OECD, Main Science and Technology Indicators, and EPO, PATSTAT. Calculations by Fraunhofer ISI.

Various factors may have played a role here. One possible cause might be an increase in technological complexity, with the result that more effort would be required to achieve patentable research results. Economic structural change – moving towards sectors that are more R&D-intensive and towards fewer patentable innovations – could also have contributed to the decline in patent intensity.

The Commission of Experts believes that the development of patent applications and patent intensity offers little evidence of a marked decline in the generation of new ideas or, as a result, in innovation activity. The falling innovator rate is therefore more likely to be a result of innovation activities becoming concentrated among fewer and fewer actors.

B 1-4 Possible causes of slower productivity growth

In the following, the Commission of Experts discusses possible causes of the phenomena described.[179]

Measurement problems in the context of digitalization

Identifying a declining productivity growth rate initially depends decisively on correct measurements of macroeconomic growth and productivity. It is often argued that certain measurement problems have increased in the course of digitalization.[180] Box B 1-6 looks into this assertion. In the Commission of Experts' assessment, however, the decline in productivity growth is not due solely to measurement problems. Although declines in growth are distinctly lower when the estimates are adjusted for any measurement errors, there is always a statistically and economically significant amount left over.

Delayed diffusion – the view of the 'technology optimists'

There is no doubt that developed economies are currently experiencing a phase of intense technological dynamics – especially with regard to the digital transformation. Seen from this angle, the observed slowdown in productivity growth is an astonishing phenomenon at first sight. New technologies such as artificial intelligence should hold great potential for innovation, and this should also be reflected in higher productivity.[181] The situation is therefore sometimes referred to as the productivity paradox or the productivity puzzle.[182]

Some studies argue in this context that the slowdown in productivity growth is most likely to be a temporary phenomenon.[183] It is claimed that particularly the use of digital technologies in production is still in its infancy, but could generate far-reaching development leaps and associated productivity gains in the future (cf. box B 1-1). The fact that future productivity gains are still outstanding could be due to various factors acting as obstacles to adoption:[184]

1. Lack of complementary human capital: There are indications that a lack of IT skills among employees can lead to IT systems and IT applications being introduced less frequently or used less intensively.[185] At the same time, recent analyses show that a considerable proportion of the workforce who have to use ICT applications in their work do not have the ICT skills needed to apply these technologies effectively.[186] In addition, there is a consensus in the literature that knowledge and skills complementary to ICT, such as problem-solving skills, have become more important.[187]

   However, there are no conclusive findings on whether a lack of IT skills can explain the slowdown in productivity growth (at least in certain countries).[188] A lack of IT skills in companies can arise from recruitment problems or a lack of further-training activities. The Commission of Experts addresses these two topics in its chapter A 4 on Digital Education.

2. Other lacking input factors that have a complementary effect: A lack of investment in the necessary infrastructure or complementary inputs could be an obvious reason for a slowdown in productivity growth.[189] The digital transformation depends to a large extent on the availability of a powerful broadband infrastructure in order to ensure the use of large-volume data-based IT services. Against this background, the Commission of Experts has repeatedly urged a forward-looking expansion of the infrastructure and called for ambitious targets.[190]

   A lack of absorptive capacity is closely linked to a lack of complementary inputs (e.g. because of outdated methods and (IT) tools). When well-established work processes in the economy need to be adapted and geared to new technological opportunities, requiring a lot of effort, companies often face high adoption costs. In this context, various studies have focused specifically on organizational learning processes and the importance of absorptive capacity in companies.[191] Accordingly, the productivity impact of external knowledge, for example, is all the greater, the more the company performs its own R&D, thus building up absorptive capacity.[192]

3. Regulatory barriers: Finally, political and institutional framework conditions also exert an influence on productivity growth. The Commission of Experts recently called for the creation of a future-oriented legal framework for the digital economy.[193] Internet-based technologies require new or adapted legal norms, e.g. in the fields of copyright, data protection and consumer protection.

The argument of delayed diffusion and underlying adoption barriers finds support in a current study conducted on behalf of the OECD.[194] It explores the evolution over time of global productivity indicators, differentiated according to companies with varying degrees of technological development. It finds that productivity is growing in companies close to the technological frontier (frontier companies), while the gap between them and already less productive enterprises (laggard companies) continues to grow.[195] According to the study, this structure primarily reflects technological progress and its diffusion in general, but is also closely linked to the observation of growing market power (see the section on the role of growing market concentration in productivity growth and innovation).

The Commission of Experts regards delayed diffusion as an important reason for the observed decline in productivity growth.

Depleted technological potential – the view of the 'technology pessimists'

Several studies argue that the low level of productivity growth, coupled with a simultaneous high level of expenditure on research, is an indication of decreasing or depleting technological potential

B

Box B 1-6

Measurement problems in the context of digitalization

Measuring changes in growth and productivity in the context of the national accounts (NA) is problematic (cf. box B 1-1). Measurement problems, which can be conceptual or empirical, can occur when collecting data on these variables.

From the conceptual point of view, for example, covering many of the technologies that have diffused quickly in the last decade (smart phones, social networks, digital media services, etc.) is problematic. This is because, although consumers spend a lot of time using them, this hardly causes them any further monetary costs. If not only the direct expenditure on the acquisition and use of these products is taken into account, but also the time spent using them, they seem to generate substantially more benefit than is expressed by their price. Indicators such as gross domestic product (GDP) cannot adequately measure this 'consumer surplus' even conceptually – a known weakness of NA. Discussions on whether GDP can be a suitable measure of welfare in an economy have therefore gained additional momentum in the course of digitalization.[196]

From the empirical point of view, data collection in the NA context becomes increasingly difficult in information- and knowledge-based economies, especially with regard to determining real GDP on the basis of price adjustments (so-called deflation). For several years, chain indices have been used in this context in accordance with international conventions and binding European regulations[197] using an annually changing price basis (previous year's price basis).[198] The deflation of ICT inputs and outputs in the service sector proves to be particularly problematic, since the price indices must also take quality improvements into account. This is often very difficult, since digitalization leads to an acceleration of both product and service innovations,[199] and substitution effects occur. This can have the consequence that, due to insufficient price deflators, growth and productivity changes are not properly recorded, especially in the case of digital products and services, leading to corresponding distortions.

These conceptual and empirical measurement problems might increase over time with the increasing diffusion of ICT. However, recent studies have come to the conclusion that the recent decline in productivity growth is not only due to measurement problems in the context of digitalization.[200] Although the majority of studies focus on productivity development in the USA, there is also evidence to suggest that declining productivity growth can be found simultaneously in at least two dozen other developed economies.[201] In this context, the respective extent to which productivity development is slowing within these countries is evidently not linked to the relative size of the local ICT industry and does not depend on whether ICT intensity is measured via consumption or production.

Various adjustments of GDP growth to take into account the effects of a distorted measurement of digital goods and products suggest that, if measurement errors were exclusively responsible for the slower productivity growth, and if its cause lay in ICT industries, then the real turnover of these industries should have been five times higher.[202] The productivity of labour in these industries would have had to increase by more than 360 percent in eleven years. Changing the conceptual approach – e.g. making the purchase and use of an internet connection a possible metric of the gains generated by new digital technologies – shows that this adjustment is not sufficient to offset the reduction in economic growth caused by the slowdown in productivity growth.[203] Even the largest (and most unrealistic) estimate – which generously prices-in the time that people spend online – would only account for a third of the supposedly underestimated growth.

('low-hanging fruits have already been picked') and thus of decreasing research productivity.[204]

Depleting technological potential could, on the one hand, only be used by companies at increasing expense; on the other, it would also generate smaller increases in productivity. Both of these could lead to falling long-term gains from innovations and to companies withdrawing from innovation activities. However, it was already argued in section B 1-3 that little empirical evidence can be found of depleted technological potential, as measured by a decrease in the number of new ideas (via patents).

Accordingly, the Commission of Experts attaches little importance to the argument that technological potential is becoming depleted on a broad front. In order to safeguard against potentials becoming depleted, one could consider strengthening basic research and emphasizing the transfer of knowledge and findings from basic research (in terms of spillover effects).[205]

The role of increasing market concentration in productivity growth and innovation

So-called markups, i.e. the margin a company can add to its marginal costs of production, are a measure of market concentration and market power. The more market power a company has, the larger these markups can be. A recent study conducted in the USA[206] argues that markups have risen continuously since about 1980. According to the authors, no decline in productivity growth would be measurable if growing market power were taken into account when calculating growth throughout the economy.

Innovations are a possible explanation of market power and its changes. If they are protected by a patent, then the resulting (temporary) market power is an important positive incentive for innovative activity. Furthermore, technological complexity that is growing as a result of innovations may make it easier for companies to secure their market position and their competitive edge even without patents – especially because it becomes increasingly cost-intensive for potential competitors to catch up technologically. In the same way, an increase in so-called strategic patenting[207] makes it possible to build high barriers to market entry vis-à-vis potential competitors.

Market-concentration processes are typical of mature markets and industries.[208] Accordingly, fewer (innovative) start-ups or other innovation-driven market entries will be observed here. In the course of this development, innovative activity becomes concentrated on fewer and fewer companies. In addition, in line with industry and technology life-cycle theory,[209] there is a tendency among the established companies to hold back more and more in the field of product and process innovations.

A phenomenon that is currently the subject of intense discussion is the rapidly growing market concentration that can be caused by 'superstar effects'[210] in younger industries and markets. Technology leaders or first movers can gain very high market shares for themselves ('winner-takes-it-all') as a result of network effects, which are particularly common in digital markets.[211] Here, too, there is a trend towards a concentration of innovation activities on a few companies and an associated creation of entry barriers to markets and technologies. The existence of market concentration due to network externalities can also increase the incentive for company founders to seek a quick sale of their company to market leaders, rather than relying on the growth of their own company.

Another reason for the growing market concentration may also be that suitable competitive framework conditions have not been created in time and undesirable developments of increasing concentration have not been sufficiently counteracted.

The Commission of Experts also regards the growing market concentration as an indication of the concentration of innovation activities on the one hand, and a reason for a declining start-up rate on the other.

Assessments B 1–5

The Commission of Experts has come to the assessment that the decline of productivity growth that can be observed in Germany and many other OECD countries cannot be attributed to a single cause. Rather, this development has been induced by several of the effects described in this chapter.

If, on the one hand, there are not yet any applications for radical innovations and, on the other hand, new technologies only diffuse slowly due to their complexity or a lack of complementary inputs

– above all skilled employees – this is reflected negatively in productivity figures. The recent wave of digital transformation has not contributed to productivity growth to the expected extent either. However, the Commission of Experts points out that also in past cases of radical innovations, the productivity development measured at the time did not lead to good forecasts of future developments.[212] In this sense, the currently observed phenomena should be assessed cautiously by political decision-makers. Even so, action should be taken against delayed diffusion, particularly in the field of digital technologies.

The Commission of Experts is fundamentally optimistic that there is no need to fear a general depletion of technological potential. Rather, established companies in mature industries are often slow to make the transition to new technologies, even if it could result in more favourable growth developments in the long term. The example of alternative drive technologies in the automotive industry illustrates how difficult business decision-makers, who are generally used to acting relatively quickly, find it to accept a far-reaching technological change – especially when industry-specific productivity indicators are positive, yet contrary to overall economic trends.[213]

Ongoing market concentration in different industries and the concentration of innovation activities among fewer and fewer actors suggest that established companies are successfully building entry barriers based on increasingly complex technologies. The resulting uncertainty about the competitiveness and profitability of new firms could be one reason for declining start-up and innovator rates. R&I policy should focus its attention on the entry barriers and innovation obstacles that are responsible for this, especially those standing in the way of radical innovations. As a first step, innovation-inhibiting regulations should be reduced and market access made easier for new players.

B 1-6 Recommendations

Ensuring long-term productivity growth requires the use of radical innovations and, in particular, their rapid diffusion. Due to its power to design the regulatory environment, the Federal Government has important influence here, which it should use. The Commission of Experts considers the following aspects essential:

- Basic research is an important source of radical innovations and should be strengthened. It should not be neglected in favour of applied research, even when the latter promises short-term contributions to innovation and growth. The key prerequisite for innovative effects is the transfer of knowledge and findings from basic research to economic application. In its last report, the Commission of Experts made detailed recommendations on both of these fields, i.e. on the science system and on transfer.[214]
- Innovations can only have a broad impact on productivity if they find widespread application. It is therefore important to take appropriate measures to support the diffusion of radical innovations and their follow-on innovations. This currently applies in particular to the digital transformation, which is yet to be universally implemented (cf. chapter B 3).
- The regulatory environment must ensure that economic actors can make agile use of new technological opportunities, and generate and market radical innovations. This requires a suitable regulatory framework, e.g. in competition law, to give new actors barrier-free market access and prevent the emergence of dominant companies; such conditions are also needed in the financial sector to support the founding and growth of innovative young companies.
- The empirical and methodological problems of measuring growth, productivity and innovation complicate the ongoing assessment of the R&I system and the development of appropriate policy measures. The Commission of Experts expressly welcomes the 'Research project for the further development of sets of indicators for research and innovation' launched by the Federal Ministry of Education and Research (BMBF).[215] It recommends drafting concrete metrics to improve ways of measuring the development of growth, productivity and innovation with the involvement of the relevant actors (Federal Statistical Office, Bundesbank, etc.).

B 2 Challenges of European R&I policy

Download data

European R&I policy uses various programmes and instruments to finance and organize research and innovation activities. In addition to funding excellence in research, European R&I policy aims to overcome development deficits in weaker regions.

B

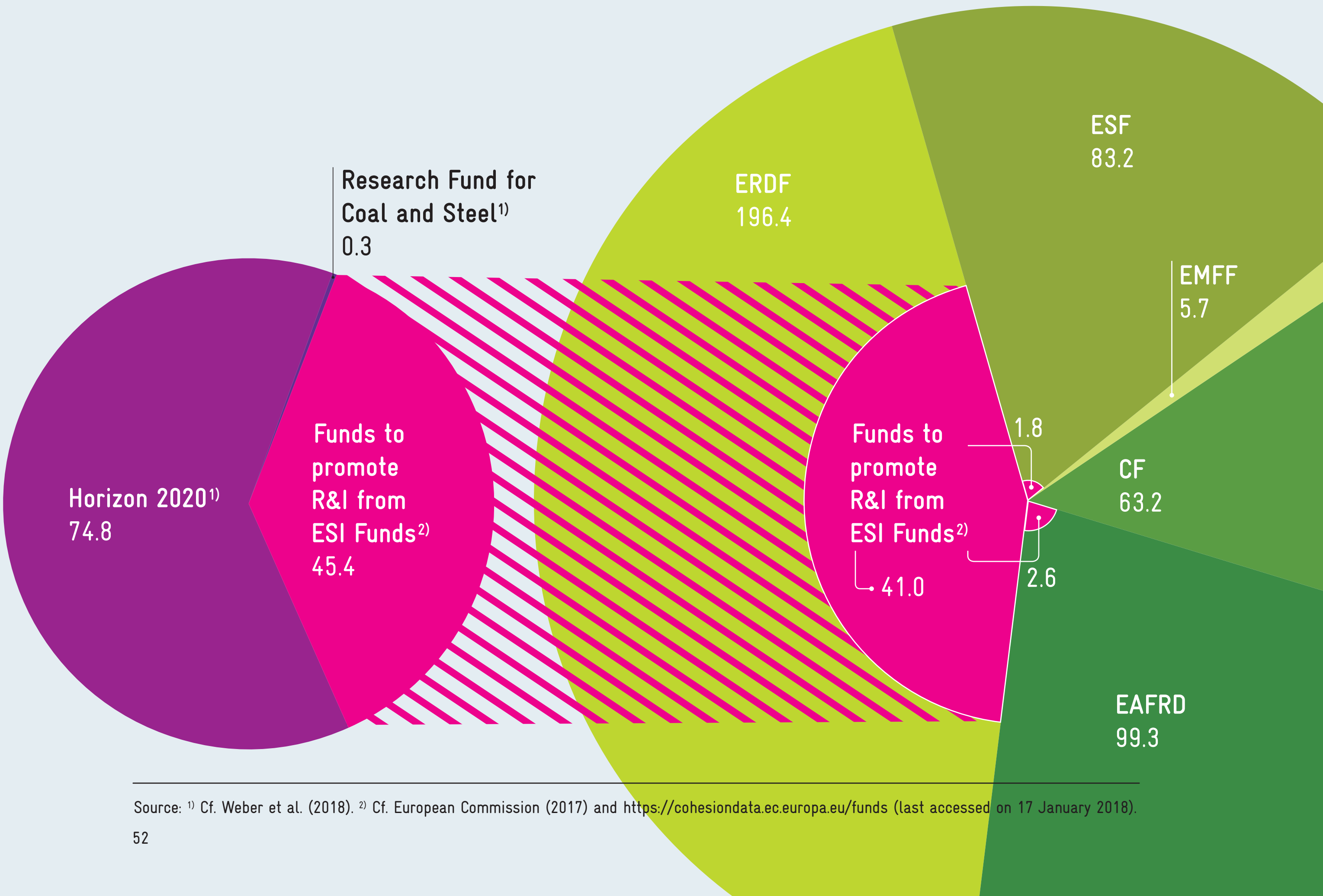
European Commission funds to promote research and innovation 2014–2020 in €bn

R&I programmes of the European Commission €120.5bn

- Horizon 2020: 8th EU Framework Programme for Research and Innovation
- RFCS: Research Fund for Coal and Steel
- Funds to promote R&I from ESI Funds

European Structural and Investment Funds (ESI Funds) €447.8bn (including €45.4bn for R&I)

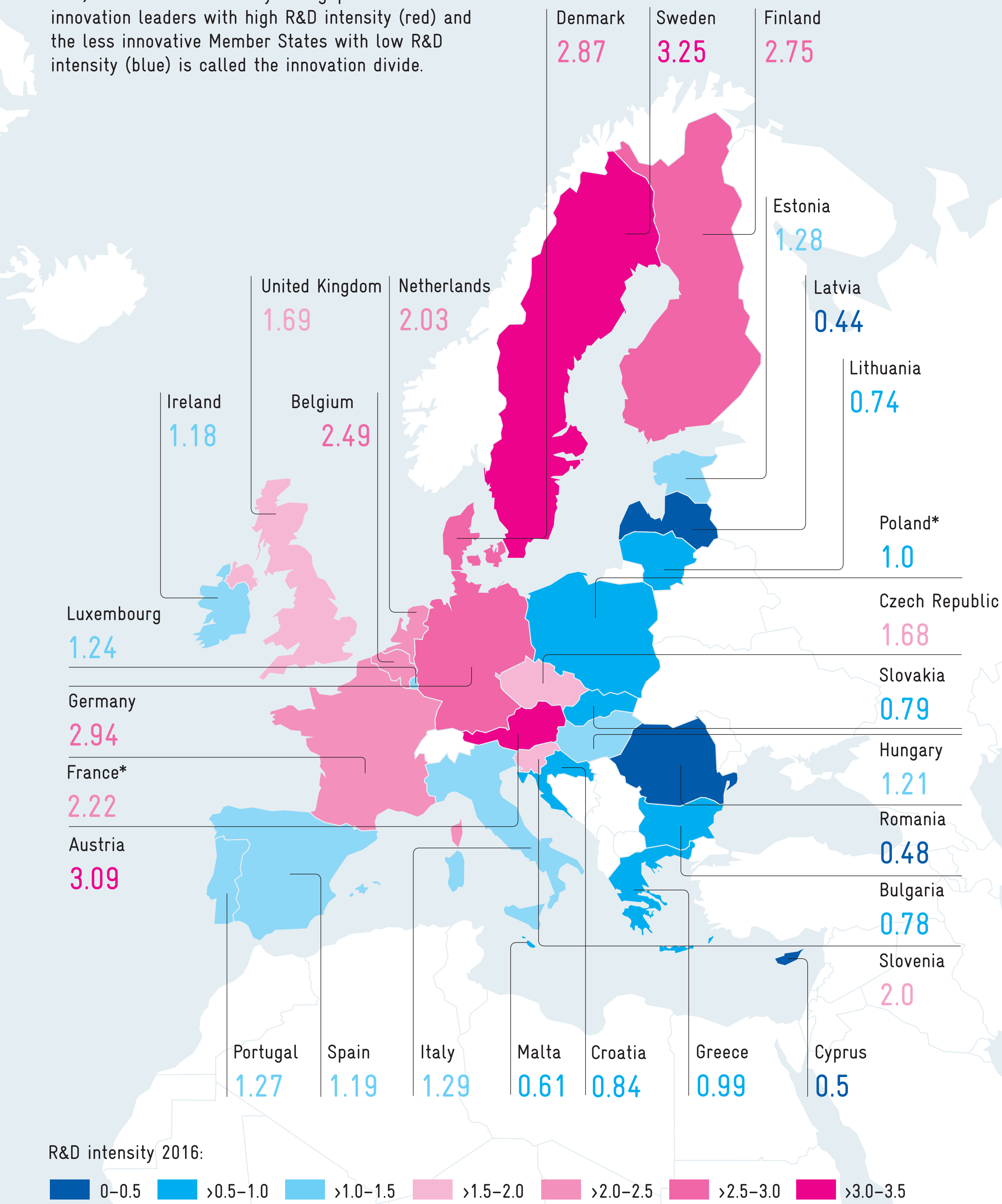
- ERDF: European Regional Development Fund
- ESF: European Social Fund
- EMFF: European Maritime and Fisheries Fund
- CF: Cohesion Fund
- EAFRD: European Agricultural Fund for Rural Development



Source: [1) Cf. Weber et al. (2018). [2) Cf. European Commission (2017) and https://cohesiondata.ec.europa.eu/funds (last accessed on 17 January 2018).

R&D intensity of the EU Member States

The innovation performance of Member States of the European Union – as shown by the R&D intensity indicator (= R&D expenditure as a percentage of GDP) – varies considerably. The gap between the innovation leaders with high R&D intensity (red) and the less innovative Member States with low R&D intensity (blue) is called the innovation divide.



* 2015 figure

Source: OECD (2018).

B 2 Challenges of European R&I policy

B 2-1 Introduction

Global competition for knowledge and innovation has intensified in the past decades. The European Union (EU) has responded to this challenge inter alia with the Lisbon Declaration (2000), in which it formulated the intention of making Europe the most competitive and dynamic knowledge-based economy in the world.[216] In order to reach this highly ambitious goal, the EU Commission and the EU Member States decided to coordinate their science, research and innovation policies more strongly than before and in this way create a European Research Area (ERA). The ERA aims to interconnect the national research systems and make them more effective, to ensure an open labour market for researchers, and to improve the exchange and transfer of scientific findings.[217]

The EU can point to successes in its R&I policy in the meantime. For example, in 2007 the European Research Council (ERC) was created – an important European institution to support excellent research projects. The cross-border and intersectoral mobility of researchers has also been strengthened, e.g. by the Marie Skłodowska-Curie actions (since 2007). In addition, the European satellite navigation system Galileo was launched in 2016, after overcoming numerous hurdles.[218]

Despite these successes, the list of challenges remains long. The further development of European R&I policy is an extremely complex undertaking. Against this background, the Commission of Experts concentrates its analysis on four areas of European R&I policy:

– the structures of European R&I policy, focusing on the 8th Framework Programme for Research and Innovation (Horizon 2020) and the European Structural and Investment Funds (ESI Funds),
– the funding of German companies by European programmes (particularly Horizon 2020),
– the establishment of a European Innovation Council (EIC), and
– the planned withdrawal of the United Kingdom from the EU (Brexit).

B 2-2 Key programmes of European R&I policy

The need for a European R&I policy – alongside national R&I policies – is justified by the creation of European added value. This added value arises structurally from cross-border and transdisciplinary cooperation, as well as from exchanging and sharing knowledge and infrastructure.[219]

Furthermore, referring to the great societal challenges in the regulation establishing its current Framework Programme for Research and Innovation, Horizon 2020, the EU points out that Member States individually will not be able to address these challenges. One form of the added value of European R&I policy therefore also lies in jointly meeting these challenges.[220]

European R&I funding comprises a large number of programmes which are administered by different EU Directorates General. There are also further programmes that are organized multilaterally and sometimes include non-EU states in addition to the EU and the Member States. These structures are complex, fragmented and very difficult to coordinate.

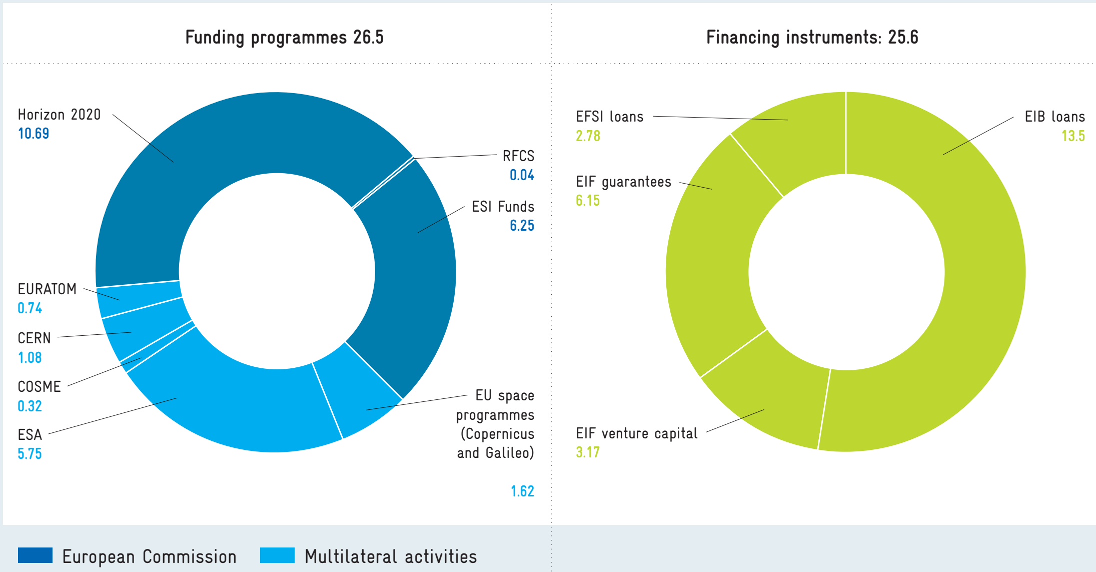
Furthermore, the financial means from the ESI Funds are provided by the EU, but are administrated at the national level. This involves a risk that the funds might not be used in line with the original targets.

Figure B 2-1 provides an overview of European R&I funding.[221] The EU's most important R&I funding programmes are the 8th Framework Programme for

Fig. B 2-1

Download data

Assignment of funds in important programmes of European research and innovation policy in €bn per annum



Funding programmes:

Horizon 2020: 8th EU Framework Programme for Research and Innovation

RFCS: Research Fund for Coal and Steel

ESI Funds: European Structural and Investment Funds

EU space programmes: Copernicus and Galileo

ESA: European Space Agency

COSME: Programme for the Competitiveness of Enterprises and for SMEs

CERN: European Organization for Nuclear Research

EURATOM: European Atomic Energy Community

Financial instruments:

EIB: European Investment Bank

EIF: European Investment Fund

EFSI: European Fund for Strategic Investment

For further information on the funding programmes and financing instruments, cf. endnote 221.
Source: diagram based on Weber et al. (2018: 14).

Research and Innovation, Horizon 2020, and the ESI Funds; both programmes run from 2014 to 2020. In addition to the EU's R&I funding programmes, there are other multilaterally organized R&I programmes as well as financing instruments for R&I activities, such as loans, guarantees and risk capital. The financing volume of the funding programmes described is about €26.5 billion per annum. An additional €25.6 billion per annum is made available via the R&I financing instruments.

The current discussion on the structure and objectives of European R&I policy focuses primarily on two issues. One is strengthening the transfer of knowledge and findings from research to economic application – an issue that already made it onto the agenda of the Lisbon Strategy during the discussion on the European Paradox (cf. box B 2-2) but has not yet been satisfactorily solved by the various framework programmes. The other is concern about an uneven development of R&I activities among the EU Member States – a problem that is discussed as the innovation divide (cf. box B 2-3) and for which R&I policy solutions are being discussed.

Strengthening the innovation aspect in Horizon 2020

The goals of Horizon 2020 are to build up an EU-wide knowledge and innovation-based society, strengthen Europe's scientific and technological base, and promote its benefits for society. The idea is thus for Horizon 2020 to contribute to the implementation

Box B 2-2

The European Paradox

In 1995, an EU document stated for the first time that Europe was weaker than the USA in the transfer of knowledge and findings, despite its relatively strong scientific performance.[222] This hypothesis is referred to as the European Paradox. The weaker transfer of knowledge and findings is regarded as the main reason for Europe's weaker innovation performance compared to the USA. More recent studies indicate, however, that Europe might also be behind the US in terms of science.

To this extent, there are doubts as to whether Europe's performance in innovation will catch up with the US in the foreseeable future.[223]

Box B 2-3

The innovation divide between the EU Member States

The R&I performance of the EU's Member States is very unevenly distributed. For example, there is a large gap between the innovation leaders in Northern and Central Europe and the less innovative Member States in Southern and Eastern Europe; this gap is referred to in the literature as the innovation divide.[224]

Within Horizon 2020, the programme entitled Spreading Excellence and Widening Participation in particular is intended to help close the innovation divide. The aim of the programme is to broaden the excellence base in the field of R&I and to expand participation – especially by the less innovative Member States – in excellence-oriented European R&I programmes. The excellence and innovation potential of the EU will, it is hoped, be released and promoted on a broader level with the help of partnership measures (cf. endnote 236).[225]

Another aim is that this promotion will also generate synergies with the ESI Funds (cf. p. 58) by coordinating the measures with the priorities encouraged under the EU's Cohesion Policy.[226]

of the Europe 2020 strategy for smart, sustainable and inclusive growth, as well as to the realization of the ERA.[227]

While the previous Framework Programmes were geared exclusively towards funding research activities, Horizon 2020 explicitly for the first time aims to integrate programmes to fund innovation.[228] Facilitating the transfer of outstanding research findings into successful innovations is the intention behind this extension, and it will principally benefit SMEs. One idea is to award 20 percent of all funds disbursed by Horizon 2020 to SMEs.[229]

In terms of content and structure, Horizon 2020 is divided in three pillars: Excellent Science, Industrial Leadership, and Societal Challenges (cf. table B 2-4); each of these focal areas is made up of different subprogrammes.[230] The first pillar, Excellent Science, primarily aims to fund science-driven basic research, better networking and increased mobility for researchers, and easier access to research infrastructures. This pillar includes the European Research Council (ERC)[231] and the Marie Skłodowska-Curie actions,[232] among others. The second pillar, Industrial Leadership, emphasizes the transfer dimension and comprises programmes for promoting industrial and key technologies.[233] This pillar for the first time also contains programmes to simplify access to venture-capital funding,[234] and includes an instrument to fund innovation in SMEs.[235] The third pillar, Societal Challenges, funds projects that can contribute to tackling major societal challenges, such as climate change or sustainable mobility.

In addition to the pillars, Horizon 2020 includes four additional cross-cutting areas (cf. table B 2-4). The Spreading Excellence and Widening Participation programme element aims to take suitable measures[236] to close the gap between the EU Member States in terms of innovative capacity (cf. box 2-3). The cross-cutting area Science with and for Society aims to improve the level of acceptance for science in society. The Joint Research Centre (JRC) acts as the European Commission's scientific service. Its remit includes compiling scientific studies in support of EU policies. The European Institute of Innovation and Technology (EIT), which was taken over into Horizon 2020 in 2014, aims to contribute to an increase in innovative capacity in the EU Member States by integrating all areas of the knowledge triangle consisting of education, research and innovation (cf. p. 60).[237]

Tab. B 2-4

Download data

Comparison of grants between the 7th Research Framework Programme (FP7) and Horizon 2020 in €m

Programme areas	FP7 2007-2013[1]	Horizon 2020 2014-2020	Percentage change from FP7 to Horizon 2020
Pillars			
I. Excellent Science	13,975	24,232	73%
II. Industrial Leadership	15,291	16,467	8%
III. Societal Challenges	18,458	28,630	55%
Cross-cutting areas			
Spreading Excellence and Widening Participation	716	817	14%
Science with and for Society	330	445	35%
Joint Research Centre (JRC)	1,751	1,856	6%
European Institute of Innovation and Technology (EIT)[2]		2,383	

[1] Since the structural realignment, several areas of the FP7 cannot be compared with areas in Horizon 2020.
[2] EIT is not part of the FP7.
Source: Weber et al. (2018).

In addition to a wide variety of different funding areas, Horizon 2020 also includes several different forms of funding such as research and innovation measures, coordination measures, co-financing measures and partnerships.[238]

Horizon 2020's total budget amounts to €74.8 billion.[239] This represents an increase of 34 percent compared to the budget of the 7th Research Framework Programme (FP7) of €55.8 billion.[240] Horizon 2020's share of the entire EU budget for the period from 2014 to 2020 is 7.3 percent.[241] The strong increase in funds is, on the one hand, the result of the integration of different programmes;[242] on the other hand, some parts of Horizon 2020 are significantly better funded than under FP7.[243] Table B 2-4 documents the budgetary development from FP7 to Horizon 2020. It shows that there were marked increases in the budgets of the pillars Excellent Science and Societal Challenges compared to FP7.[244] Funding for the Industrial Leadership pillar, by contrast, rose at a below-average rate of only 8 percent. In order to estimate the growth of the transfer of knowledge and findings dimension between FP7 and Horizon 2020, this 8 percent needs to be increased by the transfer elements that are contained in Societal Challenges, but are not clearly quantifiable, as well as the increase resulting from the integration of the EIT.

The growing importance of the ESI Funds in R&I funding

Next to Horizon 2020, the ESI Funds[245] with their resources for funding R&I are the financially strongest instruments of European R&I policy.[246] Their primary objective of overcoming development deficits in weaker regions was extended among other things by the aspect of funding research, technological development and innovation in 2007.[247] The current EU regulation on the ESI Funds passed in 2013 lists strengthening research, technological development and innovation as their main thematic goal.[248] The ESI Funds consist of five funds, three of which include resources for promoting R&I activities (ERDF, EAFRD, ESF). The overall budget of the funds for the period from 2014 to 2020 amounts to about €448 billion, approximately one tenth of which (€45 billion) is earmarked for R&I activities.

Within the framework of European Cohesion Policy, the R&I measures of the ESI Funds are supposed to help build up or enhance R&I infrastructures and R&I capacity in the less innovative EU Member States. The aim of the funding is to close the existing innovation divide between EU Member States where innovation is strong and the less innovative states, and to place the ERA on a broader basis.[249]

The European Regional Development Fund (ERDF) has a central role to play with a funding volume of about €41 billion for R&I activities.[250] The ERDF's investment priorities lie in strengthening research, technological development and innovation. By supporting the development of R&I infrastructures and promoting the enhancement of capacity for the development of top-level achievements, the ERDF aims to help reduce the innovation divide between the EU Member States.[251]

A further €2.6 billion is being made available for R&I activities by the European Agricultural Fund for Rural Development (EAFRD).[252] In addition, €1.8 billion has been earmarked by the European Social Fund (ESF) for the intensification of human capital in R&I.[253]

B 2-3 EU funding of German actors

With Horizon 2020, the EU has extended its research funding and now promotes both research and innovation. In this context, much more emphasis is now attached to the topics of transfer and SMEs. The following subsection analyses the importance of European funding for German companies compared to national funding.

Funding by Horizon 2020 important for German companies

Horizon 2020 grants funding amounting to approximately €317 million per annum to German companies. By contrast, the Federal Government's Specialized Programme disburses about €750 million per annum. In addition, the internal R&D activities of companies are funded to the tune of approximately €280 million per annum via the Central Innovation Programme for SMEs (ZIM).[254] Further support comes from the Länder and other sources outside the Federal Government's Specialized Programmes.

The funding provided by Horizon 2020 only makes up a small part of the public funding that is made available to German companies, tertiary education institutions and non-university research organizations (Außeruniversitäre Forschungseinrichtungen, AUFs) to finance R&D. For example, the funds provided by Horizon 2020 are the equivalent of only 3.1 percent of total state R&D financing (Horizon 2020, Federal Government and the Länder) provided for tertiary education institutions. The figure for AUFs is slightly higher at 4.8 percent.[255] In the corporate sector, Horizon 2020 provides 16.5 percent of all state funds. However, relative to total R&D expenditure in the corporate sector, Horizon 2020 funding only represents a share of 0.56 percent.[256]

Similar priorities of German and European R&I funding

Looking at the sources of funding (EU Framework Programmes, BMBF, BMWi and the Länder) provided to the recipient companies from different industries, it becomes clear that the funding priorities of the EU Framework Programme do not differ systematically from those of the national funding programmes (cf. table B 2-5). For example, the sector structure of the companies funded by EU Framework Programmes broadly corresponds to that of companies funded by national Specialized Programmes. In particular, the BMBF's Specialized Programmes largely match Framework Programme funding.[257] Only in Chemicals/Materials and Other Services is there a relatively high percentage of companies that receive their funding exclusively from the EU Framework Programme.[258]

Furthermore, many companies find and often use funding opportunities for their R&D activities in both programme types (71 percent across all industries). As a result, most companies that receive funding from an EU Framework Programme are also funded by the Specialized Programmes of the Federal Government.

Looking at the funding of research at SMEs, here too there are clear similarities between EU Framework Programme funding and funding by the Federal Government's Specialized Programmes. For example, SMEs make up 66 percent of all companies funded by FP7 and Horizon 2020; this is only slightly lower than the SMEs' share of Federal Government Specialized Programme funding, which was 69 percent during the reference period 2007–2016.[259]

Strengthening transfer through EU funding

By supporting R&D activities, European R&I policy contributes to the transfer of knowledge and technology in different ways. A key contribution is providing financial support for cooperation projects with different innovation actors from the EU. Since such cross-border collaborations are only promoted in exceptional cases by the German Specialized

Tab. B 2-5

Download data

Companies receiving public innovation funding, by industry* and source of funding, average 2006–2014, as percentages and in absolute terms

	Solely funding from the EU Framework Programme		Funding from the EU Framework Programme and funding by the Federal Government		Funding by the Federal Government				Länder funding	
					BMBF		BMWi			
	%	absolute	%	absolute	%	absolute	%	absolute	%	absolute
R&D services	4	30	19	322	12	682	7	548	6	489
Pharmaceuticals/electronics/ measurement technology/optics	5	34	9	149	10	618	9	698	6	523
ICT services	14	98	12	207	17	1,013	9	698	10	887
Electrical engineering/mechanical engineering/vehicle construction	11	74	14	226	16	927	22	1,693	16	1,373
Engineering services	7	51	4	74	9	551	8	603	6	532
Chemicals/materials	19	130	14	235	11	672	15	1,158	12	1,009
Other industries	9	65	12	205	15	909	20	1,526	22	1,920
Other knowledge-intensive services	9	60	5	85	5	305	4	270	7	644
Other services	22	153	10	162	4	233	6	471	14	1,214
Total	100	693	100	1,666	100	5,910	100	7,664	100	8,591

Legend: 19 percent of all publicly subsidized companies that receive funds from both the EU Framework Programme and the Federal Government can be categorized as R&D services.
* Economic sectors in R&D-intensive industries and knowledge-intensive industrial services: R&D services 72; pharmaceuticals, electronics, measurement technology, optics 21, 26; ICT services 61-63; electrical engineering, mechanical engineering, vehicle construction 27-30; engineering services 71; chemicals, materials 13, 16-17, 19-20, 22-24; other industries 5-12, 14-15, 18, 25, 31-39; other knowledge-intensive services 58-60, 64-66, 69-70, 73-74; other services 46, 49-53, 78-82.
Source: ZEW, Mannheim Innovation Panel in Weber et al. (2018) and own calculations.

Programmes, or only constitute a small proportion of their overall funding activities, this is a unique selling point for the EU Framework Programme.[260]

R&D collaborations are funded by the EU Framework Programme in large project consortia. On average, eighteen actors are involved in Horizon 2020 Projects, more than twice as many as in Specialized Programme projects of the Federal Government (seven actors). The coordination of these large international project consortia involves high transaction costs both for the companies concerned and for research organizations.[261]

In projects with the participation of at least one company, the composition of the cooperation partners differs little from that in the programmes of the EU Framework Programme and in the Specialized Programme projects of the Federal Government (cf. table B 2-6). In both EU and federal programmes, the companies' cooperation partners are often other companies.[262] Approximately 40 percent of the cooperation partners of companies are tertiary education institutions and non-university research organizations, in both federal and EU programmes.

The relatively sharp increase in the participation of the public administration in EU Framework Programme projects (FP7: 2.5 percent; Horizon 2020: 4.3 percent) could be due to the increase in public-private partnerships in the context of Horizon 2020 (cf. table B 2-6).

About a third of the cooperation partners of German companies in Horizon 2020 projects come from Western or Central Europe. The percentage of partners from Southern Europe amounts to 23 percent. The partners of 20 percent of the projects come from Germany, and 18 percent from Northern Europe. Collaborations with partners from Eastern Europe account for only 6 percent.[263]

Horizon 2020 is thus making an important contribution to collaborations between German companies and academic organizations or other companies in other European countries.

In addition to its programme funding, Horizon 2020 provides another instrument for promoting the transfer of knowledge and findings: the European Institute of Innovation and Technology (EIT), which was established in 2008. Between 2014 and 2015, German actors received the largest share of EIT funding in Europe: approximately 16 percent.[264]

The operational part of the EIT is made up of six Knowledge and Innovation Communities (KICs), two of which have their headquarters in Germany. The KICs' task is to strengthen innovative activities and entrepreneurship, advance start-up training, and finance start-ups. In this context, the KICs pursue issues that are related to the great societal challenges, such as climate change.[265]

The assessment of the EIT is ambivalent. On the one hand, an interim evaluation conducted by the European Court of Auditors in 2016 attested the EIT significant deficits with regard to "overall efficiency as a result of the complex organizational framework and management problems".[266] On the other hand, the EIT points out that the six KICs created around 375 start-ups and about 500 new products and services between 2010 and 2016. Furthermore, 18 EIT founders are to be found on the '2017 Forbes 30 under 30 Europe List'.[267]

European Innovation Council: a new instrument of EU innovation funding B 2–4

The plan to set up a European Innovation Council (EIC) was first put forward in June 2015 by Carlos Moedas, EU Commissioner for Research, Science and Innovation. From 2021, the EIC is envisaged as a powerful and visible institution for European innovators, offering similar services to those provided to European science by the European Research Council (ERC).[268]

The European Commission considers the establishment of an EIC necessary for various reasons. For example, the EU suffers from a series of deficits, particularly vis-à-vis the USA, that inhibit innovation performance. These deficits include a lack of start-up dynamics, as well as an insufficient number of fast-growing, internationally successful start-ups, especially in the high-growth digital and internet economy. According to the Commission, the existing European instruments for funding innovation have proved too unwieldy and cumbersome to rectify these deficits.[269] Although the EU now has a wide range of instruments for funding innovation, these are not regarded as effective enough when it comes to opening up new markets. It is therefore doubtful whether the funding instruments have kept pace with the changing forms and practices of innovation – particularly in the high-growth digital and internet economy.[270]

Tab. B 2-6

Download data

Project cooperation partners of companies receiving funding, by source of funding (EU, federal) and funding period as percentages

	EU Framework Programmes			Fed. Govt.'s Specialized Programmes		
	FP7 2007–2013	Horizon 2020 2014–2020	Percentage change	2007–2013	2014–continuous	Percentage change
Companies	49.4	51.4	4.0	61.2	56.3	-8.0
Universities	25.6	22.1	-13.7	21.5	25.4	18.1
Research institutions	19.4	17.6	-9.3	15.6	16.0	2.6
Public administration	2.5	4.3	72.0	0.6	0.6	0.0
Other institutions	3.1	4.7	51.6	1.2	1.6	33.3
Total	100	100	-	100	100	-

Source: Weber et al. (2018) and own calculations.

Extremely diverse demands on the EIC

Expectations and the demands made on the EIC are extremely diverse and in some cases mutually contradictory.[271] Overall, most of the proposals for the organization of the EIC can be assigned to four different models:

- support tool for scale-ups,
- funding instrument for excellent innovations with a focus on tackling societal challenges,
- motor for the coordination and integration of existing instruments,
- key to an integrated R&I policy by improving political consultations and coordination between R&I policies.[272]

The plans for the creation of an EIC were the subject of considerable controversy from the outset,[273] mainly because there are already many instruments aimed strengthening innovative activities whose relationship with the EIC is uncertain.[274] Among other things, it is uncertain where to draw the line between the EIC's role and that of the EIT, which was founded back in 2008 with the aim of it becoming the figurehead of European innovation policy.[275] The EIT supports long-term, largely autonomously operating KICs, which is a different approach from the EIC whose support is based on a bottom-up design, i.e. without thematic requirements.[276]

EIC pilot project launched in October 2017

In spite of the existing controversies, an EIC pilot project was launched at the end of October 2017 with a budget of €2.7 billion (for the period 2018–2020). Its self-declared aim is to support outstanding researchers, innovators and SMEs with brilliant ideas and international ambitions.[277] Furthermore, the pilot project is to experiment with new approaches to support the emergence of radical innovations.[278, 279]

The following key points of the project are named:
Integrated and transparent access to previous Horizon 2020 elements: Instruments such as FET Open, SME Instrument, Innovation Prize and Fast Track to Innovation[280] are bundled together to provide support, particularly for scale-ups. The objective here is to realize a one-stop-shop model and simplify access for potential funding recipients, especially for growth-oriented young companies.

New administrative procedures: In order to make the funding process faster and more adaptable, tenders will be thematically unspecified and follow a two-stage procedure in which the applicants will also be interviewed. The personality of the innovators thus carries more weight than in classic, purely project-related programmes.

Establishment of a group of high-level innovators: A group of experienced figures from the fields of innovation, risk capital and innovation funding are to share their experience in the selection of grant applications.[281]

The intention is that the experience gained with these pilot activities will form the basis for the development of the EIC in the next Framework Programme. That the establishment of an EIC is likely is suggested by the Lamy Report – an experts' report on maximizing the impact of European R&I programmes published in June 2017 on behalf of the EU Commission. The Lamy Report recommends the establishment of an EIC as a central institution within the upcoming 9th Framework Programme and as a complementary pillar to the ERC.[282]

The German government has also come out in favour of setting up the EIC. The EIC should serve as an umbrella organization for a consolidated portfolio of European innovation-funding instruments that first and foremost benefits companies.[283] In this context, the introduction of the EIC should be used to reform the existing SME Instrument which, in the Federal Government's view, currently only duplicates the funding activities of the Member States. The aim should be for EIC funding to require SMEs to cooperate with European partners from the outset "to enable SMEs to scale-up their activities on European and international markets".[284] The German government rejects the individual funding of SMEs at the European level, referring to ongoing negative developments, e.g. lack of effectiveness, decline in national funding commitment and high oversubscription rates of funding programmes.[285]

EIC support for radical innovations is mentioned, but no further details are given. It is merely pointed out that the EIC must make a contribution so that more market-opening, radical innovations are created in Europe.[286]

Concepts for funding radical innovations

Parallel to the discussion on the EIC, ideas were developed last year in Germany and France on setting up institutions aimed at generating radical innovations.

Within the framework of the Innovation Dialogue (between the Federal Government, business and science) held in summer 2017, a draft concept on the creation of an agency for radical innovation was presented to the Federal Chancellor. The reasons put forward in favour of the proposal stated that, although a well-functioning system for funding evolutionary innovation processes exists in the German innovation system, no support structures exist that are explicitly focused on generating radical innovations.[287]

To overcome this deficit, an agency was proposed whose structures would be clearly distinct from those of established funding bodies. As in the case of the DARPA (Defense Advanced Research Projects Agency) model in the USA, the agency should have an extremely high degree of independence from political control and monitoring, as well as great flexibility in managing its programmes. Scope for entrepreneurial activities and for conducting experiments are planned. The managements of both the agency and the projects would be periodically renewed to avoid institutional rigidity and ensure the influx of new ideas.[288]

In France in October 2017, representatives of science and industry called for the creation of a Franco-German agency for radical innovations.[289] The Joint European Disruptive Initiative (JEDI) is also modelled on the US DARPA. However, it differs in that it has a top-down approach, i.e. the topics are specified at management level. The initiative intends to concentrate on a small number of priorities, select projects quickly, encourage daring technological ventures, be able to provide funding of between one and €30 million per project, and focus its work on expediting prototype development wherever possible. Although JEDI is conceived as a Franco-German initiative – hitherto without any official government support – outside of the EU institutions, the initiators emphasize that they are open for other European partners.[290]

The challenge of Brexit B 2–5

United Kingdom's importance for European research

The United Kingdom is one of the most important actors in the European Research Area (ERA) and involved in numerous research collaborations. In Horizon 2020, it is participating in 4,793 projects and thus takes first place in Europe, ahead of Germany with 4,750 project participations and Spain with 3,785.[291] More than 7,300 scientists there receive funding from Horizon 2020, more than in any other EU country.[292]

The close scientific cooperation between the UK and other EU Member States is also reflected in the number of co-publications. While British researchers issued 198,000 joint publications with US researchers between 2005 and 2015, the number of publications with the three most important European partner countries alone – Germany, France and Italy – totalled 218,000 in the same period.[293]

The United Kingdom is also extremely attractive for foreign research staff. About 16 percent of the academic personnel at British universities come from the EU, a further 12 percent from outside Europe. The percentage of EU foreigners among doctoral students is 14 percent, that of non-EU foreigners even higher at 36 percent.[294] The attractiveness of the UK as a research location is also reflected in the fact that there are more ERC recipients researching at British institutions (79) that at institutions in Germany (67), France (53) or the Netherlands (35).[295]

Following the UK's decision to leave the EU taken in the referendum in June 2016, and taking into account the proposed two-year negotiation period, the EU will lose one of its most important actors and one of its most valuable science locations as from March 2019.

What this exit means for the UK and the ERA is still largely unclear. Although, in a position paper on the future of scientific cooperation with the EU, the British government has stated its desire to form a more ambitious and closer partnership with the EU after Brexit than any previous partnership between the EU and a non-EU country,[296] there have been no concrete statements on how this goal is to be achieved.

Models for links between the UK and the EU after Brexit

15 countries are currently associated with Horizon 2020. The association agreements are based on bilateral arrangements between the EU and the respective associated country. Each agreement is therefore designed very differently, especially since each has to relate to other agreements, e.g. participation in the EU Single Market.[297] In addition to association, there is also the possibility of participation in Horizon 2020 as a so-called third country.[298]

The following sections describe three countries as model examples of the different possibilities of involvement in, or ties with, European R&I policy.[299]

The Norwegian model – fully associated partner

As a member of the European Economic Area (EEA), Norway participates in the EU Single Market. Accordingly, the four fundamental freedoms – free movement of goods, services, capital and persons – apply, as do much of the rest of Union law. As a fully associated country, Norway pays contributions to the EU budget and participates fully in the EU's research-policy initiatives.

The Norwegian model – including membership of the EEA – would secure the full participation of British organizations in the Framework Programme, albeit with less say at the political level.

Swiss model (2014–2016) – partially associated partner

Switzerland is not a member of the EEA, but regulates a wide range of legal matters through bilateral agreements with the EU. In this way, Switzerland also secures access to many areas of the European Single Market.

In 2004, Switzerland was fully associated with the then 6th Research Framework Programme and paid a compulsory contribution to the EU. As a result, Swiss researchers had the same rights as their colleagues from EU member states when it came to filing project proposals. They could also receive funding directly from the EU.[300]

In 2014, the EU rejected Switzerland's return to full association with its new Framework Programme Horizon 2020 due to ratification problems regarding the free movement of persons. Switzerland thereupon received the status of a third country.[301] After the problems regarding the free movement of persons were solved, full association was restored at the beginning of 2017.

As a partially associated partner country, Switzerland was not able to participate in all areas of Horizon 2020 between 2014 and 2016. It remained associated with the so-called first pillar of Horizon 2020 (Excellent Science) and with Euratom, but was given only third-country status for the second (Industrial Leadership) and third pillars (Societal Challenges). Although Swiss researchers could still participate in European cooperation projects in these two areas, they no longer received any funding from the EU.[302]

Canadian model – non-associated third country

Canada, just like the rest of the world, is in the category of a non-associated third country as regards its relations with Horizon 2020.[303] This is also the status the United Kingdom would have without any further bilateral agreements with the EU. Although organizations from non-associated third countries can take part in Horizon 2020 projects, as a rule they receive no financial support from the EU for their participation. They only receive funding from the EU if this is explicitly provided for in the invitation to tender, or if participation by the organization concerned is considered absolutely essential for the success of the project. Canadian participants must therefore seek co-financing in their own country.[304]

Otherwise, the only remaining chances to participate in Horizon 2020 are projects that expressly provide for international cooperation with non-associated third countries, such as the ERA-NET. The ERC and the Marie Skłodowska-Curie actions also offer non-associated third countries opportunities for participation. ERC grants are open to researchers from other countries if they use the assigned funds to carry out their research projects at an institution in the EU or an associated state.[305]

B

B 2-6 Recommendations

The EU's R&I policy is a relatively young policy area characterized by the formulation of very ambitious goals.

As early as 2000 in Lisbon, the European Council formulated the intention of making Europe the most competitive and dynamic knowledge-based economy in the world by 2010.[306] In this context, the EU also expressed its aim to increase R&D expenditure to 3 percent of gross domestic product (GDP) in all EU countries by 2010.[307] A few years later, the EIT was founded with the intention of creating a European answer to America's MIT (Massachusetts Institute of Technology).[308] What combines all three goals is that their realization was probably already far beyond what was feasible when they were formulated.[309] The current discussion about the European Innovation Council (EIC) reveals parallels in this respect. The expectations formulated in connection with the establishment of the EIC are so ambitious and varied that they are unlikely to be fulfilled.

The Commission of Experts is concerned that the EU's repeated marked failure to meet self-proclaimed objectives will undermine the credibility of European R&I policy in the medium term.

Structures of European R&I policy

The structures of European R&I policy are very complex, and responsibilities fragmented.

– The Commission of Experts regards the consolidation and simplification of European R&I structures as a key task of national and European policy. This task must take precedence over the creation of new institutions and the development of additional funding instruments.

European R&I policy should keep to its goal of promoting excellent research. Overcoming the so-called innovation divide between Member States must be seen as an equally valid goal and pursued more effectively than hitherto.

– Horizon 2020 is primarily geared towards excellence in research. This orientation must be maintained in the design of the 9th Framework Programme for Research and Innovation and should not be diluted by the inclusion of additional elements.
– At the same time, a governance structure must be created which ensures that the funds earmarked in the ESI Funds for the promotion of research and innovation are used by the national governments in a more target-oriented and effective way than in the past. For example, an EU body should be involved in the operational planning of the respective national funding.

European Innovation Council (EIC)

The Commission of Experts is critical of the establishment of an EIC on the basis of the current pilot project, since its integration into the institutional structure of the European R&I policy is unclear and its orientation insufficiently substantiated.[310]

– The establishment of an EIC should be made subject to the condition that applicants must prove a concrete need for funding which can best be covered by the EU. If this happens, the tasks and structures of an EIC should be defined promptly and precisely.
– The Commission of Experts is sceptical about whether creating a new EU institution is the best way to effectively promote radical innovations. The short decision-making paths and flexible structures necessary for such a venture are difficult to realize within EU structures that are geared towards balancing interests and achieving a proportional representation of countries. The Commission of Experts therefore recommends creating an institution for the promotion of radical innovations outside EU structures. Two proposals that are differently structured in terms of content have been made here: the concept for setting up an agency for radical innovations in Germany and the French Joint European Disruptive Initiative (JEDI).

Brexit

– In view of the importance of the United Kingdom as one of the strongest R&I systems in Europe, the Commission of Experts urgently advises forging the closest possible links between the country and European structures. Ideally, integration would follow the Norwegian model, i.e. a soft Brexit with as few changes to the status quo as possible. In such a case, the continuation of tried-and-tested cooperation in the Framework Programme, the mobility of researchers between

British and continental European institutions, and the unhindered exchange of knowledge would still be possible.

B 3 Autonomous systems

Download data

Using algorithms and methods of artificial intelligence, autonomous systems are able to solve complex tasks independently. They learn on the basis of data, and can act largely without human intervention even in unfamiliar situations.

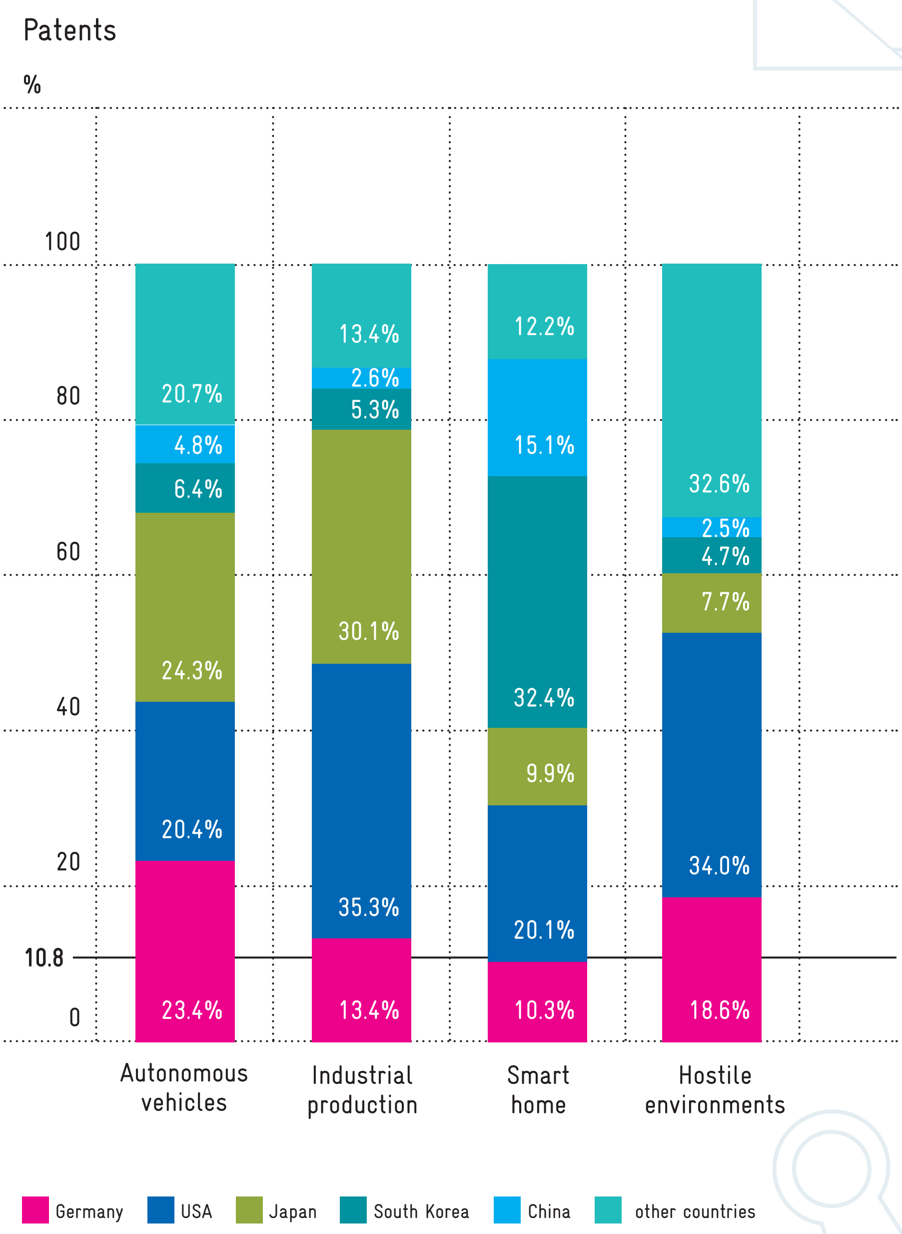
B

Autonomous systems are developed for many areas of application* – artificial intelligence forms a basis for this as a cross-cutting technology.

Source: *Dumitrescu et al. (2018).

Germany's share of transnational patents by international comparison for the four examined areas of application of autonomous systems, 2002–2016

Compared to the proportion of transnational patent applications by German inventors (horizontal line) in all sectors, Germany reveals a particular specialization in the application areas autonomous vehicles and hostile environments. Germany is a world leader here: about level with the USA and Japan in autonomous vehicles, and in second place behind the USA in the field of hostile environments.



Source: own calculations based on Pötzl and Natterer (2018) and Youtie et al. (2018). Cf. also table C 6-2.

B 3 Autonomous systems

B 3-1 Autonomous systems: a technology of the future

Autonomous systems can operate without direct human guidance, solve complex tasks, make decisions, learn independently, and react to unforeseen events. The potential economic and societal benefits of autonomous systems are considerable. Their use can help improve road safety, support people in work processes, make life more pleasant for the individual, and improve societal participation. For example, autonomous systems can be used in nuclear waste disposal or landmine clearance.[311] The integration of artificial intelligence (AI) can generate value-creation potential in a wide range of fields, particularly in areas other than industrial manufacture.[312]

A common example from the field of autonomous systems is autonomous driving. Human error is the cause of almost 90 percent of road accidents involving personal injuries.[313] Reliable estimates suggest that a massive reduction in personal injuries and material damage can be achieved by using autonomous systems.[314] Autonomous driving is made possible by the interplay of different technical components which register a vehicle's environment and, with this information, take driving decisions that solve problems in real-time. As the degree of automation rises, more and more driving decisions are transferred from humans to the system. In fully autonomous vehicles, humans only assume the role of a passenger who can spend their time in the car as they see fit. Among other things, this opens up new mobility possibilities for people who cannot drive a car themselves due to a disability.

At present, the use of autonomous systems is still in its infancy in many fields. Further progress will be required primarily in AI before there is a breakthrough at the technological level (cf. box B 3-1). Another important factor is shaping the framework conditions for the deployment of autonomous systems.

Germany is in a good starting position for reaping the potential benefits of autonomous systems in terms of added value and new applications. In basic research on AI, Germany can build on a solid foundation and has many strengths. Furthermore, the country has an internationally competitive basis for the development of autonomous vehicles. In other areas of application, however, Germany is lagging behind the market leaders in the development of autonomous systems. In addition, it is becoming apparent that other countries, above all the USA and China, but also the United Kingdom and France, are giving the topic of AI high priority in their research and industrial policy. In addition to designing a regulatory framework, therefore, German policy-makers must also increase their funding for research in the fields of both autonomous systems and AI.

B 3-2 Definition, components and technological development status

Based on algorithms and methods of artificial intelligence, autonomous systems are able to solve complex tasks independently. They learn on the basis of data, and can act largely without human intervention even in unfamiliar situations. The borderline between autonomous and automated systems is often defined by different degrees of automation.

Taking the example of automated driving, automation and autonomy can be divided into six levels and described as shown in figure B 3-2.[315] The starting

Box B 3-1

Artificial intelligence

The concept of AI was coined in 1956,[316] although the idea of machines mimicking aspects of human intelligence goes back much further. As long ago as 1950, Alan Turing described the possibility of a form of intelligence simulated by computers, and some of the components this would require, such as learning.[317] This was the beginning of an area of research dealing with artificial systems that are capable of solving complex problems rationally and can even reach their objectives in unfamiliar environments.[318]

In the following years, AI found application in a wide variety of fields. For example, heuristic search methods were developed, computer vision and computational linguistics (natural language processing) advanced, and initial progress was made in the field of machine learning.[319] However, difficulties in the practical implementation of AI in the late 1970s and early 1980s led to a decline in research interest.[320] Although the use of so-called expert systems led to the first successful applications of AI over the subsequent decade, these had the disadvantage of often being unable to cope well enough in unexpected scenarios; creating them was also cost-intensive.[321]

With more computing power becoming available and efforts focusing on specific, realistic tasks (e.g. image recognition), AI research has successfully become established since the mid-1990s.[322] The availability of large amounts of data has supported the development of AI and, in particular, machine learning over the last 20 years.[323] In the recent past, so-called 'deep learning' using neural networks has played a decisive role. This development has been made possible and accelerated by the use of graphics processors. In the field of image recognition, this progress particularly came to the fore in the 2012 ImageNet Competition.[324]

Results of AI research have already become part of commercial services, medical diagnoses and scientific research. By contrast, it seems that 'Artificial General Intelligence', which describes systems comparable to a human that are capable of carrying out a whole range of cognitive tasks with seemingly intelligent behaviour, will not be feasible in the foreseeable future.[325]

point is level 0, in which all processes are controlled by humans. As the degree of automation increases between levels 1 and 4, more and more functions are transferred from the driver to the system. The term autonomous driving is used for level 5 systems. There is no human vehicle guidance in such a vehicle. All driving functions are taken over by the vehicle. This classification can be transferred to other areas of application of autonomous systems.

The deployment of autonomous systems is possible in many areas of application. Apart from autonomous driving, these include hostile environments, the smart home, industrial production, agriculture, energy and health. In the following, the Commission of Experts concentrates on the application fields of hostile environments, the smart home, industrial production and autonomous vehicles.[326]

High complexity of autonomous systems

To be able to function without human intervention, autonomous systems must be able to solve a wide range of tasks reliably and independently. They must assimilate and process information, make and execute decisions, and communicate with other autonomous systems or human beings. A special challenge in this context is managing all this in unfamiliar situations or in environments that are not very structured – or not structured at all. Furthermore, systems operating at different degrees of automation must function both alongside each other and with each other (mixed operation).

Figure B 3-3 provides an overview of the components of autonomous systems. These components can be of two types: environment technologies or core technologies.

Environment technologies – sensors, actuators, and man-machine or machine-machine communication – are required for environment recognition, communication and carrying out instructions.[327] Their concrete design depends essentially on the autonomous system's area of application. In the field of automated driving, for example, cameras, radar and laser-based sensors (LIDAR) can be used.[328]

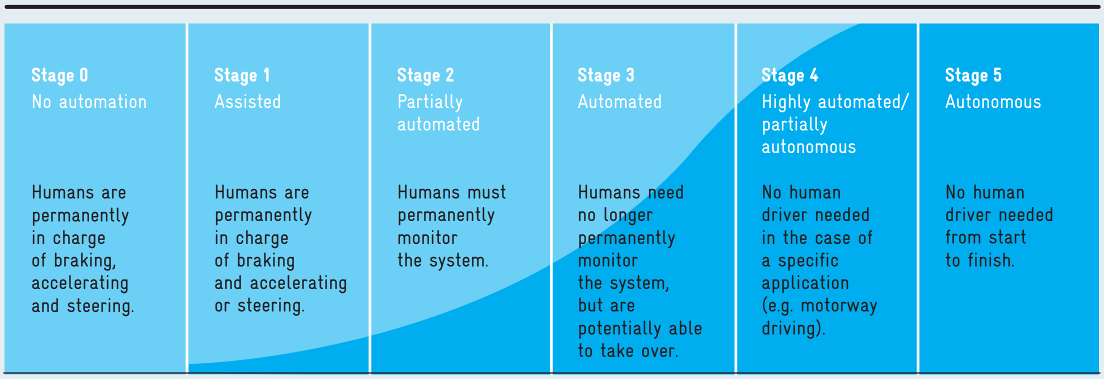
The core technologies of autonomous systems include perception, learning, action and self-regulation. Starting with sensor technology to register the environment, an autonomous system uses perception technologies to process the data on its surroundings. The environment can be perceived on the basis of real-time images from a camera, which can be used to assign a designation such as 'stop sign' to an object that is in front of a vehicle. As a consequence, the autonomous vehicle will draft an action plan to 'come to a halt at the stop sign' on the basis of learning technologies. In order to implement this action plan, the action technologies specify concrete instructions. The vehicle's actuators then convert the instructions into steering movements and braking operations. To ensure that these functions also function reliably in new environments, the core technology of self-regulation continuously optimizes the vehicle's systems.[329]

B

Fig. B 3-2

Download data

Degrees of automation in driving



Source: own diagram based on Dumitrescu et al. (2018) and VDA (2015).

Fig. B 3-3

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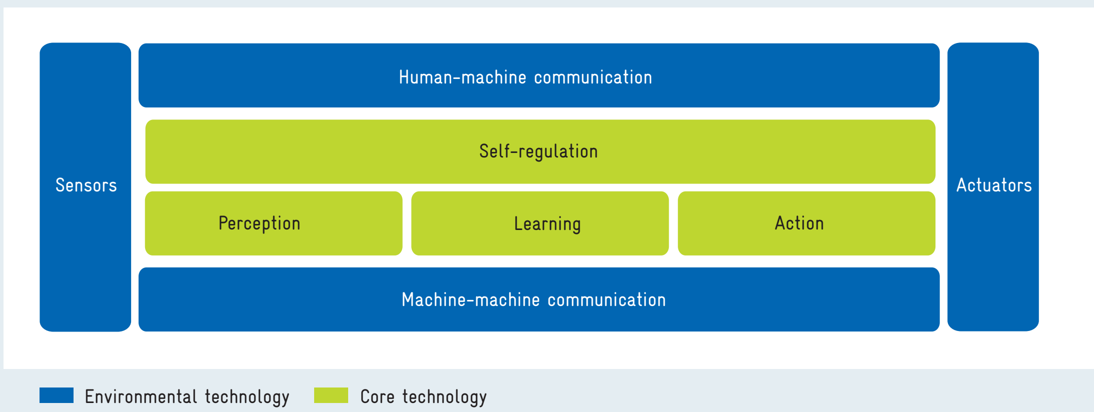
Environmental and core technologies of autonomous systems



Source: own diagram based on Dumitrescu et al. (2018).

As cross-cutting procedures, AI methods are very important for autonomous systems, since they make reliable operations possible even in relatively unstructured environments. Thus, the use of autonomous systems is highly dependent on progress in the field of AI. The deployment of AI is not limited to autonomous systems, but can already be meaningful in highly automated systems.[330]

Autonomous systems still require further development

A survey of experts has been carried out on behalf of the EFI to assess the international level of technological development in the field of autonomous systems.[331] The international technological development level of autonomous systems was evaluated by 37 national and 32 international experts; distinctions were made both according to the four areas of application selected for the study (hostile environments, the smart home, industrial production and autonomous vehicles) and according to the components of autonomous systems (environmental and core technologies).

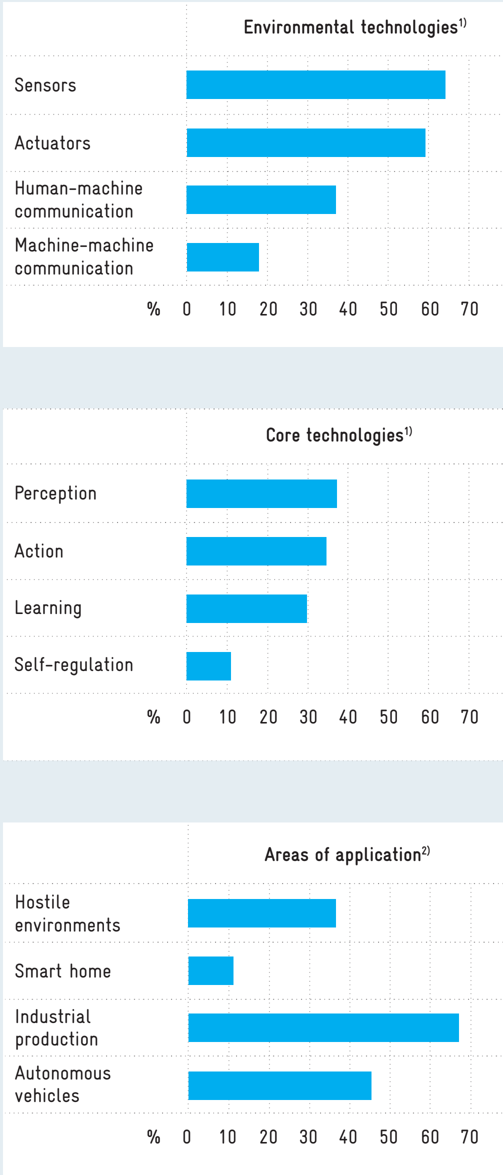
The international development level of the various environmental and core technologies of autonomous systems is assessed by the experts surveyed on the basis of a six-point scale ranging from 'undeveloped' to 'very highly developed'. On this basis, the percentage of respondents who assign one of the two highest levels on the scale to a technology is used as an indicator of a high level of development (cf. figure B 3-4).[332] The respondents see major differences in the development levels of the different environmental and core technologies. Nearly two-thirds of the experts assess sensors and actuators as being highly developed. The relatively low level of development in all other areas indicates a considerable need for research in these fields.

Differences in the level of development are also revealed in the areas of application of autonomous systems. Only in the field of industrial production do the majority of respondents believe that development has reached level 4 or 5 (cf. figure B 3-2). The majority of respondents expect level-5 systems to reach market maturity within the next ten years (cf. figure B 3-5).

Fig. B 3-4

Download data

State of development of autonomous systems by components and areas of application

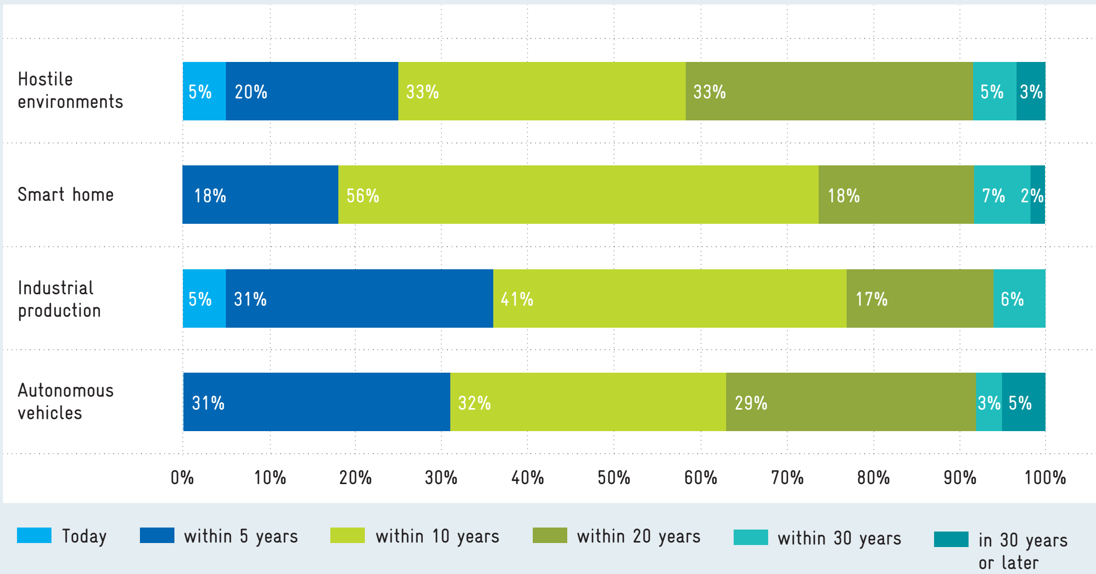


Results of a survey of 37 national and 32 international experts.
1) Percentage of respondents who assign one of the two highest ratings to environmental and core technologies on a six-point scale between 'undeveloped' and 'very highly developed'.
2) Percentage of respondents who currently assign rating 4 or 5 to the areas of application (cf. figure B 3-2).
Source: own calculations based on Dumitrescu et al. (2018).

Fig. B 3-5

Download data

Duration until market maturity of autonomous systems (level 5) by area of application



Results based on the results of a survey of 37 national and 32 international experts.
Percentage of respondents expecting autonomous systems to reach market maturity during the period stated.
Source: own calculations based on Dumitrescu et al. (2018).

B 3-3 Potential and challenges

The use of autonomous systems promises a wide range of benefits, as exemplified in box B 3-6 for four application areas studied here: hostile environments, the smart home, industrial production and autonomous vehicles.[333] However, it also poses great challenges for citizens, companies and policy-makers. These must be quickly overcome in order to be able to tap into the potential benefits.

Need to tackle complex challenges

The increasing digitization of the processes used in autonomous vehicles, the smart home and industrial production is generating ever larger amounts of data. Many applications of AI and autonomous systems must have the ability to access many different kinds of data in real time.

The quality of automated learning processes – and the associated potential for innovative business models, as well as for more and better AI applications – essentially depends on access to and the quality of the available test data. Data can therefore be understood as essential facilities, as defined by competition economics,[334] control of which confers market power and thus needs to be regulated.[335] Moreover, state funding for the provision of data seems a good idea, since test data have the properties of public goods. If data management is in purely private hands, there is a risk of a shortage from society's point of view.[336]

Further need for regulation stems from the nature of the data that is generated. A distinction can be made here between personal data and data created in communication between things/objects (Internet of Things, IoT). The demands that must be made on data protection and data security vary in these two cases. Here, too, the Commission of Experts sees major challenges for policy-makers.

In industrial applications, aspects of data protection and privacy play a relatively minor role, and these must be clarified in the process of designing work processes; however, when it comes to applications related to individual persons, data protection plays a key role in autonomous systems. In industrial applications and the IoT, on the other hand, data security is of particular importance.

It is also yet to be decided how and to what extent autonomous systems and AI should be monitored in day-to-day operations – or perhaps pass through a registration process prior to their introduction.[337] In this regard, the Federal Government has taken an important step towards initiating a public discussion and clarifying the situation by creating the Ethics Committee on Automated and Networked Driving.[338] The debate on ethical aspects and data-protection issues is comparatively intense in Germany,[339] although not all relevant dimensions of autonomous systems are included in the discussion.

In order to tap into the benefits of autonomous systems, it will furthermore be key to reach a critical level of societal acceptance of such systems in the course of the societal discourse. In the assessment of the Commission of Experts, many people have positive associations with autonomous driving as an area of application. A social-media analysis conducted by the Commission of Experts draws a differentiated picture here.[340] Although scepticism is expressed in some cases, positive associations with autonomous driving prevail. There are three times more positive than negative German-language online posts about autonomous driving. By comparison, English-language contributions contain only about twice as many positive as negative comments on autonomous driving. Moreover, the societal discourse covers a broad range of topics, and the effects of autonomous driving are intensively discussed in a wide range of forums, blogs and media.[341]

An increasingly common question in discussions on the effects of AI and autonomous systems is their impact on the world of work. The ongoing adjustment of job profiles in many professions has accompanied technological progress continuously since industrialization. Similarly, the diffusion of autonomous systems will involve changes in the demand for existing occupations or perhaps change job profiles. At the same time, the use of autonomous systems can be expected to create possible ways of meaningfully complementing human work and transferring more and more repetitive tasks to technical systems. Such developments are usually associated with increases in the remuneration of labour. In the context of the diffusion of autonomous systems, the Commission of Experts believes there is no scientific justification for horror scenarios relating to the labour market.[342] However, far-reaching measures will have to be taken, above all in education, in order to tap the comprehensive potential benefits of autonomous systems (cf. chapter 2).

In addition to a stable and powerful internet connection, AI requires further complementary infrastructures. These include platforms on which data and algorithms can be stored, shared and re-combined, as well as powerful computer hardware. In addition to the physical input factors (computers, servers, buildings, high-performance internet), a significant part is played by complementary intangible input factors (development of data sets, company-specific human capital, implementation of new business processes, platforms). The reorganization of business processes requires not only purely technical adjustments, but also workforce-training measures.

In view of the foreseeable great importance of autonomous systems and the complexity of the tasks to be carried out, the Commission of Experts is in favour of setting up a Bundestag Committee of Inquiry to look closely at issues of ethics, data privacy, data security, military use and competition.

Germany's position by international comparison B 3–4

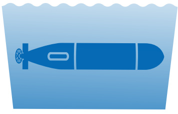
Germany's performance is measured and internationally compared using three indicators: the number of publications at the most important international AI conferences, publications in the areas of application of autonomous systems, and patent applications in the areas of application.

Basic research on AI well positioned in Germany

In order to assess the performance of German science in the AI field, the Commission of Experts consulted data on contributions to scientific research as recorded in the relevant conference proceedings (proceedings

Box B 3-6

Benefits for the economy and society

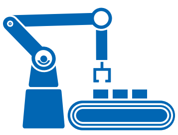


Hostile environments

In hostile environments – e.g. in outer space, underwater,[343] in the aftermath of earthquakes, after accidents in nuclear power plants or during their decommissioning – autonomous systems make it possible for work steps to be executed without endangering people. One advantage of autonomy in a system is that no permanent communication link with a human being is needed; another is that the system can plan parts of its deployment itself. For example, an autonomous robot can find its own way through a damaged nuclear power plant or a building in danger of collapse. Furthermore, in rescue or site-clearance work, robots can be deployed in situations that are too dangerous for people.[344]

The smart home

Autonomous systems can save energy and maximize comfort for the inhabitants by intelligently controlling heating and air-conditioning in buildings. Furthermore, intelligent energy management makes it possible to gear the operation of household appliances like washing machines to the time-related cost structure of the electricity supply (smart metering); in this way it can also react to fluctuating electricity generation from wind or solar energy. In addition, autonomous systems can be used in buildings to take over security functions and coordinate permanently installed monitoring systems with mobile units such as drones.[345] In future, the home, as the focal point of a person's life, could assume an integrating function for autonomous systems in different areas of life.[346] It would be conceivable, for example, to link smart-home functions with mobility solutions in which electric vehicles could be used to store locally generated energy; or the smart home itself requests an autonomous vehicle when a resident leaves the house.



Industrial production

In the field of industrial production, autonomous systems make it possible to both accelerate production and make it more flexible,[347] thus allowing a more individualized final product. For example, autonomous systems can be used in form of driverless transport systems for a company's internal logistics or in human-robot collaborations. The latter make it possible, among other things, to expand quality controls during the manufacturing process and to document work steps in real time.[348] Furthermore, autonomous systems reduce downtime by means of predictive maintenance. To do this, machine data are collected and analysed in real time to discover and report anomalies and initiate necessary measures before a defect occurs.

Autonomous driving

In road transport, autonomous systems will be used in the form of autonomous driving, among other applications. Autonomous driving promises a massive reduction in the number of accidents by avoiding human error, e.g. lack of attention. In addition, networked autonomous vehicles can make traffic more efficient with less congestion, since they can drive in a more proactive and coordinated way than people.[349] Time otherwise spent driving can be used for other purposes. Apart from autonomous vehicles, transport infrastructure, such as traffic lights, can also operate autonomously and in this way adapt dynamically to traffic situations. Parallel to this, different types of autonomous vehicles, such as buses and trains in a public transport network, offer a chance to develop new mobility concepts in combination with autonomous cars. Autonomous driving can also lead to changes in logistics, improve safety and reduce fuel consumption by means of driverless or digitally coupled trucks ('platooning'). At the same time, actors in the logistics industry hope to mitigate the looming shortage of truck drivers.[350, 351] However, a basic prerequisite for the effective operation of autonomous systems in the field of autonomous vehicles is unhindered, cross-border traffic, which ensures that vehicles are supplied with software updates across all national boundaries and, vice versa, that domestic manufacturers can retrieve data from vehicles that are currently abroad.[352]

contributions).[353] The conferences examined are regarded as especially important global forums for basic research on AI. These data were combined with bibliometric information to obtain information on the authors' respective location and on the citation balance of the publications.[354] The results of the evaluation are given in table B 3-7, which shows the countries and regions with the most publications.

The past decade is divided into two equally long time periods (2007–2011 and 2012–2016), which are compared. The choice of periods was influenced by the fact that there has been major progress in key AI components (e.g. neural networks) in recent years since the 2012 ImageNet Competition (cf. box 3-1), which led to a sharp reduction in AI research costs. At the same time, the number of disciplines in which AI is an important part of research is rising continuously. Publication activity has accelerated in the course of this development. The number of recorded proceedings contributions rose from 5,524 in the 2007-2011 period to 7,429 in the 2012–2016 period, a growth of about 35 percent.[355]

Almost half of the proceedings contributions were compiled at US research institutions. This US dominance of AI proceedings contributions is stable in both time windows. In addition to the number of proceedings contributions, their quality is important. To serve as a measure, we observed the ten percent of proceedings contributions that were cited most frequently, thus forming the group of highly cited proceedings contributions, or 'top publications'. Among the US proceedings contributions, these top publications accounted for 11.4 percent, slightly above the average of ten percent.

The gap between the USA and the group of countries made up of Germany, China, Canada, the UK and France is immense – these five countries together are responsible for only about half as many contributions (51 percent) as researchers from the USA. Taken together, EU countries reach a share of 22.8 percent during the period 2007–2011, and 21.6 percent between 2012 and 2016.

Researchers in Germany authored a similar number of contributions over the entire 2007–2016 period as researchers from other large EU countries (UK and France) or in China.

However, researchers from the UK and France increased the number of their proceedings contributions in the second five-year interval by more

Tab. B 3-7

Download data

B

Contributions to important AI conferences by country or region of author

Country (region)	Proceedings contributions 2007–2011	Share	Proceedings contributions 2012–2016	Share	Growth	Proceedings contributions 2007–2016	Share of highly cited proceedings contributions 2007–2015*
USA	2,729	49.4%	3,683	49.6%	35.0%	6,412	11.4%
EU	1,258	22.8%	1,607	21.6%	27.7%	2,865	
of which:							
Germany	336	6.1%	348	4.7%	3.6%	684	9.5%
United Kingdom	284	5.1%	430	5.8%	51.4%	714	10.7%
France	233	4.2%	367	4.9%	57.5%	600	9.1%
Other EU countries	405	7.3%	462	6.2%	14.1%	867	
Canada	318	5.8%	324	4.4%	1.9%	642	13.9%
China	283	5.1%	356	4.8%	25.8%	639	11.4%
Japan	160	2.9%	199	2.7%	24.4%	359	3.7%
Other countries	776	14.0%	1,260	17.0%	62.4%	2,036	7.4%
Total	5,524	100.0%	7,429	100.0%	34.5%	12,953	10.0%

Fractions are used to assign the authors to the countries of the research institutions with which they are affiliated. The percentage of highly cited publications is approximately corrected for distortions caused by the fact that the 90-percent percentile is stated in whole numbers. Authors are assigned to the group of frequently cited publications on the basis of citation distributions in the specific year of publication.
* Publications in 2016 were not taken into consideration when determining the share of highly cited publications, because the time period is too short for a reliable delimitation.
Source: calculations by the Max Planck Institute for Innovation and Competition on the basis of data from the Digital Computer Science Bibliography (DBLP) and Scopus.

than 50 percent (58 percent for France, 51 percent for the UK), while the number of German proceedings contributions virtually stagnated. Chinese proceedings contributions rose by approximately 26 percent, those by researchers in the USA by 35 percent. The number of Canadian proceedings contributions remained about the same. However, Canada has a very high proportion of highly cited proceedings contributions. The low share of Japanese researchers' proceedings contributions and their relatively low citation frequency is striking.

As in other leading reference countries, AI research in Germany is concentrated in a small number of locations and conducted by only a few scientists. 39.7 percent of the proceedings contributions analysed during the period 2007–2016 come from the Tübingen/Stuttgart (23.8 percent) and Berlin/Potsdam (15.9 percent) areas. Further particularly active regions or cities are Bonn/St. Augustin (6.9 percent), Saarbrücken (6.8 percent) and Munich/Garching (6.2 percent). These five locations thus generate 59.4 percent of the proceedings contributions recorded.

Relatively few publications on areas of application

In order to be competitive in the development of autonomous systems, it is essential to engage not only in basic research, but also in research and development (R&D) in the areas of application. Based on a study conducted on behalf of the Commission of Experts, this section looks at publication data in four areas of application: hostile environments, the smart home, industrial production and autonomous vehicles. The indicator for Germany's publication performance by international comparison is available for the period from 2002 to May 2017.[356]

From a global perspective, there was a marked increase in publication activities in the areas of application of autonomous systems over the last five years (2012–2016).[357] The most publication activity was recorded in the application area of autonomous vehicles. Here, there has been a substantial increase in publication activity since 2012 at an average annual growth rate of almost 19 percent.

In addition to the quantity of publications, their quality, as measured by the so-called top publications, is also an important indicator for assessing a country's scientific performance. Top publications are often identified by the frequency with which they are cited. In figure B 3-8, the top publications shown refer to the most highly-cited 10 percent of all publications in the relevant area of application.[358]

Figure B 3-8 shows the cumulated publication activities of selected countries in the individual areas of application over the last 15 years.[359] Figure B 3-8 visualizes the quantity indicator (i.e. the number of publications) on the horizontal axis. The quality indicator, i.e. the number of top publications, is plotted on the vertical axis.[360]

In the area of application of autonomous vehicles, the USA takes the leading position both in all publications and in top publications. Germany's publication output is just over one third (approximately 36 percent) of the USA's. This puts Germany slightly ahead of Japan and South Korea, but a long way behind China. However, in top publications Germany is ahead of China with about 26 percent of the US figure.[361]

China, the USA and South Korea are particularly strong in the area of application of the smart home. China is ahead of the USA and South Korea when it comes to total publications. However, the USA again dominates in top publications. Germany generates just under 36 percent of the leading nation China's output of total publications, and approximately 23 percent of the leading nation USA in top publications.[362]

In the area of application of industrial production, Germany is on a par with China and the USA in all publications. However, these two countries are ahead in top publications. China's strong position is striking, whereas Germany only accounts for about 31 percent of the USA's top publications in this category.[363]

The area of application of hostile environments is also dominated by the USA and, to a lesser extent, China. The dominant role of US researchers manifests itself particularly when it comes to top publications. Germany's publication performance relative to the USA is less than 17 percent for all publications and less than 11 percent for top publications.[364]

Good position in patents on autonomous vehicles

In order to be able to study patenting activities in the four areas of application, the Commission of Experts uses the results of two studies that it commissioned.[365] In the following discussion, the Commission of Experts refers to international patenting activities evidenced by transnational patent applications.[366] figure B 3-9 shows the distribution of the patent families determined in this way according to the inventor country. The results are shown explicitly for inventors from Germany, the USA, Japan, South Korea and China.

Patents of inventors from other countries are summarized (other countries). Patent families whose earliest application was in 2002 and thereafter are included. The figures mentioned here for inventors from Germany can be compared with the patents of German inventors as a percentage of total transnational patent applications. This percentage amounted to 10.8 percent in 2015 (cf. table C 6-2).

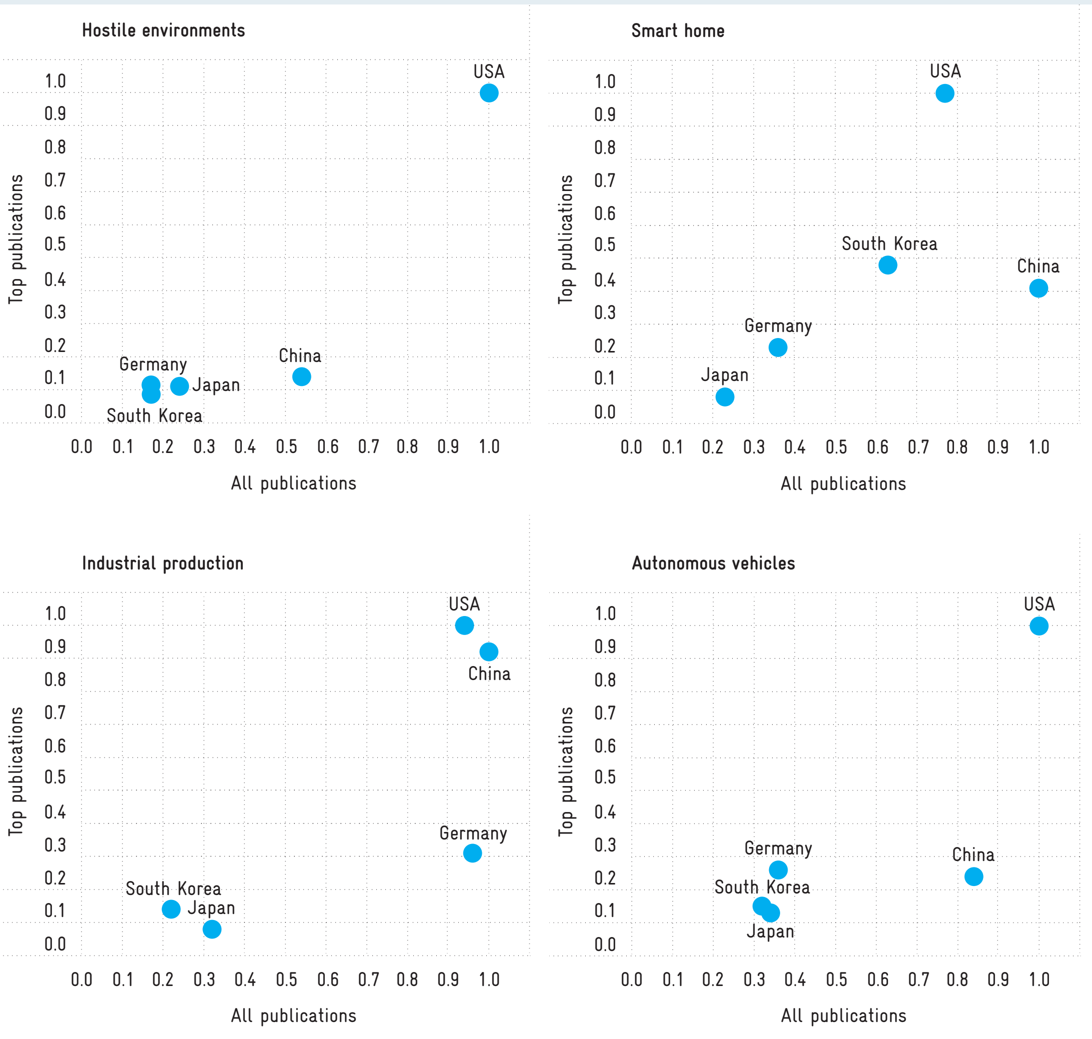
In the area of application of automated driving, 6,140 transnational patent families were identified. Application activity has accelerated: approximately one third of the identified patent families have been submitted since 2014. Inventors from Japan (24.3 percent), Germany (23.3 percent) and the USA (20.4 percent) have similarly high shares of the total number of patent families. South Korea (6.4 percent) and China (4.8 percent) follow some distance behind. In the remaining group (other countries), inventors from France (4.5 percent) and the UK (3.0 percent) record significant activities. Overall, these results indicate that Germany is very important as a location for R&D in the field of automated driving, and that German patent applicants have a competitive patent portfolio.[367]

In the area of application of industrial production, inventors from the USA (35.3 percent) and Japan (30.1 percent) hold the leading positions. Inventors active in Germany represent 13.4 percent of all the patent families considered here. South Korean (5.3 percent) and Chinese (2.6 percent) inventors reveal significantly lower patenting activities. Patenting in the area of application of the smart home is dominated by South Korean inventors, who make up 32.4 percent of the identified patent families. They are followed by inventors from the USA (20.1 percent), China (15.1 percent), Germany (10.3 percent) and

Fig. B 3-8

Download data

Publications and top publications* in relation to the leading country in the respective area of application for selected countries 2002–2017



Publications from 2017 are included up until May 2017. The numbers of all publications and top publications are shown below according to the following pattern: area of application (number of top publications by the leading country in this application area, number of all publications by the leading country in this area of application). Hostile environments (431, 2,733), smart home (135, 912), industrial production (118, 654), autonomous vehicles (947, 5,648).
* The top publications are defined as the top 10 percent of publications by citations. In the smart home area of application, this means that publications that were cited more than 60 times are taken into consideration. In the industrial production area of application, it is publications with more than 10, in autonomous vehicles more than 12, and in hostile environments more than 13 citations.
Source: own calculations based on Youtie et al. (2018).

Japan (9.9 percent). In the area of application of hostile environments, inventors from the USA (34.0 percent) again reveal particularly strong activities. German inventors follow with 18.6 percent.

Overall, these data suggest that Germany is in a particularly strong position in the area of application of automated driving and autonomous systems in hostile environments. Germany's position in the area of application of industrial production is slightly higher than German inventors' 10.8 percent share of all transnational patents. The position in the area of application of the smart home is roughly equivalent to that of German inventors for all transnational patents in 2015. So there is no particularly strong specialization here.

Assessment of the German position

The analyses of publication and patent activities reveal a mixed picture as regards Germany's position by international comparison. Germany holds a promising position when it comes to patents in the areas of autonomous vehicles and hostile environments. In publications, Germany is in a strong international position only in the number of publications on industrial production, but not among top publications. Up to now, Germany has also been strong in the field of AI basic research. However, activity among international competitors is much more dynamic here. Furthermore, China's strong position is striking; it has more publications than Germany in all the areas of application of autonomous systems; it also produces more top publications with the exception of the field of autonomous vehicles.

B 3-5 Funding measures and strategies

Autonomous systems and related individual technologies receive state funding at both the national and the international level. In Germany, different federal ministries are involved in the funding activities. The Federal Ministry for Education and Research (BMBF), for example, has introduced a platform called 'Learning Systems' and launched the 'Expert Forum on Autonomous Systems in the High-Tech Forum' together with the Federal Ministry of Economics and Technology (BMWi). Alongside many other funding programmes and projects of these ministries, there are also funding activities at other ministries such as the Federal Ministry of Transport and Digital Infrastructure (BMVI).[368] Overall, these measures[369] reveal a funding priority for autonomous driving as the current leading-edge application. Other priority topics include robotics and industrial manufacturing.[370] Autonomous driving is a priority at the European level, too. Most of the funding of autonomous systems in this field takes place within the framework of the 7th EU Research Framework Programme and Horizon 2020.[371]

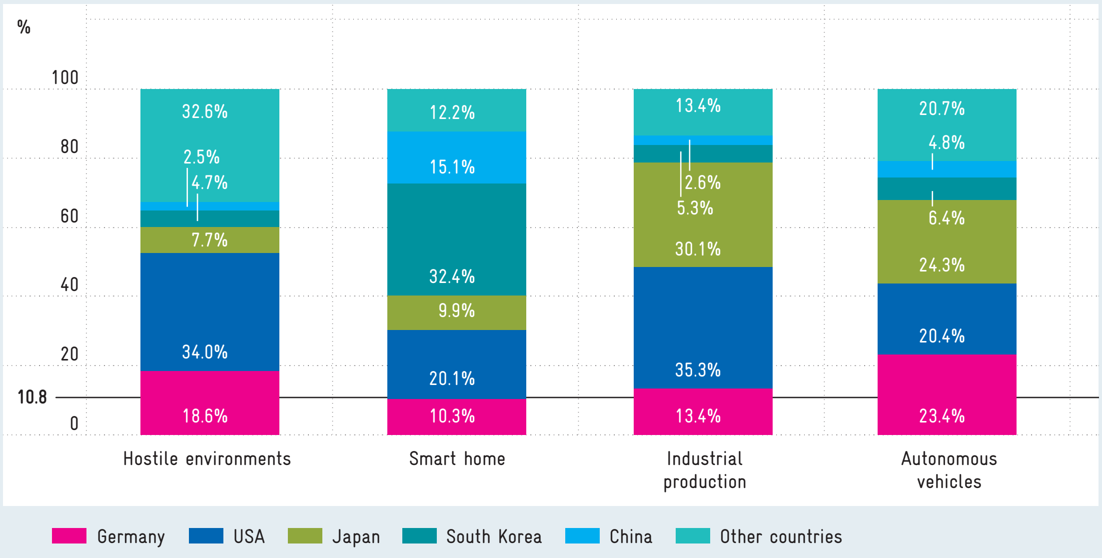
In Germany, the German Research Foundation (DFG) also funds research into autonomous systems: e.g. the priority programmes 'Cooperatively Interacting Automobiles' (since 2015) and 'Autonomous Learning' (since 2012), as well as the Collaborative Research Centres/Transregio projects 'A Companion Technology for Cognitive Technical Systems' (2009

B

Fig. B 3-9

Download data

Germany's share of transnational patents by international comparison for the four areas of application of autonomous systems examined 2002–2016



The horizontal line shows patents from German inventors as a percentage of total transnational patent applications. This amounted to 10.8 percent in 2015. Cf. table C 6-2.
Source: own calculations based on Pötzl and Natterer (2018) and Youtie et al. (2018).

to 2017) and 'Cognitive Automobiles' (2006 to 2010).[372] In addition, the Volkswagen Foundation funds integrative research approaches in the social and engineering sciences in the field of AI with the programme 'Artificial Intelligence and the Society of the Future'.[373]

Furthermore, the 'Cyber Valley' research network was initiated by the state of Baden-Württemberg in 2016.[374] Various partners from science and industry in the Stuttgart/Tübingen region collaborate in this network to advance research and development of intelligent systems, ensure the transfer of technologies, and create a favourable environment for business start-ups.[375] The Commission of Experts welcomes this initiative, especially since it builds on the region's unequivocal leadership in basic research on AI (cf. section B 3-4).

An international comparison shows that other countries have announced massive funding efforts in the AI field. Many of these announcements have not yet been implemented. Nevertheless, they reveal an awareness of the importance of AI among Germany's international competitors. China, for example, aims to achieve a leading position in both technological developments and AI applications by 2030.[376] To this purpose, the state plans massive investments in AI start-ups, basic research and 'moonshot projects'.[377] The plan of the city of Tianjin near Beijing, announced in 2017, to set up a fund worth approximately €4.2 billion[378] to support the AI industry, deserves mention as an exemplary measure in China’s AI-funding strategy.[379] In 2016, the government of South Korea also announced its intention of investing €780 million[380] in building an AI research centre by 2020 together with partners from industry, such as Samsung, LG Electronics and the Hyundai Motor Company.[381] In 2017, Japan published a strategy paper on AI technology which envisages R&D priorities in the fields of productivity, autonomous vehicles and health. The paper simultaneously supports collaborations between the government, industry and academic institutions and emphasizes the need for training in the field of AI. AI applications are also part of Japan's so-called Revitalization Strategy announced in 2017.[382] The USA also published several strategy papers in 2016 stressing the importance of AI for both the economy and national security, and presenting strategies for funding it.[383]

Despite a large number of individual measures, special institutions and platforms,[384] no strategy on the part of the Federal Government that sets comparably strong priorities on the funding of AI research can currently be seen in Germany.

Recommendations

B 3–6

The Commission of Experts welcomes the fact that policy-makers became active at an early stage by setting up the Ethics Committee on Automated and Networked Driving, in order to promote a societal discourse on the ethical issues of autonomous systems. It also welcomes the fact that several ministries have incorporated the technological development of autonomous systems into their research-funding programmes. The platform Learning Systems set up by the Federal Ministry of Education can generate important new ideas for the future practice of funding and application.

Nevertheless, there is still a considerable need for action in various areas to put Germany in an advantageous position amidst the dynamic, international competition for innovation in the fields of AI and autonomous systems.

– The Commission of Experts therefore calls for the establishment of a Bundestag Committee of Inquiry on 'Autonomous Systems and Artificial Intelligence'. The key tasks of this 'Enquete Commission' should be:

  - to bundle the societal discourse on the design and use of autonomous systems,
  - to draw up development principles which ensure that autonomous or AI-based systems are monitored and adapted on the basis of socially recognized ethical principles,
  - to embrace relevant new technical, economic and social developments,
  - to link the debate in Germany with international and, in particular, European discussion processes,
  - to develop suitable indicators for regular reviews of both the framework conditions and Germany's performance by international comparison.

– The Commission of Experts calls for the development of a national strategy for AI with the aim of boosting Germany's scientific and technological competitiveness.

- This strategy should be embedded in a European strategy, since Germany alone is unlikely to be able to keep pace with the ambitious plans of companies and research institutions in the USA and China in the foreseeable future. By contrast, a scientific and economic counterweight can be built up within the network of European actors.
- The Commission of Experts recommends forging ahead with the already visible AI centres in Germany within the framework of this strategy. By ensuring competitive funding for basic research, the aim should be to encourage prolifically publishing researchers to stay in Germany, attract talent, and develop a good basis for the transfer of knowledge and the commercial use of AI.
- In addition, the Commission of Experts recommends supporting such 'AI lighthouses' by conducting research in the humanities and social sciences, in order to address the societal implications of AI at an early stage, recognize areas where regulation is needed, and accompany the societal discourse.

– The Commission of Experts calls on the Federal Government to actively accompany and support the process initiated by the European Commission for the creation of a European single market for data. Only if a cross-border flow of data, unhampered by legal frictions, is possible, can the potential of increasingly data-based value-creation processes be realized.
– The Federal Government must ensure that companies cannot use data to build barriers to market entry that will obstruct competition in the long term. In this case, data should be treated by the competition authorities as essential facilities.[385]
– The Commission of Experts recommends funding the transfer of knowledge and findings between different actors via the Learning Systems platform. SMEs in particular should be included here. The budget allocated to the platform must be publicized and transparently kept separate from funds for ongoing projects.
– The fact that funding policy has hitherto been strongly focused on current strengths of the German economy could prove to be an obstacle to the development of new areas of application. The Commission of Experts advises incorporating all application fields of autonomous systems into funding.

B

STRUCTURE AND TRENDS

Contents

C 3 Innovation behaviour in the private sector

C 4 Financing research and innovation

C 5 New enterprises

C

C 6 Patents

C 7 Scientific publications

C 8 Production, value added and employment

Overview

Measuring and reporting Germany's performance as a location for research and innovation is an integral part of the annual reports of the Commission of Experts for Research and Innovation. The process involves compiling a number of indicators which allow conclusions to be drawn on the dynamics and efficiency of Germany's research and innovation system. For the sake of clarity, the indicators are divided into eight thematic sets. Based on these indicator sets, the performance of the German research and innovation system is presented in an intertemporal comparison, and compared with the most important competing countries.[386] Furthermore, individual indicators are shown at the Länder level to reveal differences in performance within Germany. Most of the indicators have been drawn from studies on the German innovation system commissioned by the Commission of Experts. In addition to the indicators listed here, these studies also offer comprehensive further material for indicators and analysis. All the studies can be accessed and downloaded on the Commission of Experts' website. The same applies to all the charts and tables in the report and to the related data sets.

C 1 Education and qualification

Investment in education and a high level of qualification strengthen a country's medium- and long-term innovative capacity and its economic growth. The indicators listed in section C 1 provide information on qualification levels, as well as an overview of Germany's strengths and weaknesses as an innovation location. To facilitate an assessment of Germany's performance at the international level, these findings are compared with figures from other industrialized countries.

C 2 Research and development

Research and development processes are an essential prerequisite for developing new products and services. As a rule, a high level of R&D intensity has positive effects on competitiveness, growth and employment. R&D investments and activities by companies, tertiary education institutions and governments therefore provide an important source of information for assessing a country's technological performance. Section C 2 provides insights into how Germany's R&D activities compare with those of other countries, how much the individual Länder invest, and which sectors of the economy are especially research-intensive.

C 3 Innovation behaviour in the private sector

Innovation activities by companies aim to create competitive advantage. In the case of a product innovation, a new or improved good is launched onto the market. By definition, this good differs from any other goods previously sold on the market. The launch of a new or improved manufacturing process is referred to as a process innovation. Section C 3 depicts the innovation behaviour of the German economy by showing the innovation intensity of industry and knowledge-intensive services, and the percentage of turnover that is generated with new products, in the context of an international comparison.

C 4 Financing research and innovation

The financing of business and, in particular, R&D activities is a key challenge, above all for young, innovative enterprises. Since these companies initially generate little or no turnover, self-financing is often not an option. Debt financing is also difficult, as it is not easy for investors such as banks to assess the success prospects of innovative business start-ups. Alternative methods of corporate financing include raising equity or venture capital, as well as public funding. Section C 4 describes the availability of venture capital and public R&D funds in Germany and other countries.

C 5 New enterprises

Business start-ups – especially in research- and knowledge-intensive sectors – challenge established companies with innovative products, processes and business models. The creation of new companies and the market exit of unsuccessful (or no longer successful) companies is an expression of innovation competition for the best solutions. The business dynamics described in section C 5 is therefore an important aspect of structural change. Young enterprises can open up new markets and leverage innovative ideas – especially in new fields of technology, when new demand trends emerge, and in the early phase of transferring scientific knowledge to the development of new products and processes

C 6 Patents

Patents are intellectual property rights for new technical inventions. Thus, they often provide the basis for exploiting innovations on the market, while at the same time supporting coordination and the transfer of knowledge and technology between the stakeholders in the innovation system. Section C 6 presents the patent activities of selected countries, while also examining the extent to which these countries have become specialized in the fields of high-value and cutting-edge technology.

C 7 Scientific publications

The continuous creation of new knowledge greatly depends on the efficiency of the respective research and science system. Using bibliometric data, section C 7 depicts Germany's performance in this field by international comparison. A country's performance is determined on the basis of its researchers' publications in scientific journals. The perception and importance of these publications is measured by the number of citations.

C 8 Production, value added and employment

Levels of work input and value creation in a country's research- and knowledge-intensive sectors – as percentages of the economy as a whole – reflect the economic importance of these sectors and allow conclusions to be drawn on the country's technological performance. Section C 8 depicts the development of value added and productivity in research-intensive industries and knowledge-intensive services by international comparison. The section also provides insights into Germany's global trade position in the fields of research-intensive goods and knowledge-intensive services.

Education and qualification[387]

C 1

In 2016, 31.2 percent of Germany's working population had tertiary qualifications (ISCED 5+6 and ISCED 7+8); this figure was 0.5 percentage points higher than in the previous year (C 1-1). The percentage of people with low qualifications (ISCED 0-2) in Germany is the second lowest after Finland by international comparison.

The number of new tertiary students as a percentage of the relevant age group (C 1-2) in Germany declined slightly in 2015 for the first time since 2007 and amounted to 63 percent. The proportion of new tertiary students rose markedly from 34 to 64 percent in the period 2007–2014.

In 2016 there were 453,622 qualified school-leavers in Germany (C 1-3). The rate of qualified school-leavers, i.e. the number of school-leavers qualified for higher education as a percentage of the relevant age group, was thus 52.1 percent.

In 2016, the number of first-time graduates (C 1-4) fell slightly compared to the previous year from 317,102 to 315,168. There was also a slight decline in engineering sciences as a percentage of all subject groups. This figure fell from 25.6 percent in 2015 to 24.9 percent in 2016. Please note that, in that year, the subject structure rate was calculated for the first time according to the Federal Statistical Office's new subject-group classification, which, above all, changed the relations between subject groups. In order to maintain comparability over the years, the data entered into the table for the winter semester 2015/16 was converted to the subject-group classification of the previous years.

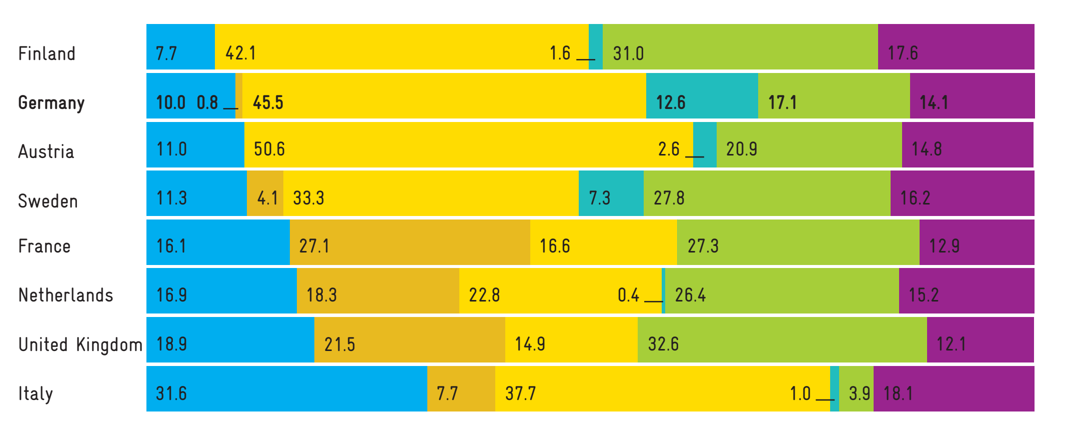
The number of foreign students in Germany (C 1-5) was 356,895 in the winter semester 2015/16. This meant that their number has increased by around 152,754 or 57 percent since the winter semester 2001/02.

The further-education rate (C 1-6) rose to 5.2 percent in 2016, compared to 4.9 percent in 2015. The biggest rise was recorded in the participation of gainfully employed persons in further training with an increase from 5.5 to 5.8 percent.

Fig. C 1-1

Download data

Qualification levels of gainfully employed persons in selected EU countries in 2016 as percentages



Classification of the ISCED qualification levels[1].

- ISCED 0–2: (Pre)primary and lower secondary education
- ISCED 3*: General and vocational upper secondary education without direct access to tertiary education
- ISCED 3**: General and vocational upper secondary education with direct access to tertiary education
- ISCED 4: Post-secondary non-tertiary education (Abitur school-leaving examination and apprenticeship)
- ISCED 5+6: Short, career-related tertiary education (2 to less than 3 years), Bachelor's degree, training as a master craftsman or technician or equivalent vocational school qualification
- ISCED 7+8: Master's degree, doctoral degree or equivalent qualification

[1] UNESCO uses the ISCED classification of educational levels as standards for international comparisons of country-specific education systems. They are also used by the OECD.
Source: Eurostat, European Labour Force Survey. Calculation by CWS in Gehrke and Kerst (2018).

C

Tab. C 1-2

Download data

Number of new tertiary students as a percentage of the relevant age group in selected OECD countries and China

University entry rate: number of new tertiary students as a percentage of the relevant age group.

OECD countries	2005	2006	2007	2008	2009	2010	2011	2012	2013 [1]	2014 [1]	2015 [1]	2015*
Germany	**36**	**35**	**34**	**36**	**40**	**42**	**46**	**53**	**59**	**64**	**63**	**56**
France	–	–	–	–	–	–	39	41	–	–	–	–
United Kingdom	51	57	55	57	61	63	64	67	58	61	69	61
Japan	41	45	46	48	49	51	52	52	–	80	80	–
Sweden	76	76	73	65	68	76	72	60	56	62	62	55
South Korea	54	59	61	71	71	71	69	69	–	–	–	–
USA	64	64	65	64	70	74	72	71	52	52	52	50
OECD average	**54**	**56**	**56**	**56**	**59**	**61**	**60**	**58**	**67**	**68**	–	–
China	–	–	–	–	17	17	19	18	–	–	–	–

[1] The table shows the university entry rates according to the ISCED classification for levels 5, 6 and 7. Please note: figures from 2013 and later were compiled according to ISCED 2011, figures before 2013 according to ISCED 97; this table is therefore not comparable with previous years. ISCED 2011 used here has nine levels, while ISCED 1997 only had seven. ISCED 2011 distinguishes between four instead of two levels in the field of higher education (ISCED 1997: Levels 5A and 6; ISCED 2011: Levels 5 to 8) and enables a distinction to be made between 'general and vocational upper secondary education without direct access to tertiary education (ISCED 3*)' on the one hand and 'general and vocational upper secondary education with direct access to tertiary education (ISCED 3**)' on the other.
* Adjusted rate excluding new international tertiary students.
Sources: OECD (ed.): Education at a glance. OECD indicators, various years in Gehrke and Kerst (2018).

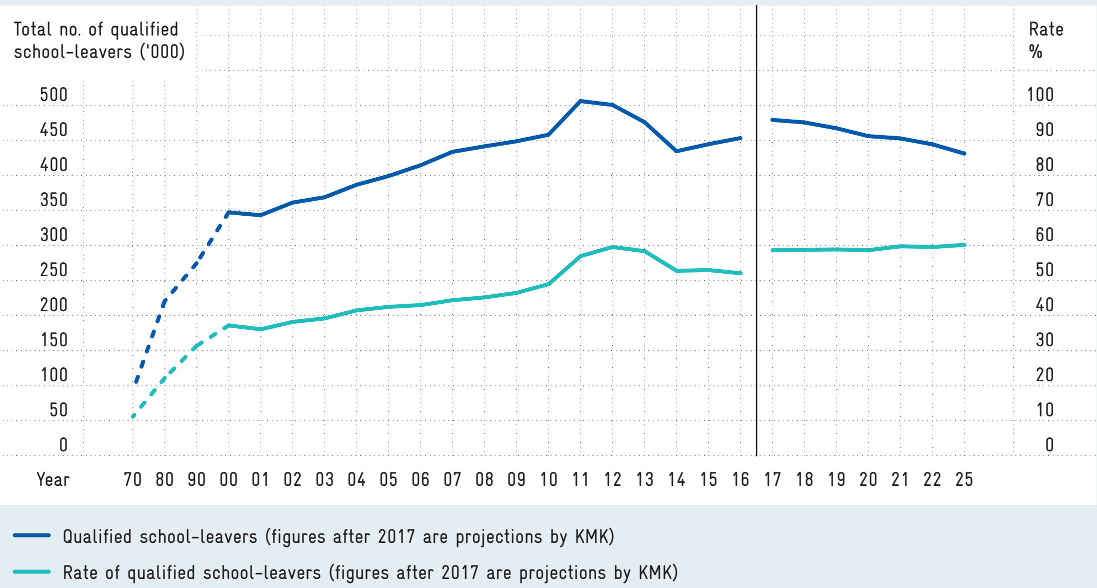
C

Fig. C 1-3

Download data

School-leavers qualified for higher education in Germany 1970–2025 (figures for 2017 and later are projections)

School-leavers qualified for higher education: either with a 'general' or 'technical' school-leaving certificate* (in Germany Abitur). Rate of qualified school-leavers: number of school-leavers qualified for higher education as a percentage of the relevant age group.



* Since 2013, the actual figures no longer include school leavers who have passed the school part of the 'technical' Abitur but must still do a period of professional practical training according to Länder rules to fully qualify for tertiary education.
Source of forecast figures: statistical publications of the Standing Conference of Education Ministers (KMK) in Gehrke and Kerst (2018).

C

Tab. C 1-4

Download data

Number of first-time graduates and subject-structure rate [1)]

First-degree graduates and subject structure rate: the subject structure rate indicates the percentage of first-degree graduates who have completed their studies in a particular subject or group of subjects. First-degree graduates are persons who have successfully completed a first degree.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total number of graduates [2)]	**220,782**	**239,877**	**260,498**	**287,997**	**294,330**	**307,271**	**309,621**	**309,870**	**313,796**	**317,102**	**315,168**
Percentage of women	51.6	51.8	52.2	51.7	52.1	51.4	51.3	51.5	51.2	51.1	52.0
Percentage of graduates from universities	61.9	62.4	62.4	62.0	62.0	62.1	61.3	59.9	59.0	56.8	54.7
Humanities	**27,361**	**30,997**	**36,458**	**38,684**	**38,385**	**39,435**	**38,444**	**38,247**	**38,788**	**37,135**	**34,886**
Percentage of subject group	12.4	12.9	14.0	13.4	13.0	12.8	12.4	12.3	12.4	11.7	11.1
Legal, economics and social sciences	**91,643**	**98,668**	**101,418**	**116,414**	**119,289**	**122,294**	**122,239**	**123,171**	**125,628**	**128,273**	**132,737**
Percentage of subject group	41.5	41.1	38.9	40.3	40.5	39.8	39.5	39.7	40.0	40.5	42.1
Human medicine	**12,230**	**13,358**	**14,345**	**15,142**	**15,222**	**15,686**	**15,856**	**16,534**	**17,331**	**17,935**	**19,521**
Percentage of subject group	5.5	5.6	5.5	5.2	5.2	5.1	5.1	5.3	5.5	5.7	6.2
Agriculture, forestry and food sciences, veterinary medicine	**6,227**	**6,534**	**7,204**	**7,729**	**7,125**	**7,521**	**7,345**	**7,158**	**7,008**	**7,442**	**6,978**
Percentage of subject group	2.8	2.7	2.8	2.7	2.4	2.4	2.4	2.3	2.2	2.3	2.2
Art	**10,503**	**10,399**	**11,185**	**11,544**	**11,820**	**12,525**	**12,866**	**12,542**	**11,913**	**11,514**	**11,268**
Percentage of subject group	4.8	4.3	4.3	4.0	4.0	4.1	4.2	4.0	3.8	3.6	3.6
Mathematics, natural sciences	**20,520**	**22,986**	**27,377**	**30,953**	**32,800**	**34,096**	**32,793**	**31,665**	**31,635**	**30,001**	**28,081**
Percentage of subject group	9.3	9.6	10.5	10.7	11.1	11.1	10.6	10.2	10.1	9.5	8.9
Engineering	**49,169**	**53,496**	**58,514**	**64,004**	**65,621**	**71,128**	**75,697**	**77,049**	**78,018**	**81,300**	**78,552**
Percentage of subject group	22.3	22.3	22.5	22.2	22.3	23.1	24.4	24.9	24.9	25.6	24.9

[1)] The Federal Statistical Office's new subject-group classification has been in use since the 2015/16 winter semester. Apart from minor changes, such as the renaming of study subjects or the merger of Veterinary Medicine with Agricultural, Forestry and Food Sciences, there were two major re-classifications. The subject group Legal, Economic and Social Sciences now also includes Psychology, Education and Special Needs Education, which used to be assigned to the subject group Language and Cultural Sciences (now called Humanities). Since the changeover, Computer Science has been counted under Engineering and not, as previously, as part of Mathematics, Natural Sciences. Furthermore, a new area of study called Materials Science was introduced under Engineering. These two subjects had previously been assigned to Mechanical Engineering. All the time series have been retrospectively reclassified to fit the new system of subjects. This avoids breaks in the time series. However, comparisons with the tables from the previous EFI Reports are now only possible to a limited extent.
[2)] Graduates with first academic degree.
Source: Federal Statistical Office and research by DZHW-ICE, in Gehrke and Kerst (2018).

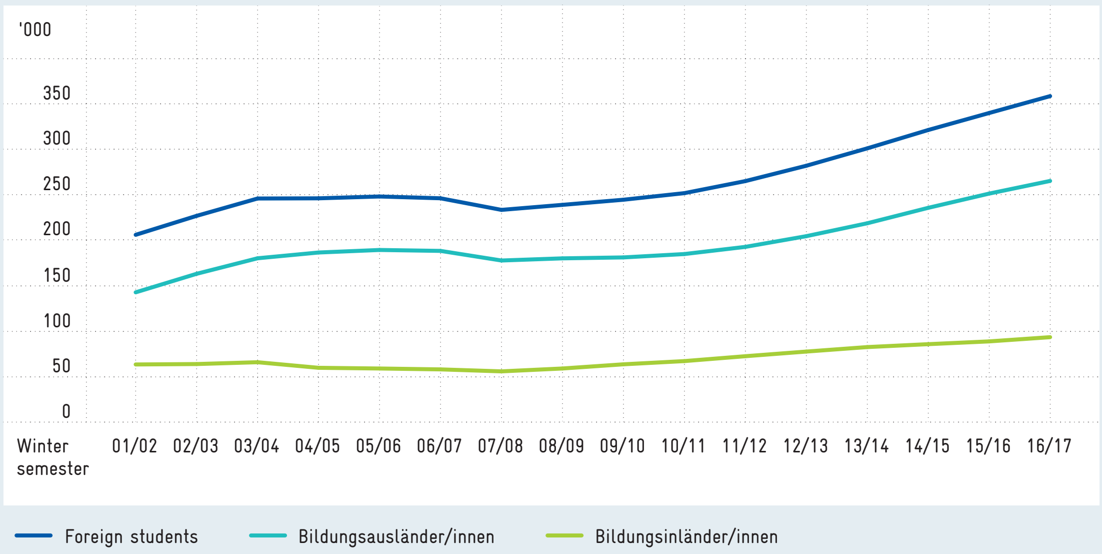
C

Fig. C 1-5

Download data

Foreign students at German tertiary education institutions

Foreign students are defined as persons without German citizenship. They can be divided into students who obtained their higher-education entrance qualification in Germany (Bildungsinländer/innen), and those who obtained this qualification abroad (Bildungsausländer/innen).



Source: Federal Statistical Office and research by DZHW-ICE, in Gehrke and Kerst (2018).

Tab. C 1-6

Download data

Participation of individuals and companies in further training as percentages

Individual further-education rate: percentage of people who had participated in a further-education measure in the last four weeks prior to the time of the survey. Corporate participation in further training: percentage of companies where employees were released for training or whose training costs were paid.*

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
a) Individual further-education rate	4.6	4.9	5.5	5.0	4.9	4.9	5.1	4.9	4.8	4.9	5,2
Gainfully employed persons	**5.7**	**5.9**	**6.4**	**5.8**	**5.6**	**5.6**	**5.9**	**5.6**	**5.5**	**5.5**	**5,8**
low (ISCED 0-2)	1.3	1.5	1.7	1.4	1.3	1.0	1.4	1.4	1.3	1.2	1,5
medium (ISCED 3-4)	4.0	4.1	4.4	4.2	3.9	3.9	4.1	3.9	4.2	4.3	4,5
high (ISCED 5-8)	11.2	11.4	12.2	10.6	10.5	10.3	10.6	10.1	9.4	9.3	9,7
Unemployed persons	**2.8**	**3.1**	**4.9**	**4.3**	**3.9**	**4.6**	**3.8**	**3.6**	**3.7**	**3.7**	**3,4**
low (ISCED 0-2)	1.1	2.5	2.4	2.7	3.5	3.6	3.1	2.9	2.8	2.6	2,0
medium (ISCED 3-4)	3.0	2.9	5.3	4.0	3.2	4.0	3.6	3.4	3.3	3.4	3,9
high (ISCED 5-8)	5.6	5.4	8.1	8.4	8.3	10.0	6.6	5.4	6.4	6.3	6,1
Inactive persons	**1.6**	**1.7**	**2.3**	**1.9**	**2.0**	**1.9**	**1.6**	**1.8**	**1.8**	**2.0**	**2,2**
low (ISCED 0-2)	0.9	0.8	1.4	1.8	1.6	1.5	1.4	1.4	1.3	1.7	2,3
medium (ISCED 3-4)	1.3	1.7	1.8	1.5	1.8	1.9	1.4	1.5	1.6	1.6	2,1
high (ISCED 5-8)	4.2	3.5	5.4	3.4	3.6	2.7	2.8	3.5	3.4	3.7	3,5
b) Corporate participation in further training	**-**	**45.5**	**49.0**	**44.6**	**44.1**	**52.6**	**53.1**	**52.1**	**53.6**	**52.8**	**-**
By sector											
Knowledge-intensive manufacturing	-	65.3	65.1	52.6	55.9	62.9	65.5	66.7	69.9	70.6	-
Non-knowledge-intensive manufacturing	-	33.2	37.8	32.5	33.3	41.2	43.2	41.8	43.0	44.5	-
Knowledge-intensive services	-	63.2	68.3	58.7	57.1	68.7	67.2	67.4	67.0	67.5	-
Non-knowledge-intensive services	-	37.3	39.4	38.0	37.5	44.9	45.3	44.3	46.0	43.8	-
Non-commercial economy	-	49.9	53.8	51.9	51.2	59.0	60.3	58.4	61.9	60.1	-
By company size											
< 50 employees	-	43.2	46.9	42.5	41.8	50.5	50.9	49.8	51.4	50.5	-
50 – 249 employees	-	85.1	86.7	81.3	83.3	90.8	89.7	90.1	90.8	89.3	-
250 – 499 employees	-	95.2	95.9	92.0	93.3	95.9	96.5	97.0	96.9	96.8	-
≥ 500 employees	-	95.3	97.8	96.0	97.9	98.4	97.8	99.1	99.1	97.1	-

All figures are provisional. Cf. C 1-1 for information on ISCED.
Population a): All persons aged between 15 and 64.
Population b): all establishments with at least one employee covered by social security insurance.
* Question in the IAB Establishment Panel: "Were employees released to participate in in-house or external training measures and/or were the costs of training measures paid wholly or in part by the establishment?"
Source a): European Labour Force Survey (special evaluation). Calculations by CWS in Gehrke and Kerst (2018).
Source b): IAB Establishment Panel (special evaluation). Calculations by CWS in Gehrke and Kerst (2018).

C

C 2 Research and development[388]

R&D intensity (C 2-1) in Germany – i.e. R&D expenditure as a percentage of gross domestic product – amounted to 2.94 percent in 2016.[389] R&D intensity thus rose slightly by 0.02 percentage points compared to the previous year, but is still below the Federal Government's three-percent target. The level of R&D intensity has a similarly low level of dynamics in the UK and Sweden: R&D intensity in Sweden decreased slightly by 0.02 percentage points to 3.25 percent between 2015 and 2016; in the UK it rose from 1.65 to 1.67 percent in the same period. The development of R&D intensity in South Korea is striking, where R&D intensity decreased from 4.29 to 4.23 percent. This was the first decline during the study period.

In 2015, the budgetary estimate – i.e. the financial resources set aside in the state budget – for civil R&D (C 2-2) in Germany was 64 percent above the initial level of 2007. By far the strongest growth was recorded in Switzerland, where the budgetary estimate for civil R&D in 2016 was 102 percent higher than the initial level of 2007. Sweden and South Korea recorded growth approximately comparable with Germany: about 60 percent up on 2007.

As regards the indicator 'distribution of the gross domestic expenditure on R&D by performing sector' (C 2-3), no new data were collected. Only individual data were revised; no new comment was made.

The R&D intensity of Germany's Länder (C 2-4) increased in all 16 federal states between 2005 and 2015. The state of Lower Saxony was the most dynamic; here, R&D intensity rose from 2.19 to 3.45 percent. As a result, Lower Saxony has the third-highest R&D intensity for 2015 of all Länder after Baden-Württemberg (4.94 percent) and Berlin (3.55 percent).

Internal corporate R&D expenditure (C 2-5) amounted to almost €61 billion in 2015. Vehicle construction alone accounted for €23.5 billion and electrical engineering/electronics companies for €9.8 billion. This means that there is a very high concentration and economic dependency in R&D on vehicle construction.

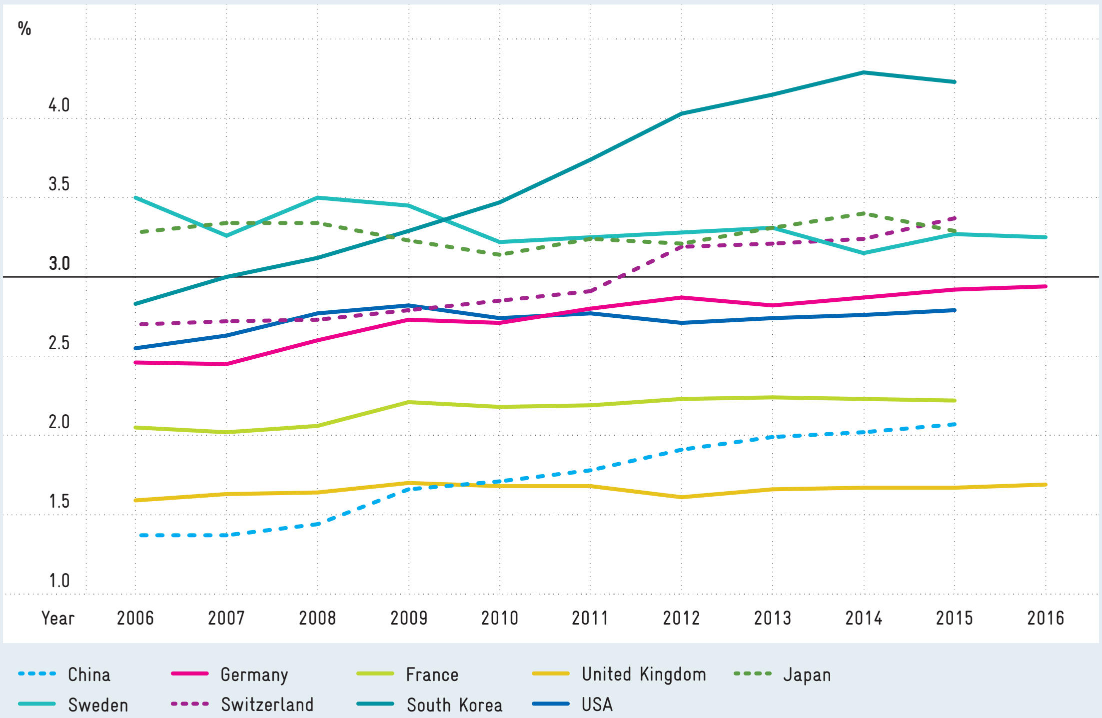
The indicator 'internal corporate R&D expenditure as a percentage of turnover from the company's own products' (C 2-6) documents a marked increase in internal R&D expenditure in the pharmaceuticals industry for 2016. R&D expenditure as a percentage of turnover from the companies' own products increased from 11.9 percent in 2015 to 14 percent in 2016.

Fig. C 2-1

Download data

R&D intensity in selected OECD countries and China 2006–2016 as percentages

R&D intensity: percentage of an economy's gross domestic product (GDP) spent on research and development.[1]



[1] Gross domestic product based on the methodology of the European System of National and Regional Accounts (ESA 2010).
Some of the data for Switzerland were estimated.
China 2009, France 2010, Japan 2008, South Korea 2007 break in the series.
Source: OECD, EUROSTAT. Calculations and estimates by CWS in Schasse et al. (2018).

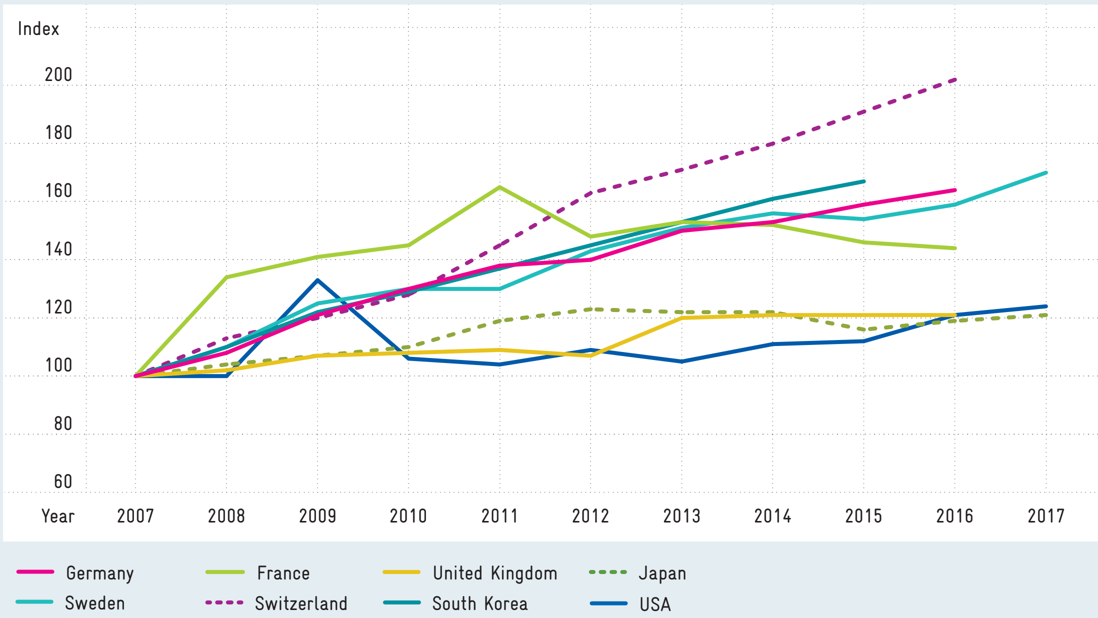
C

Fig. C 2-2

Download data

State budget estimates for civil R&D

R&D budget estimates: the chart shows the amounts set aside in the budget to finance R&D.



Index: 2007 = 100, data partially based on estimates.
Source: OECD, EUROSTAT. Calculations and estimates by CWS in Schasse et al. (2018).

C

Tab. C 2-3

Download data

Distribution of gross domestic expenditure on R&D (GERD) by performing sector in 2005 and 2015

Gross domestic expenditure on research and development (GERD) in industry, the higher-education sector and the public sector.

	2005					2015				
		of which ... (in %) was performed by					of which ... (in %) was performed by			
Country	GERD in USD m	Economy	Tertiary education institutions	State	Private Nonprofit*	GERD in USD m	Economy	Tertiary education institutions	State	Private Nonprofit*
Germany	63,868	69.3	16.5	14.1	-	114,778	68.7	17.3	14.1	-
France	39,530	62.1	18.8	17.8	1.3	60,819	65.1	20.3	13.1	1.5
United Kingdom	30,640	61.4	25.7	10.6	2.3	46,260	65.7	25.6	6.8	1.9
Japan	128,695	76.4	13.4	8.3	1.9	170,003	78.5	12.3	7.9	1.3
Sweden	10,388	72.8	22.0	4.9	0.3	15,372	69.7	26.7	3.4	0.2
Switzerland[1)]	8,436	73.7	22.9	1.1	2.3	17,688	71.0	26.7	0.9	1.5
South Korea	30,618	76.9	9.9	11.9	1.4	74,051	77.5	9.1	11.7	1.6
USA	328,128	68.9	14.3	12.3	4.4	502,893	71.5	13.2	11.2	4.1
China	86,828	68.3	9.9	21.8	-	408,829	76.8	7.0	16.2	-

[1)] 2004 instead of 2005.
* Private non-profit organizations are included under 'public sector' in some countries (e.g. Germany).
Source: OECD, EUROSTAT. Calculations by CWS in Schasse et al. (2018).

Tab. C 2-4

Download data

R&D intensity of Germany's Länder in 2005 and 2015 as percentages

R&D intensity: Länder expenditure on research and development as a percentage of their gross domestic product, broken down by sectors.

Länder	2005 Total	2005 Economy	2005 State	2005 Tertiary education institutions	2015 Total	2015 Economy	2015 State	2015 Tertiary education institutions
Baden-Württemberg	4.08	3.27	0.40	0.41	4.94	4.02	0.41	0.51
Bavaria	2.89	2.32	0.26	0.31	3.16	2.44	0.31	0.41
Berlin	3.48	1.69	1.03	0.76	3.55	1.47	1.20	0.89
Brandenburg	1.17	0.29	0.61	0.27	1.64	0.60	0.70	0.34
Bremen	2.15	0.90	0.62	0.63	2.79	1.02	1.09	0.68
Hamburg	1.77	1.06	0.33	0.37	2.24	1.26	0.46	0.51
Hesse	2.46	2.00	0.15	0.30	2.82	2.15	0.24	0.43
Mecklenburg-Western Pomerania	1.45	0.31	0.62	0.51	1.87	0.60	0.63	0.65
Lower Saxony	2.19	1.46	0.33	0.40	3.45	2.53	0.39	0.53
North Rhine-Westphalia	1.72	1.06	0.25	0.41	1.95	1.13	0.32	0.50
Rhineland-Palatinate	1.66	1.17	0.16	0.33	2.35	1.79	0.15	0.41
Saarland	1.01	0.31	0.29	0.41	1.54	0.64	0.38	0.52
Saxony	2.35	1.08	0.65	0.62	2.72	1.19	0.78	0.76
Saxony-Anhalt	1.20	0.35	0.41	0.44	1.39	0.37	0.49	0.54
Schleswig-Holstein	1.14	0.52	0.30	0.32	1.47	0.77	0.34	0.36
Thuringia	1.87	0.98	0.39	0.49	2.01	0.97	0.46	0.58
Germany	**2.43**	**1.68**	**0.34**	**0.40**	**2.92**	**2.01**	**0.41**	**0.50**

Source: SV Wissenschaftsstatistik in Schasse et al. (2018).

C

Tab. C 2-5

Download data

Internal corporate R&D expenditure by origin of funds, economic sector, company size and technology category in 2015

Internal R&D: research and development that is conducted inside the company, either for the company's own purposes or commissioned by a third party.

	Internal R&D expenditure				
	Total	of which funded by			
		private sector	public sector	other domestic entities	foreign entities
	in €'000	in percent			
All researching companies (without joint research)	**60,657,135**	**90.1**	**3.1**	**0.1**	**6.7**
Manufacturing	51,912,569	90.8	2.0	0.1	7.1
Chemical industry	3,786,071	90.1	1.4	0.0	8.4
Pharmaceutical industry	3,956,079	76.4	0.5	0.0	23.1
Plastics, glass and ceramics	1,398,754	92.6	2.7	0.3	4.4
Metal production and processing	1,354,999	80.5	9.3	0.2	9.9
Electrical engineering/electronics	9,790,457	91.1	2.7	0.0	6.2
Mechanical engineering	5,459,450	95.1	2.1	0.1	2.7
Vehicle construction	23,473,463	92.4	1.3	0.2	6.0
Other manufacturing industries	2,693,298	93.0	4.3	0.1	2.6
Remaining sectors	8,744,565	86.1	9.5	0.1	4.2
fewer than 100 employees	2,539,754	75.4	17.4	0.2	6.9
100–499 employees	5,247,883	84.6	7.9	0.2	7.2
500–999 employees	3,660,396	87.6	6.2	0.1	6.1
1,000 employees and more	49,209,102	91.6	1.6	0.1	6.6
Technology categories in industry					
Cutting-edge technology (> 9 percent of costs/turnover spent on R&D)	13,463,726	84.9	3.4	0.0	11.7
High-value technology (3-9 percent of costs/turnover spent on R&D)	32,511,084	93.3	1.1	0.2	5.5

Source: SV Wissenschaftsstatistik in Schasse et al. (2018).

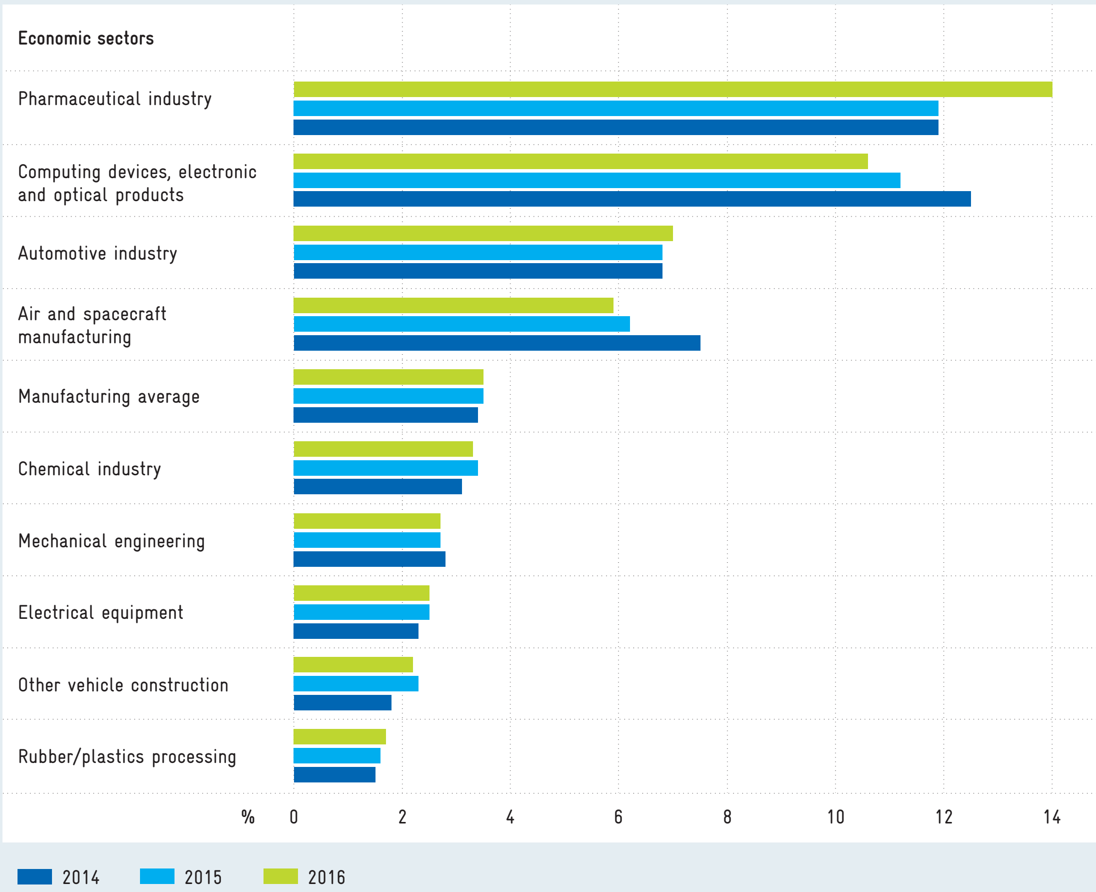
C

Fig. C 2-6

Download data

Internal corporate R&D expenditure as a percentage of turnover from the company's own products 2014, 2015 and 2016

Internal R&D: research and development that is conducted inside the company, either for the company's own purposes or commissioned by a third party.



Figures net, without input tax. 2016 provisional.
Source: SV Wissenschaftsstatistik, Statistisches Bundesamt (Federal Statistical Office), corporate results for Germany.
Calculations by CWS in Schasse et al. (2018).

C 3 Innovation behaviour in the private sector

The Europe-wide Community Innovation Surveys (CISs) are conducted every two years and provide the underlying data for the international comparison of the private sector's innovation behaviour (C 3-1).[390] Coordinated by Eurostat and based on a harmonized methodology, the CISs are conducted in all EU member states and a number of other European countries. The CISs are based on a largely uniform questionnaire and directed at businesses with ten or more employees in the manufacturing industry and selected services sectors.

The current analysis relates to 2014 (CIS 2014). In that year, the innovation intensity of the research-intensive industries in Germany amounted to 7.0 percent. It was thus higher than that of most reference countries. However, Sweden's innovation intensity was considerably higher at 11.1 percent in the research-intensive industries.

The data on innovation behaviour in the German private sector, as shown in charts C 3-2 and C 3-3, are based on the Mannheim Innovation Panel (MIP), an annual innovation survey that has been conducted by the Centre for European Economic Research (ZEW) since 1993.[391] Data from the MIP constitute the German contribution to the CISs. In addition to the data to be reported to Eurostat, the panel also includes data on businesses with five to nine employees. According to this definition, the innovation intensity (C 3-2) of R&D-intensive industries was 8.8 percent in 2016, thus increasing for the second time in succession after a fall in 2014. In other industries the rate in 2016 was 1.4 percent, i.e. at the same level as in previous years. In knowledge-intensive services (excluding financial services), innovation intensity fell in 2016 by 0.3 percentage points to 4.8 percent. In the field of financial services, the rate was 0.7 percent in 2016, as in the previous year. The level of innovation intensity was the same in other services. While the proportion of revenue generated with new products (C 3-3) increased slightly in 2016 in the R&D-intensive industries (from 33.9 to 34.3 percent) compared to the previous year, it fell quite substantially in other industries (from 8.2 to 6.5 percent). There was a slight increase in the rate in knowledge-intensive services (from 10.1 to 10.2 percent), and a relatively marked increase (from 4.8 to 6.7 percent) in other services.

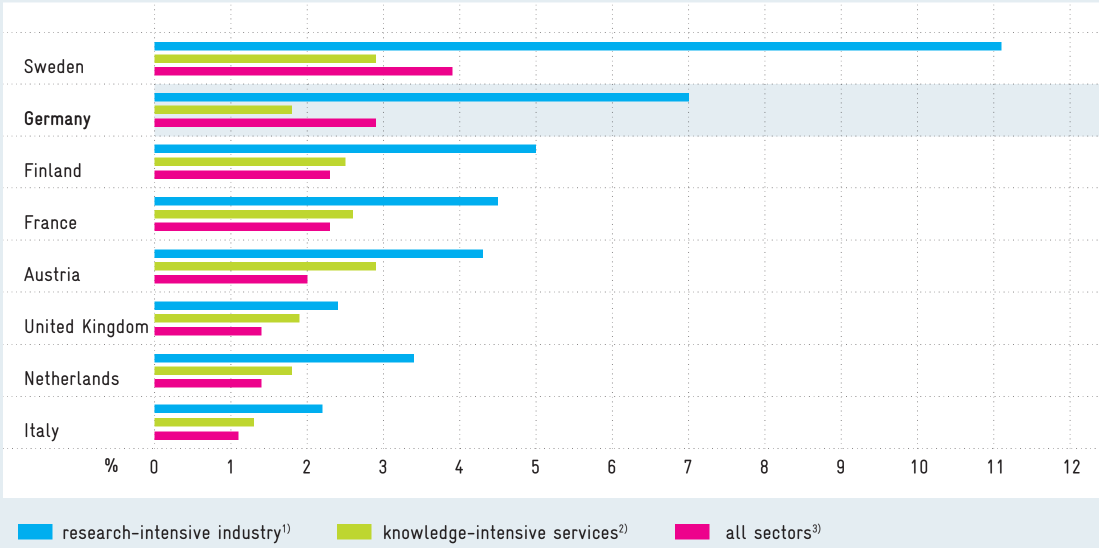
Standardization is an important factor in the commercialization of innovative technologies. At the international level, standards are developed by the committees of the International Organization for Standardization (ISO). By participating in these committees, a country can make a significant impact on global technical infrastructures (C 3-4).[392] German companies are more frequently involved in the work of the ISO than representatives of other countries.[393] China has recorded the largest increase by more than tripling the number of ISO secretariats run by Chinese representatives.

Fig. C 3-1

Download data

Innovation intensity by European comparison in 2014 as percentages

Innovation intensity: innovation expenditure by companies as a percentage of their total turnover.



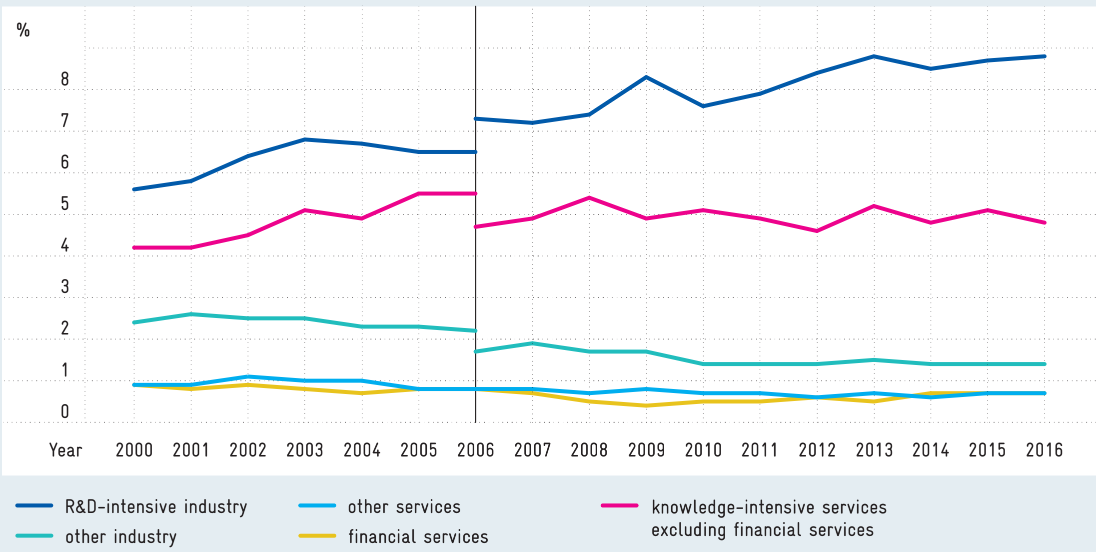
1) Research-intensive industry: divisions 19–22, 25–30 of WZ classification. Since data are not available for all sectors in all countries, the definition of research-intensive industries used in the European comparison differs from the definition normally used by the EFI.
2) Knowledge-intensive services: divisions 58–66, 71–73 of WZ classification. Since data are not available for all sectors in all countries, the definition of knowledge-intensive services used in the European comparison differs from the definition normally used by the EFI.
3) All sectors divisions 5–39, 46, 49–53, 58–66, 71–73 of WZ classification.
Source: Eurostat, Community Innovation Surveys 2014. Calculations by ZEW (Centre for European Economic Research).

Fig. C 3-2

Download data

Innovation intensity in industry and knowledge-intensive services in Germany as percentages

Innovation intensity: innovation expenditure by companies as a percentage of their total turnover.



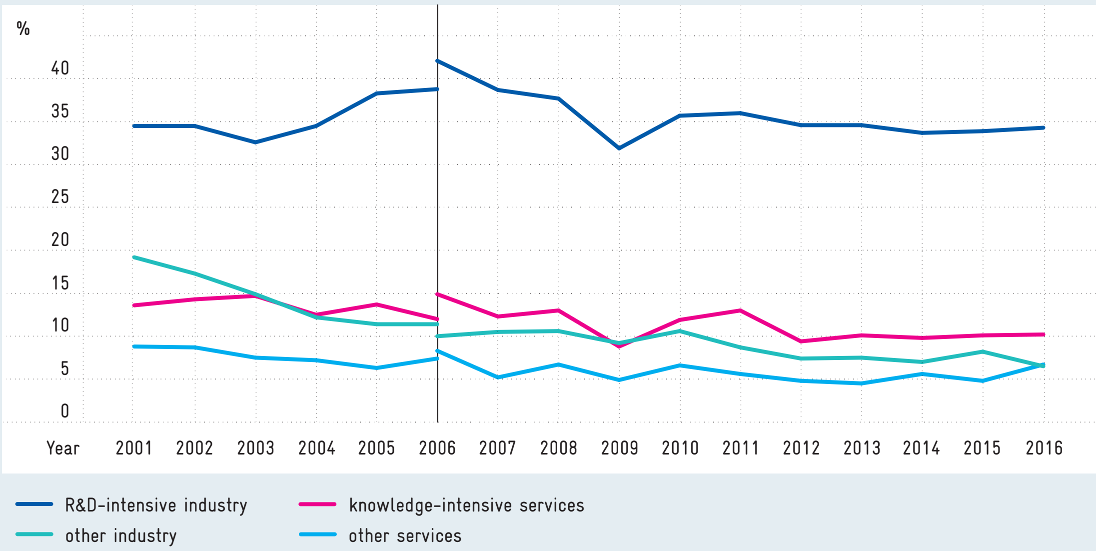
2006: break in time series. Figures for 2016 are provisional.
Source: Mannheim Innovation Panel. Calculations by ZEW (Centre for European Economic Research).

C

Fig. C 3-3

Download data

Percentage of turnover generated by new products in industry and knowledge-intensive services

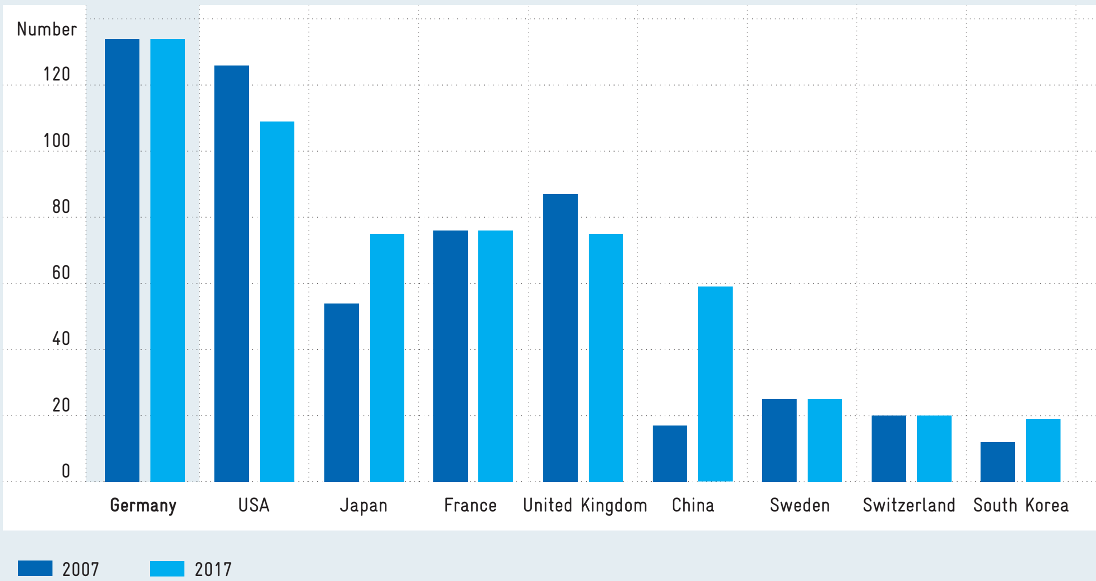


2006: break in time series. Figures for 2016 are provisional.
Source: Mannheim Innovation Panel. Calculations by ZEW (Centre for European Economic Research).

Fig. C 3-4

Download data

Number of secretariats listed by the technical committees and subcommittees of the International Organization for Standardization (ISO)



Source: own diagram based on ISO (2008: 15) and
http://www.iso.org/iso/home/about/iso_members.htm (last accessed on 13 November 2017).

Financing research and innovation[394] C 4

Public financing of research and development (R&D) in the private sector can take place via either direct R&D funding (project funding) or indirect R&D funding (in particular tax-based R&D funding). Figure C 4-1 shows direct and indirect R&D funding as a percentage of gross domestic product in selected countries. The instrument of tax incentives for R&D activities is available to businesses in most of the countries listed; however, up to now Germany has not made use of this funding option.

Financing constitutes a major challenge for many innovative companies – not only in the start-up phase, but also during the growth phase.[395] Young, innovative enterprises can often only establish themselves successfully on the market if private investors provide venture capital during the start-up and growth phases.

Figure C 4-2 provides an overview of venture-capital investment as a percentage of national gross domestic products in selected European countries. The data used for the comparison come from Invest Europe, formerly the European Private Equity and Venture Capital Association (EVCA); they offer good international comparability due to the harmonized collection and processing system used.[396] Germany ranks about mid-table here in the European comparison. The highest levels of venture-capital investment in 2016 were recorded in Finland and Sweden. In Germany, venture-capital investment as a percentage of gross domestic product rose only slightly in 2016 compared to the previous year.

Since the Invest Europe data only include venture-capital investment companies that are organized in the association, there is a risk of underestimating volumes.[397] Therefore, for the first time, data from transactional databases are used for the analysis of venture-capital investment in Germany in addition to the Invest Europe data.[398] They have the advantage that the individual transaction is the observation unit; this increases the likelihood that co-investments by atypical market participants[399] and non-European investors are also included.

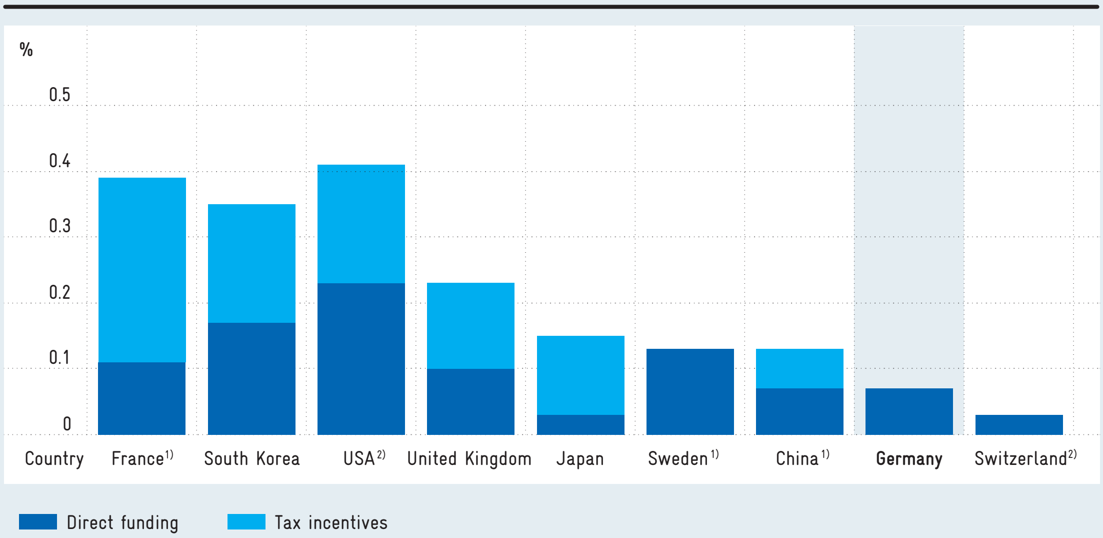
Figure C 4-3 provides an overview of the development of venture-capital investment in Germany. Analysis of the Invest Europe data reveals a slight increase in venture-capital investment compared to the previous year. When the transaction data are included in the observation of venture-capital investment, a significant increase can be observed in the period 2007–2016. Using this data leads to a significant change in the structure of venture-capital investment. However, such a change would probably also be found for other countries. The extended data base does not, therefore, allow conclusions to be drawn on whether Germany's weak position by international comparison as regards the availability of venture capital might have improved relative to other countries in the meantime.

Fig. C 4-1

Download data

R&D spending in business sector directly and indirectly funded by the public sector in 2015 as a percentage of national GDP

The public funding of private-sector R&D is divided into direct R&D funding (project funding) and indirect R&D funding (through tax incentives).



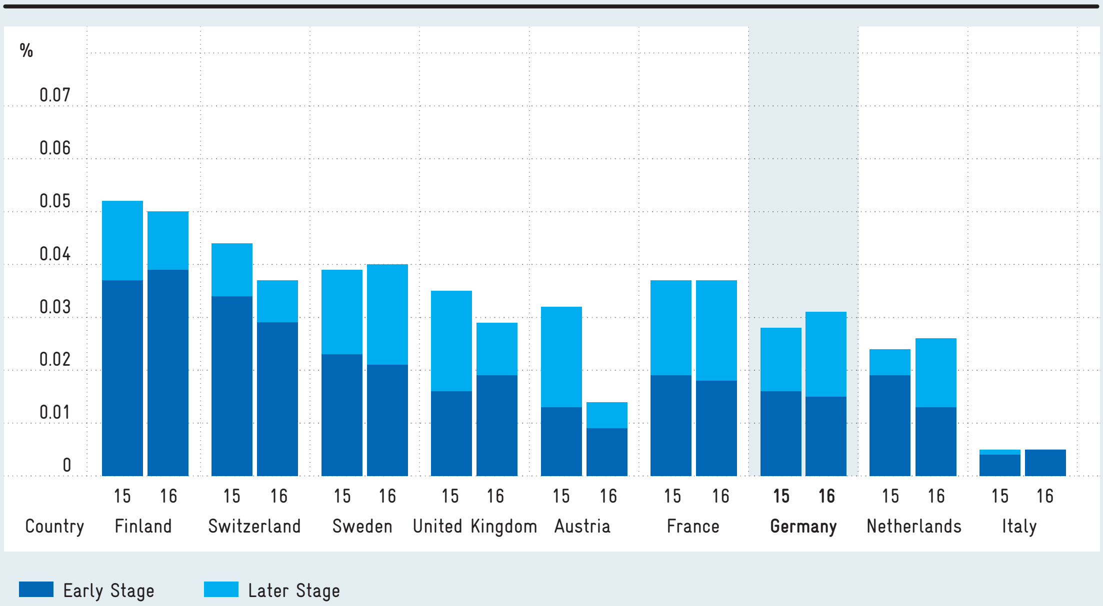
[1] 2014. [2] 2013.
Source: OECD (2017).

Fig. C 4-2

Download data

Venture-capital investment as a percentage of national GDP in 2015 and 2016

Venture capital is defined here as temporary equity investments in young, innovative, non-listed companies.



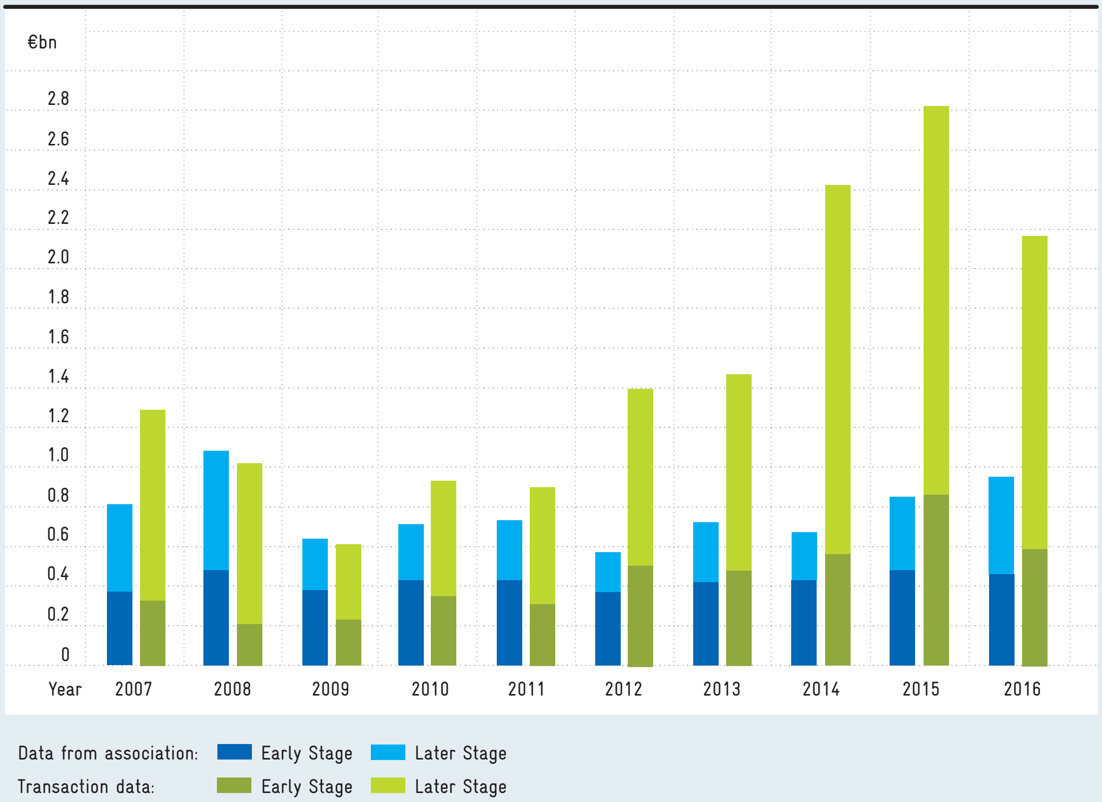
Investments are broken down according to the portfolio companies' head offices.
Early stage comprises the seed phase and the start-up phase.
Source: Invest Europe (2017), Eurostat. Calculations by ZEW in Bersch et al. (2018).

Fig. C 4-3

Download data

Development of venture-capital investment in Germany 2007–2016 in €bn

Venture capital is defined here as temporary equity investments in young, innovative, non-listed companies.



Investments are broken down according to the portfolio companies' head offices. Early stage comprises the seed phase and the start-up phase.
Source of association data: Invest Europe (2017). Calculations by ZEW in Bersch et al. (2018).
Source of transaction data: Bureau van Dijk, Majunke (2017). Calculations by ZEW in Bersch et al. (2018).

C

C 5 New enterprises[400]

An international comparison of start-up rates – i.e. the number of start-up businesses as a percentage of the total number of companies – is only possible at the European level.[401] The Business Demography Statistics provided by Eurostat are used for this purpose (cf. C 5-1). They constitute part of the European Union's Structural Business Statistics (SBS), an official database that is based on evaluations of business registers in the individual Member States. The figures for Germany are provided by the Federal Statistical Office's business demography statistics, which are derived from the German business register.[402] In 2015, the start-up rate in Germany was 7.1 percent, well below the figures for the UK (14.7 percent), the Netherlands (9.7 percent) and France (9.4 percent).[403] Germany did not reach a top position in knowledge-intensive services either; here its start-up rate was 8.3 percent. Germany's start-up rate of 3.8 percent in the R&D-intensive industries was the lowest of the countries examined here.

The figures on company dynamics in the knowledge-based economy shown in charts C 5-2 to C 5-4 are taken from an evaluation of the Mannheim Enterprise Panel (MUP) conducted by the Centre for European Economic Research (ZEW). The MUP is a ZEW panel dataset on businesses located in Germany. It is compiled in cooperation with Creditreform, the largest credit information bureau in Germany. The definition of 'company' used by the MUP is restricted exclusively to economically active companies; 'start-ups' are defined as original, newly formed companies.[404] The start-up rate shown in figure C 5-2 is calculated on the basis of different data from those used in the Business Demography Statistics, which means that a direct comparison cannot be drawn here.[405] According to the data provided by the MUP, the start-up rate in the knowledge-based economy in 2016 was 4.6 percent, 2.4 percentage points lower than ten years earlier (C 5-2).[406] As in previous years, the field of IT/telecommunications had the highest start-up rate – 6.0 percent in 2016 – within the knowledge-based economy.

The closure rate in the knowledge-based economy was 4.3 percent in 2016, around 0.8 percent lower than in 2015 (C 5-3).[407] In all the sectors of the knowledge-based economy examined, the current rate was lower than in the previous year.

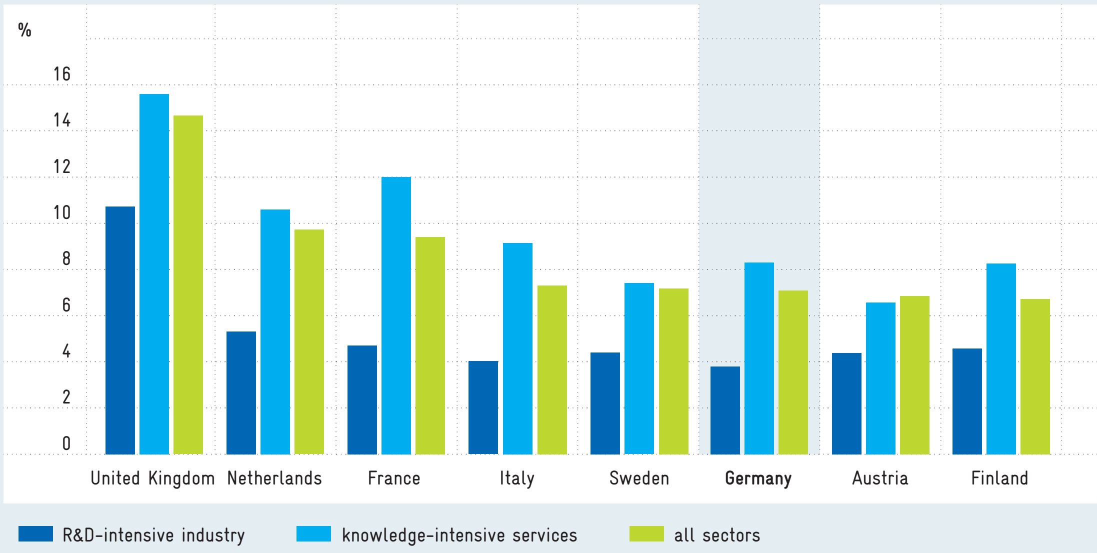
Comparison of the Länder reveals significant differences in start-up rates within Germany (C 5-4).[408] Berlin had the highest start-up rates of all Länder: across all industries (7.4 percent), in R&D-intensive industries (5.6 percent), and in knowledge-intensive services (7.1 percent). The lowest rates were seen across all industries in the east German Länder. The figure was 3.5 percent in Thuringia, 3.8 percent in Saxony, 4.0 percent in Saxony-Anhalt, 4.1 percent in Brandenburg and 4.6 percent in Mecklenburg-Western Pomerania.

Fig. C 5-1

Download data

Start-up rates in 2015 by international comparison as percentages

Start-up rate: number of start-up businesses as a percentage of the total number of companies.



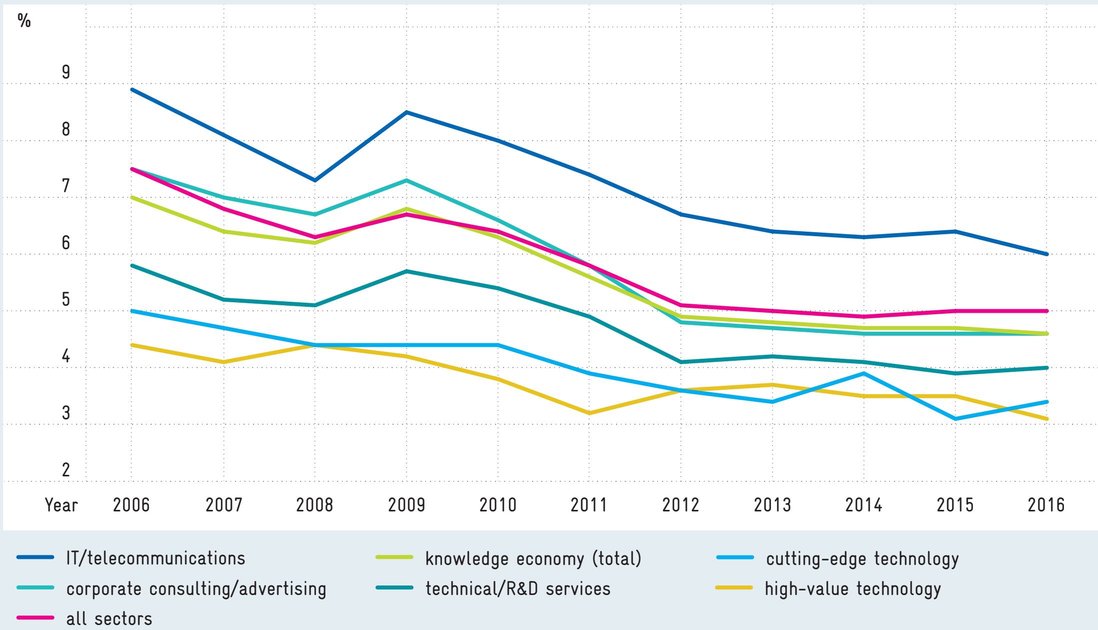
Source: Business Demography Statistics (Eurostat).
Calculations by ZEW in Bersch et al. (2018).

Fig. C 5-2

Download data

Start-up rates in Germany's knowledge economy 2006–2016 as percentages

Start-up rate: number of start-up businesses as a percentage of the total number of companies.



All figures are provisional.
Source: Mannheim Enterprise Panel (ZEW). Calculations by ZEW in Bersch et al. (2018).

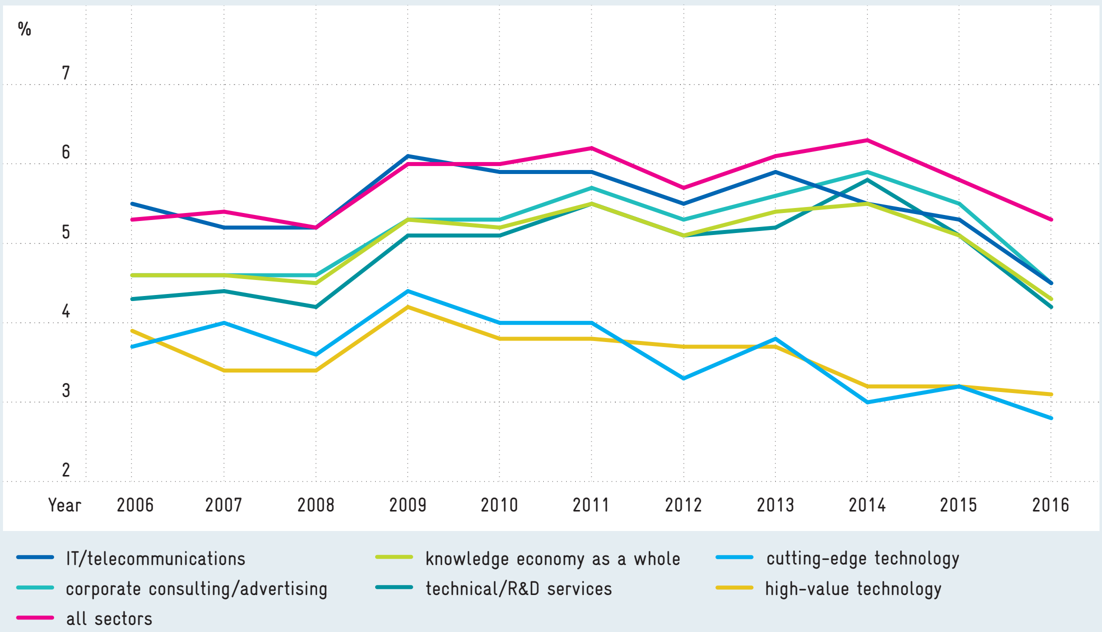
C

Fig. C 5-3

Download data

Closure rates in Germany's knowledge economy 2006–2016 as percentages

Closure rate: number of companies that close down during a year as a percentage of all companies.



All figures are provisional.
Source: Mannheim Enterprise Panel (ZEW). Calculations by ZEW in Bersch et al. (2018)

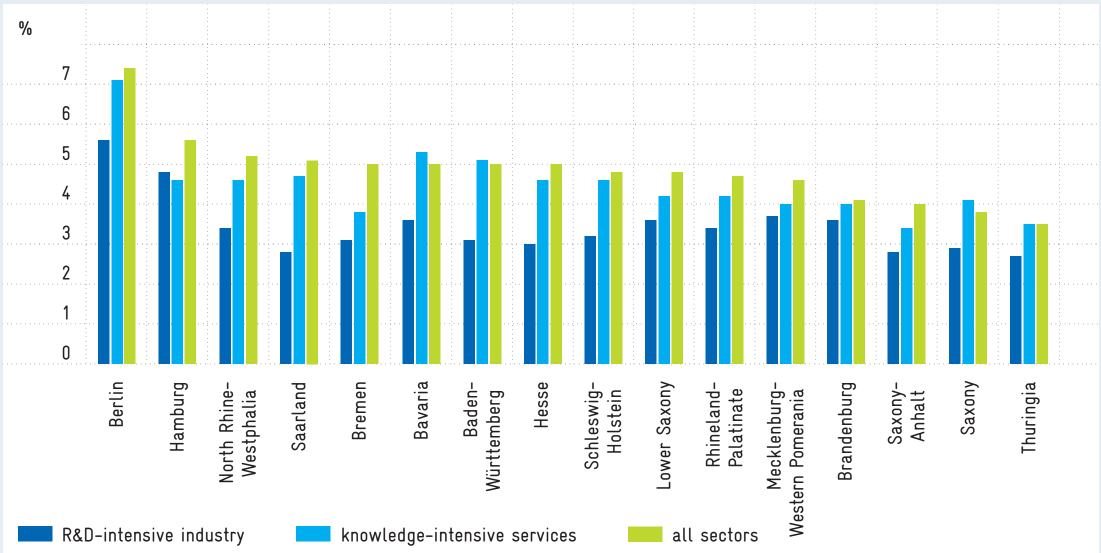
C

Fig. C 5-4

Download data

Start-up rates by Länder 2014–2016 as percentages

Start-up rate: number of start-up businesses as a percentage of all companies.



All figures are provisional.
Source: Mannheim Enterprise Panel (ZEW). Calculations by ZEW in Bersch et al. (2018)

Patents[409] C 6

Since the mid-2000s, transnational patent applications have been stagnating both in Germany and in other major European economies like the UK, Sweden and Switzerland (cf. C 6-1). By contrast, particularly China, South Korea and Japan have recorded high growth rates. China has overtaken Germany in the meantime and is now one of the leading nations in transnational patent applications together with Germany, the USA and Japan.

While the USA is in the lead in terms of the absolute number of applications in 2015, it is not among the frontrunners with regard to patent intensity (i.e. patent applications per million of the working population (C 6-2)). Here the leaders are Switzerland, Sweden and Japan, followed by Finland, Germany and South Korea. Patents are an important tool for securing market shares in the context of the international technology trade. A high patent intensity therefore reflects both a strong international orientation and a pronounced export focus on the part of the respective economy.

Further conclusions on a country's technological performance can be drawn from patent activities in the field of R&D-intensive technologies. This sector is made up of industries that invest more than 3 percent of their turnover in R&D (R&D intensity). R&D-intensive technology comprises the areas of high-value technology (R&D intensity between 3 and 9 percent) and cutting-edge technology (R&D intensity over 9 percent).

International comparisons show that Germany is highly specialized in high-value technology (C 6-3) as a result of its traditional strengths in the automotive, mechanical-engineering and chemical industries. Only Japan is slightly more specialized in this field.

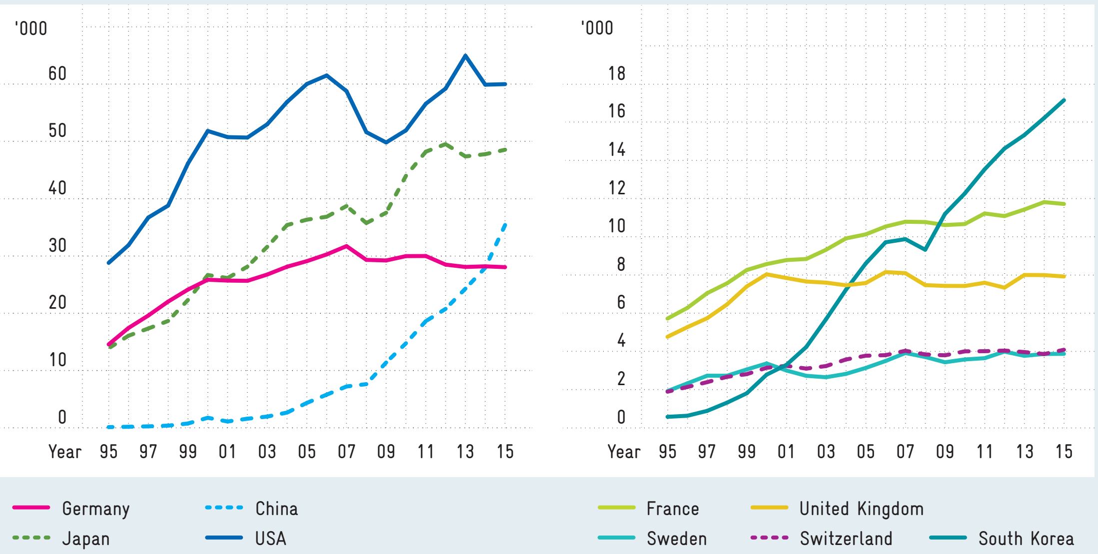
By contrast, China, Sweden, South Korea and the USA are particularly specialized in cutting-edge technology (C 6-4).

Fig. C 6-1

Download data

Development of the number of transnational patent applications in selected countries over time

Transnational patent applications comprise applications in the form of patent families that include at least one application filed with the World Intellectual Property Organization (WIPO) via the Patent Cooperation Treaty (PCT) procedure, or one application filed with the European Patent Office.



Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2018)

C

Tab. C 6-2

Download data

Absolute number, intensity and growth rates of transnational patent applications in the field of R&D-intensive technology in 2015

The R&D-intensive technology sector comprises industries that invest more than three percent of their turnover in research and development. Intensity is calculated as the number of patents per million gainfully employed persons.

	absolute [1]	intensities [1]	intensities in R&D-intensive technology	growth (2005 = 100) [1]	growth in R&D-intensive technology (2005 = 100)
Total	**260,467**	**-**	**-**	**131**	**133**
China	35,394	46	34	812	830
Germany	**28,042**	**701**	**401**	**96**	**98**
EU-28	75,623	342	195	107	108
Finland	1,800	741	436	103	89
France	11,719	439	260	116	117
United Kingdom	7,922	257	150	105	104
Italy	5,644	254	124	96	96
Japan	48,529	761	467	134	128
Canada	3,433	191	121	90	84
Netherlands	4,573	550	293	109	102
Sweden	3,873	801	559	124	138
Switzerland	4,086	823	450	108	109
South Korea	17,151	661	430	199	190
USA	59,975	403	267	100	100

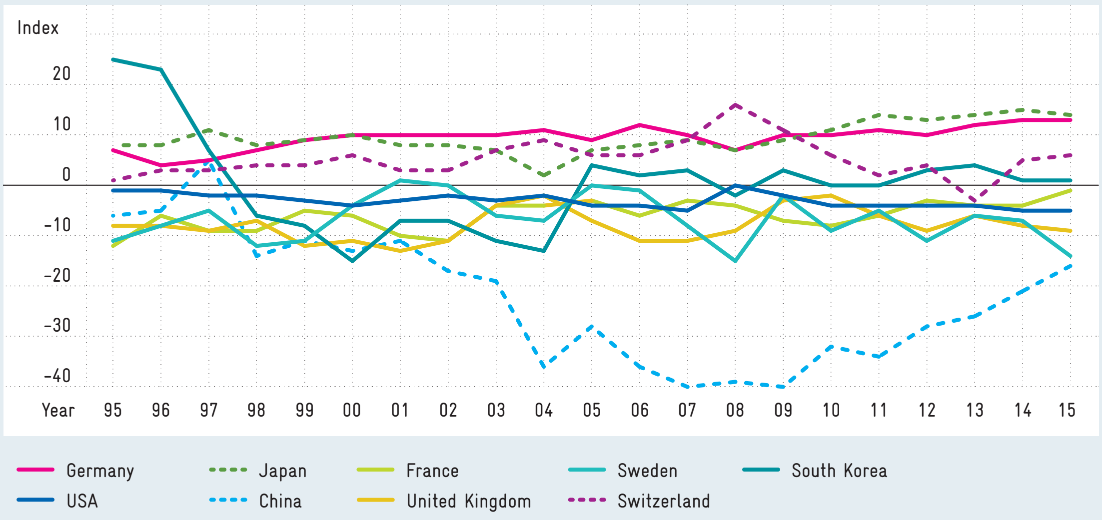
[1] Figures refer to all industries.
Source: EPO (PATSTAT), OECD (MSTI), World Bank, calculations by Fraunhofer ISI in Neuhäusler et al. (2018).

Fig. C 6-3

Download data

Development of the specialization index in selected countries over time in the field of high-value technology

The specialization index is calculated on the basis of all transnational patent applications worldwide. Positive or negative values indicate whether the surveyed country's level of activity in a given field is disproportionately high or disproportionately low compared to the global average.



Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2018)

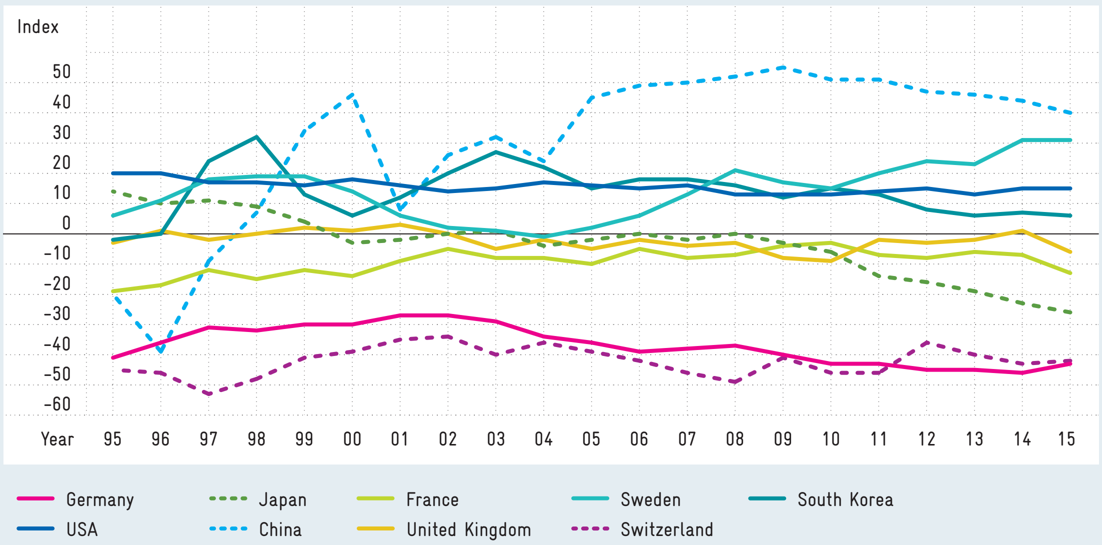
Fig. C 6-4

Download data

C

Development of the specialization index in selected countries over time in the field of cutting-edge technology

The specialization index is calculated on the basis of all transnational patent applications worldwide. Positive or negative values indicate whether the surveyed country's level of activity in a given field is disproportionately high or disproportionately low compared to the global average.



Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2018)

C 7 Scientific publications[410]

A large proportion of new technologies and services are based on developments and results from science. Bibliometric indicators and metrics are regularly used as yardsticks for evaluating scientific achievements to estimate the performance of a research and science system in both quantitative and qualitative terms.

The bibliometric database Web of Science (WoS) covers worldwide publications in scientific journals, as well as citations from these publications. The research affiliation of scientists referenced in the database makes it possible to assign individual publications to a specific country. Fractional counting is employed in cases where several co-authors from different countries contribute to a publication. Indicators on the quantity and quality of scientific publications can be used to assess the performance of a research and science system.

Looking only at the number of publications, individual countries' shares of all WoS publications changed considerably between 2006 and 2016 (C 7-1). China in particular more than doubled its share of publications from 7.4 to 17.0 percent. The shares of South Korea, Brazil and India also increased during this period. By contrast, lower shares were recorded in particular by the established science systems of the USA, Western Europe, Israel and Japan. Germany's share fell from 5.8 to 4.5 percent. Despite the massive increase in publications from China, some countries in Europe, such as Denmark or Poland, still succeeded in increasing their share slightly over time.

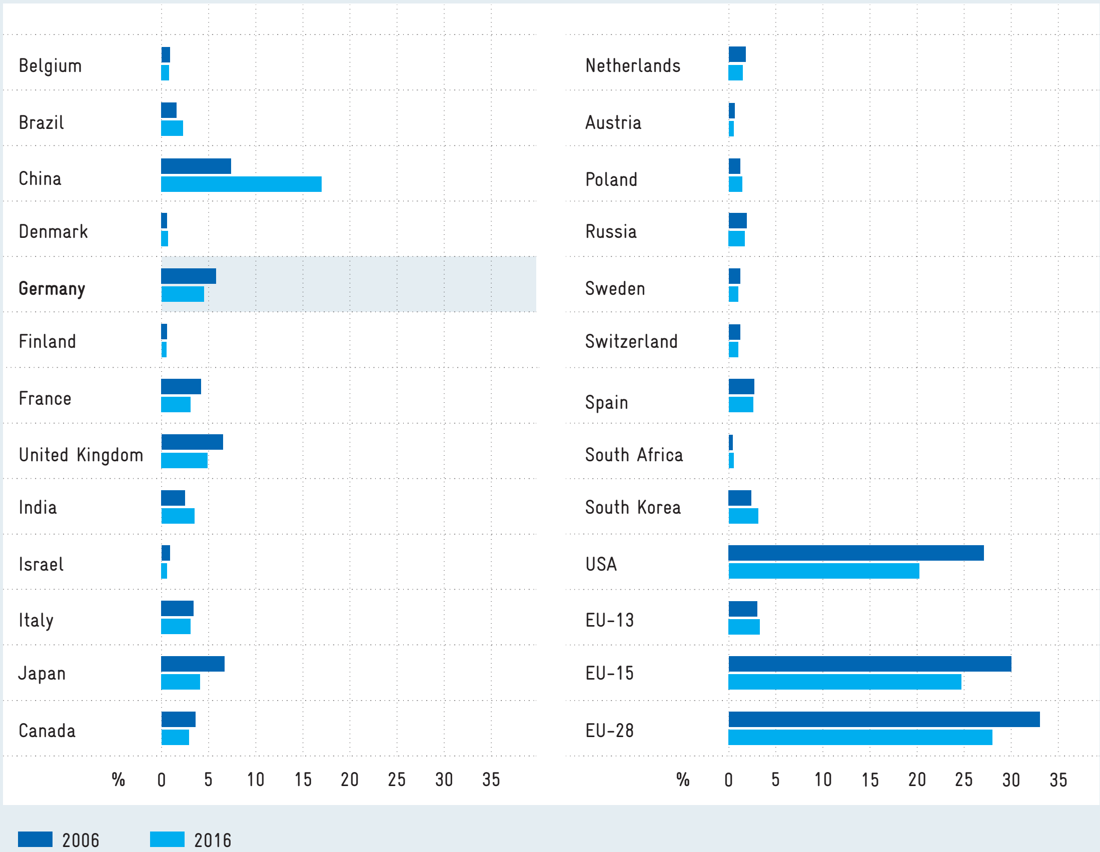
Publications in scientific journals with an international alignment (IA) are an indicator of the quality of scientific publications. In this field, particularly the USA, the Netherlands and Switzerland held a strong position in 2014 (C 7-2). According to this quality indicator, Germany has overtaken such countries as Israel, Canada and Sweden, and caught up with the United Kingdom since 2006, but has not yet quite reached the top group. By contrast, since 2006, scientists from the USA seem to have lost ground in terms of both the quantity (see above) and the quality of their published works in a relative comparison. Most of the BRICS countries – with the exception of Brazil – succeeded in improving their position in the index over time. However, they are still well below the average. The scientific regard (SR) of publications shows that in 2014 publications from Switzerland, the USA, Denmark, China and the UK were cited particularly frequently in scientific journals by international comparison (C 7-3). Germany falls short of this group, and its performance has worsened since 2006. The BRICS countries, by contrast, have improved or – in the case of Russia – stagnated.

Fig. C 7-1

Download data

Percentages of all publications in the Web of Science from selected countries and regions in 2006 and 2016

The analysis concentrates on countries' shares, rather than on absolute figures, to compensate for changes, especially the ongoing expansion of data collection.



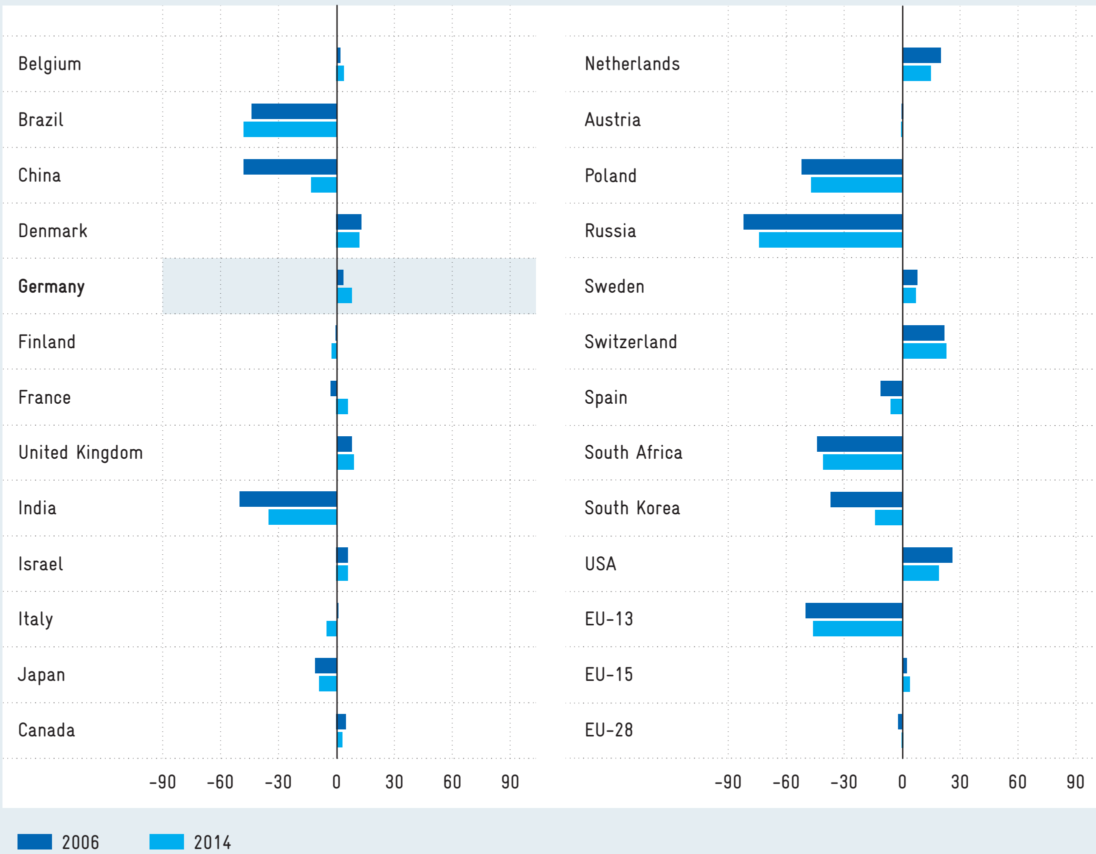
Fractional counting.
Source: Web of Science. Research and calculations by Fraunhofer ISI in Helmich et al. (2018).

Fig. C 7-2

Download data

International alignment (IA) of publications in the Web of Science from selected countries and regions in 2006 and 2014 (index values)

The IA index indicates whether a country's authors publish in internationally more highly recognized or less highly recognized journals relative to the world average. Positive or negative values indicate an above-average or below-average IA.



Fractional counting.
Source: Web of Science. Research and calculations by Fraunhofer ISI in Helmich et al. (2018).

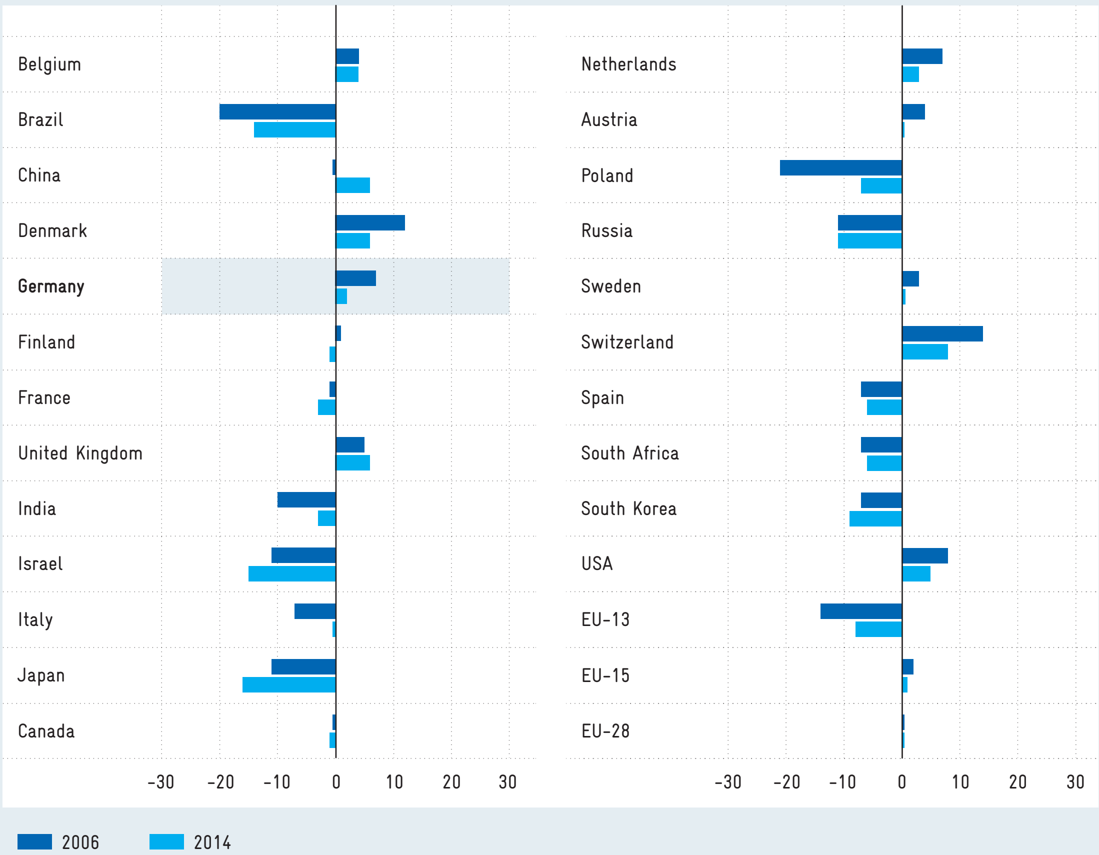
C

Fig. C 7-3

Download data

Scientific regard (SR) of publications in the Web of Science from selected countries and regions in 2006 and 2014 (index values)

The SR index indicates whether a country's articles are cited on average more frequently or more seldom than other articles in the journals in which they appear. Positive or negative values indicate an above-average or below-average scientific regard. The index is calculated without self-citations.



Fractional counting.
Source: Web of Science. Research and calculations by Fraunhofer ISI in Helmich et al. (2018).

C 8 Production, value added and employment[411]

A country's specialization pattern in foreign trade can be measured using the RCA indicator,412 which shows a product group's export/import ratio relative to the export/import ratio of the manufacturing sector as a whole. In 2016, as in previous years, Germany again showed a comparative advantage in trade in R&D-intensive goods (C 8-1). R&D-intensive goods are made up of high-value technology goods and cutting-edge technology goods. A more precise analysis of these two groups of goods shows that Germany has a positive comparative advantage only in trade in high-value technology goods; in trade in cutting-edge technology goods it has a negative comparative advantage, albeit with a slightly positive trend. France, the UK, Switzerland, South Korea and the USA have positive RCA indicator figures for cutting-edge technology; Sweden, Japan and China, on the other hand, have a negative RCA indicator here.

The contribution of research- and knowledge-intensive industries to a country’s value added reflects the importance of these industries and allows conclusions to be drawn about the country’s technological performance (C 8-2). Relative to the other countries studied, Germany has the highest share of value added in the field of high-value technology: in 2015, 9.0 percent of total German value added. In the field of cutting-edge technology, Germany's figure of 2.9 percent is much lower than the frontrunners Switzerland (8.2 percent) and South Korea (8.1 percent). In all the countries, knowledge-intensive services contribute much more to national value added than research-intensive industries. However, with a value-added share of 25.3 percent they play a more minor role in Germany than in other European countries and the USA.

Following the decline in gross value added in several industrial sectors in the crisis year of 2009, value added in Germany has recovered since 2010 (C 8-3). At 3.7 percent, growth in knowledge-intensive services was higher in 2015 than in the previous year (2014: 2.9 percent). A fall in value added was recorded in non-knowledge-intensive services (5.0 percent compared to 6.3 percent in 2014). In manufacturing, the increase in value added was slightly lower in 2015 than in 2014. In 2015, it was 4.2 percent in knowledge-intensive manufacturing (2014: 5.7 percent), and 4.0 percent in non-knowledge-intensive manufacturing (2014: 4.1 percent).

The services sector was the main source of the increase in employment subject to social insurance contributions in different industrial sectors of the German economy between 2009 and 2016 (C 8-4). Employment rose by 17.3 percent in non-knowledge-intensive services, and by 17.2 percent in knowledge-intensive services during this period. Employment subject to social insurance contributions rose by 4.7 percent in the non-knowledge-intensive manufacturing industry and by 7.9 percent in the knowledge-intensive manufacturing sector.

Tab. C 8-1

Download data

Revealed comparative advantage (RCA) of selected countries in foreign trade in research-intensive goods 2005–2016

Year	China[1]	**Germany**	France	United Kingdom	Japan	Sweden	Switzerland	South Korea	USA[2]
				R&D-intensive goods					
2005	-29	**10**	7	14	42	-1	18	17	17
2010	-27	**12**	6	11	33	-6	22	19	1
2015[3]	-27	**13**	5	3	31	-5	28	13	2
2016	-32	**12**	4	17	29	-4	29	10	1
				High-value technology goods					
2005	0	**27**	6	4	75	-2	24	11	-5
2010	-16	**30**	-2	15	61	-3	21	7	-10
2015[3]	-3	**27**	-6	1	63	1	21	13	-14
2016	-2	**24**	-7	16	63	1	25	10	-17
				Cutting-edge technology goods					
2005	-53	**-34**	8	33	-14	1	4	24	55
2010	-35	**-35**	20	1	-22	-11	25	33	22
2015[3]	-46	**-23**	21	8	-35	-22	41	12	27
2016	-55	**-20**	20	19	-41	-20	37	11	30

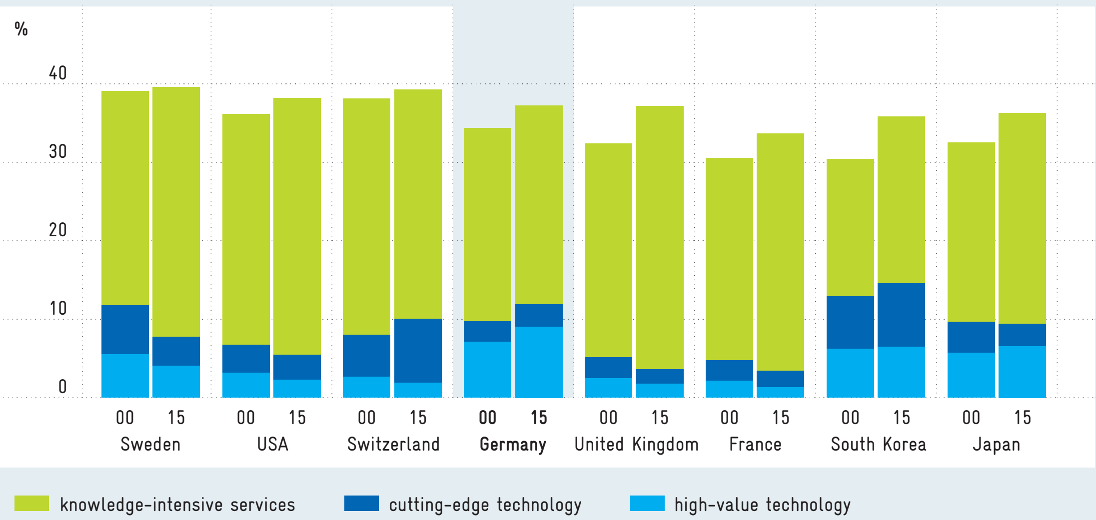
A positive RCA value means that the exp./imp. ratio for this product group is higher than for manufactured industrial goods as a whole.
[1] Incl. Hong Kong. – [2] From 2009, data for the USA were revised on the basis of national sources. – [3] Some of the basic data revised.
Source: UN COMTRADE database, researched September 2017. Calculations and estimates by CWS in Gehrke and Schiersch (2018).

Fig. C 8-2

Download data

R&D-intensive industries and knowledge-intensive services as a percentage of value added in 2000 and 2015

R&D-intensive industries have an above-average R&D intensity, while knowledge-intensive services are characterized by an above-average proportion of employees with tertiary education qualifications.



Source: OECD-NA (2017), OECD-STAN (2017), OECD-SBS (2017), Eurostat-NA (2017), Eurostat-SBS (2017), EU KLEMS (2017), JIP (2015). Calculations and estimates by DIW Berlin in Gehrke and Schiersch (2018).

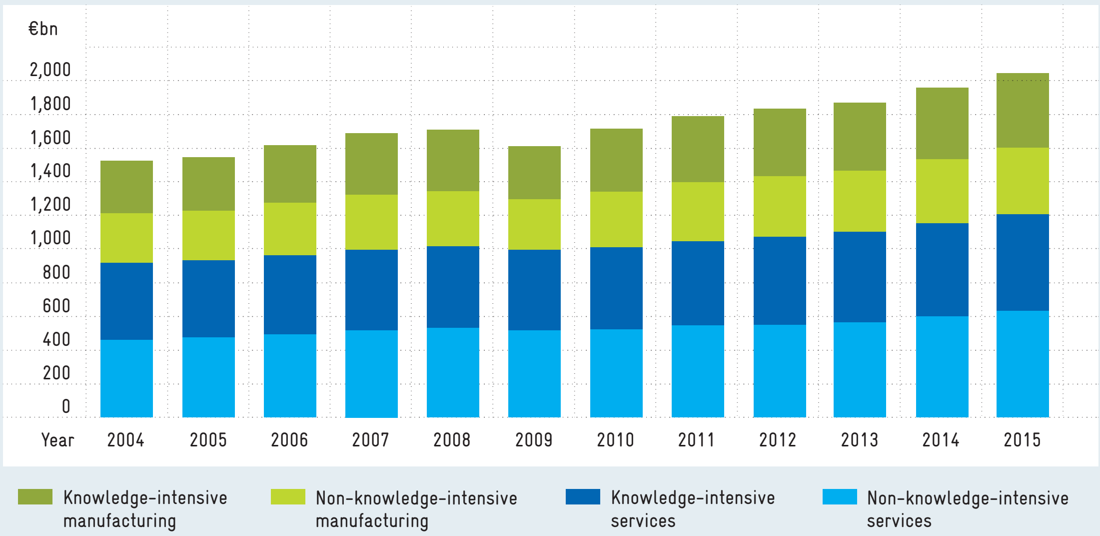
C

Fig. C 8-3

Download data

Development of gross value added in different industrial sectors of the economy in Germany 2004–2015 in €bn

Gross value added is the difference between the total value of all goods and services produced and the intermediate inputs received from other companies for their production.



Not including agriculture, forestry, fisheries, public administration and services, real estate and housing, education, private households, social insurance, religious and other organizations, associations and trade unions.
Source: Statistisches Bundesamt (Federal Statistical Office), Fachserie 18, Reihe 1.4. Calculations by CWS in Gehrke and Schiersch (2018).

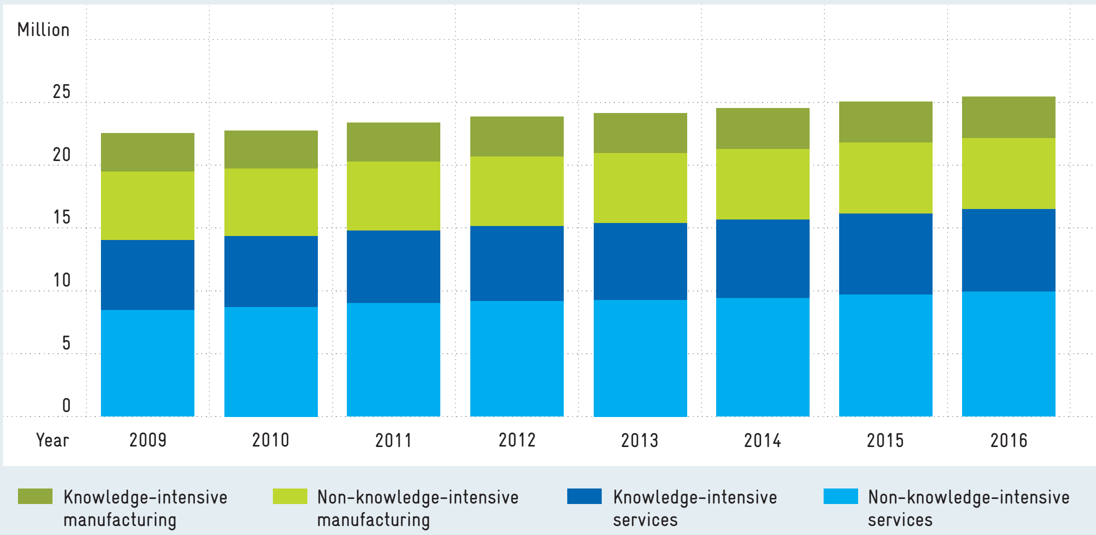
Fig. C 8-4

C

Download data

Development of the number of employees subject to social insurance contributions in different industrial sectors of the economy in Germany 2009–2016

Employees covered by social security insurance comprise all employees who are liable to contribute to health, pension and long-term care insurance, and/or to pay contributions according to German employment-promotion law, or for whom contribution shares must be paid to statutory pension insurance or according to German employment-promotion law.



Source: Federal Employment Agency. Calculations by CWS in Gehrke and Schiersch (2018).

LISTS

D

Contents

List of figures, tables and boxes

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D 2 List of abbreviations

Art.	Article
AUF	non-university research institution
BBC	British Broadcasting Corporation
BIBB	Bundesinstitut für Berufsbildung [Federal Institute for Vocational Education and Training]
GDP	gross domestic product
BMBF	Bundesministerium für Bildung und Forschung [Federal Ministry of Education and Research]
BMVI	Bundesministerium für Verkehr und digitale Infrastruktur [Federal Ministry of Transport and Digital Infrastructure]
BMWi	Bundesministerium für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy]
CIS	Community Innovation Survey
DARPA	Defense Advanced Research Project Agency
DFG	Deutsche Forschungsgemeinschaft [German Research Foundation]
DIHK	Association of German Chambers of Industry and Commerce
ERA	European Research Area
ERDF	European Regional Development Fund
EIC	European Innovation Council
EIT	European Institute of Innovation and Technology
EAFRD	European Agricultural Fund for Rural Development
ERA-NET	European Research Area Networks
ERC	European Research Council
ESF	European Social Fund
ESI Funds	European Structural and Investment Funds
EU	European Union
EEA	European Economic Area
R&I	research and innovation
CFCs	chlorofluorocarbons
FET	future and emerging technologies
RFP	Research Framework Programme
R&D	research and development
GERD	Gross Domestic Expenditure on Research and Development
GG	Grundgesetz [Basic Law, Germany's constitution]
HR	human resources
HTS	High-Tech Strategy
ICILS	International Computer and Information Literacy Study
ICT	information and communication technology
IoT	Internet of Things
IT	information technology
ITA	Innovation and Technology Analysis

JEDI ... Joint European Disruptive Initiative
JRC ... Joint Research Centre
AI ... artificial intelligence
KIC ... Knowledge and Innovation Community
KldB ... Classification of Occupations
SMEs ... small and medium-sized enterprises
Lidar ... Light Detection and Ranging
Mbit/s ... megabits per second
MINT-EC ... Excellence network of schools specializing in mathematics and the natural sciences
MIT ... Massachusetts Institute of Technology
MOOC ... massive open online course
OECD ... Organisation for Economic Cooperation and Development
PIAAC ... Programme for the International Assessment of Adult Competencies
RRI ... Responsible Research and Innovation
SDG ... Sustainable Development Goal
TFP ... total factor productivity
IVTF ... inter-company vocational training facility
NA ... National Accounts
UAS ... university of applied sciences
WBGU ... Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen [German Advisory Council on Global Change]
WLAN ... Wireless Local Area Network
ZIM ... Zentrales Innovationsprogramm Mittelstand [Central Innovation Programme for SMEs]

D 3 Glossary

Actuators, actuatorics
Actuators convert control signals primarily into movement, but also, for example, into pressure or temperature. In actuatorics, which is seen as a branch of drive engineering, distinctions are made between mechanical, pneumatic, electromechanical, biological, optical and thermal actuators.

Anchor investor
An anchor investor is an investor that acquires a large or the largest share in listed companies, start-ups or venture capital funds. In this way, the financing of the company is visibly secured, making it easier to attract the remaining funds required, since the confidence of interested investors is strengthened.

Basic funds
Basic funds are the budgetary funds of tertiary education institutions

Benchmark study
A benchmark study is a process that aims to continuously evaluate one's own performance and compare it with that of competitors in the market. The aim is to increase one's own efficiency.

Bibliometrics
Bibliometrics is the quantitative study of publications, authors and institutions – mostly using statistical methods. It is a subfield of scientometrics, the quantitative study of science and scientific processes.

Bologna Reform or Bologna Process
It is based on the Sorbonne Declaration of 1998, which was incorporated into the EU's Bologna Declaration of 1999. The goal was described as the EU-wide harmonization of higher education and its tertiary degrees by 2010. Key aspects are: comparable tertiary degrees (two-tier system with Bachelor's and Master's degrees), uniform assessment standards (performance points or 'credits' according to the ECTS system), more mobility by overcoming obstacles, and European collaborations in the field of quality assurance.

Closure rate
The closure rate is defined as the number of closed-down companies as a percentage of the annual average number of active companies in a country.

Community Innovation Surveys
The Community Innovation Surveys (CISs) are the European Union's most important statistical instrument for surveying innovation activities in Europe. The CISs analyse the economic effects of innovation by polling a representative sample of companies.

Curriculum
The curriculum (plural: curricula) is a systematic representation of the intended teaching targets, contents and methods over a certain period of time for the purpose of preparing, implementing and evaluating teaching.

Cutting-edge technology
When an annual average of more than nine percent of turnover is spent on research and development in the manufacture of an R&D-intensive product (cf. ibid), the latter is called a product of cutting-edge technology.

Debt capital
Debt capital is provided to companies by capital investors for a set period. In return, the investors expect the capital to be repaid with interest. In order to ensure the servicing of a loan, bankers require adequate planning of reliable future operating results and/or the provision of collateral.

Dual education system
The term 'dual education system' refers to professional training conducted in parallel at the workplace and at a vocational school or Berufsakademie (university of cooperative education). The workplace training is conducted according to a clearly defined training scheme for the respective profession, and the scholastic training according to the specifications of the respective education authority.

E-government
E-government (electronic government) means using information and communication technologies via electronic media to run governmental and

administrative processes. In e-government, public services and administrative matters are digitized and made available online.

Early stage
'Early stage' describes the financing of a company's early-phase development – beginning with the funding of research and the product design (seed phase), continuing with the formation of the company until the beginning of operational business activities, and including product development and initial marketing (start-up phase). The seed phase is limited to R&D up to market maturity and the initial implementation of a business idea with a prototype; during the start-up phase a business plan is drafted, and production and product marketing begin.

Economies of scale
Economies of scale refer to cost advantages due to size: the costs per unit – i.e. the costs incurred by the company to make one unit of a product – decrease as the production volume increases. Economies of scale explain why many companies strive for greater size by opening up new markets or buying up other companies.

Enquete-Kommission (Committee of Inquiry)
An Enquete-Kommission is a working group set up by a parliament (e.g. the Bundestag) to debate complex future issues. Together with external experts, MPs discuss economic, social and legal aspects of the issue. The work of the Enquete-Kommission prepares the content of legislative proposals.

Equity capital
Equity capital is a company's liable capital. Equity capital is raised by the company's owners themselves, or provided by profits generated by, and left within, the company. It can also be obtained from external investors, i.e. in the form of venture capital (cf. ibid).

EU-13 countries
The countries that joined the EU between 2004 and 2007 (Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia) plus Croatia, which joined in 2013.

EU-15 countries
Countries that were already EU Member States in April 2004 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK).

EU-28 countries
Since July 2013, the EU has comprised 28 member countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the UK).

EU Research Framework Programme
Public funding of research and development in the European Union is implemented through specific programmes, each of which addresses a certain research area and usually runs for several years. These programmes are subsumed under a larger unit, the Research Framework Programme.

EU State Aid Framework
In the Community Framework for State Aid for Research and Development and Innovation (abbreviated to EU State Aid Framework), which came into force on 1 January 2007, the European Commission sets out, among other things, the conditions under which research institutions are deemed to be recipients of state aid, and the conditions under which companies are recipients of indirect state aid from state-funded public research institutions.

Europe 2020 Initiative
The core objective of the Europe 2020 Initiative is better coordination of the national and European economy. It is the successor programme to the Lisbon Strategy (strategy to make Europe the most competitive and dynamic knowledge-based economy in the world) and pursues a more comprehensive approach to R&D funding, lifelong learning and the promotion of environment-friendly technologies.

European Structural and Investment Funds
The European Structural and Investment Funds (ESI Funds) are the European Regional Development Fund (ERDF), the European Social Fund (ESF), the Cohesion Fund (CF), the European Agricultural Fund for Rural Development (EAFRD) and the European Maritime and Fisheries Fund (EMFF).
Alongside the CF, the ERDF and the ESF are the key control instruments of European Cohesion Policy. Their primary aim is to promote convergence, competitiveness and the employment situation in structurally weak regions, as well as supra-regional cooperation.

Externalities
Externalities are defined as impacts of economic activities on third parties for which no compensation is paid. One example is knowledge externalities (cf. ibid).

Frascati guidelines
The Frascati guidelines come from the OECD's Frascati Manual, in which terms from research and development are defined and classified. They also specify calculation methods and conventions on R&D.

Frascati Manual
The OECD's Frascati Manual specifies methods for collecting and analysing data on research and development. In 1963, OECD experts met for the first time with members of the NESTI group (National Experts on Science and Technology Indicators) in Frascati (Italy) to define key concepts such as 'research' and 'development'. The results of these discussions formed the basis of the first Frascati Manual. The Frascati Manual has been revised several times since then. The most recent edition dates from 2015.

Governance
Governance refers to the control and regulatory system in the sense of structures (organization and workflows) of a political-societal unit, e.g. the state, an administration, a municipality, a private or public organization. The term is often also used in the sense of the control or regulation of any organization (such as a company or factory).

Gross domestic product (GDP)
The GDP is the total value of all goods produced and services provided in a country's economy within a year. It is not relevant in this context whether domestic or foreign actors are involved in the production of GDP; the only important factor is where the value is added. The GDP is an indicator of the economic performance of an economy by international comparison.

High-Tech Strategy (HTS)
The High-Tech Strategy is a policy initiative by the Federal Government to integrate innovation funding across all federal ministries. The current New High-Tech Strategy was adopted by the Federal Cabinet in September 2014.

High-value technology
High-value technology refers to R&D-intensive goods (cf. ibid) in the production of which, on an annual average, more than 3 percent, but not more than 9 percent, of turnover is spent on research and development.

Higher-education acts of the Länder
The higher-education acts of the Länder (federal states) regulate all issues relating to state-run tertiary education institutions in the respective federal state. Each federal state exercises its independence in cultural and educational matters by adopting its own higher education act. The Standing Conference of Education Ministers (Kultusministerkonferenz, KMK) is responsible for coordination between the Länder.

Higher Education Pact
The Higher Education Pact is an agreement between the Federal and Länder governments that was launched in 2007 and is designed to continue until 2020. It aims, on the one hand, to provide a range of study courses that is in line with demand and, on the other, to intensify competition for research funding by financing the DFG programme allowance.

Horizon 2020
Horizon 2020 is the European Union's Framework Programme for Research and Innovation. It not only continues the EU's Seventh Research Framework Programme, but also integrates the European Institute of Innovation and Technology (EIT) and the innovation-related elements of the previous Competitiveness and Innovation Framework Programme (CIP).

Incremental innovation
Innovation achieved by improving an existing product is referred to as incremental. By contrast, radical innovation (cf. ibid) refers to fundamental innovations that lead to entirely new product concepts and technical solutions.

Inducement prize contest
Inducement prize contests (IPCs) are an instrument for promoting innovation. They are funding competitions in which prize money is paid out. The organization and design of these competitions can vary greatly. Important elements which influence the effect of this instrument include the amount of prize money, the number of potential winners,

any stipulations on the exploitation of intellectual property rights, and whether the award is tied to the market success of the proposed solutions.

Industry 4.0
In industrial production, machines, plants and products are connected to form an IT network of embedded systems to increase flexibility and efficiency. The term Industry 4.0, which was coined in Germany within the framework of the 2011 Hannover Messe (Hanover Trade Fair), thus focuses on the use of the 'Internet of Things' (cf. ibid) in an industrial context.

Innovation expenditure
Innovation expenditure relates to spending on ongoing, completed and cancelled projects within a year. It is made up of current expenditure (personnel and material costs, etc.) and investment expenditure. Innovation expenditure includes innovation-related spending on machinery, equipment, software and external knowledge (e.g. patents, licences), on engineering, design, product design, service concept, employee training and further education/training, market launch and other preparations for the production and distribution of innovations, as well as all internal and external expenditure on research and development.

Innovation intensity
Innovation intensity is defined as innovation expenditure as a percentage of turnover.

Innovator rate
The innovator rate is defined as the number of companies that have launched a product or process innovation within a three-year period as a percentage of all the companies active in a country.

Internet of Things
The use of information and communication technologies in everyday objects has created a connection between the real world and the virtual world. This networking of devices and people is called the 'Internet of Things' (IoT) or 'Internet of Things and Services'. Examples include computer systems embedded into clothing that monitor the wearer's vital functions, imprinted chip codes that make it possible to track packages via the internet, and refrigerators that autonomously order foodstuffs when stocks are low.

Investment capital
Investment capital is defined as funds from an investor/lender that serve the external self-financing of a company. This kind of financing is highly dependent on the legal form (cf. Equity capital).

Knowledge externalities
In research and innovation, externalities occur in the form of knowledge spillover. Competitors can gain knowledge by inspecting innovative products and processes, without having to bear the full cost of knowledge production themselves.
Conversely, this means that innovators are unable to privatize the full social or societal returns on their product or process developments. The private returns on the innovation deviate from the social returns, so that, from a societal point of view, the innovator will invest too little in the production of knowledge as a result.

Knowledge economy
The knowledge economy encompasses R&D-intensive industries and knowledge-intensive services (cf. chapter D 4 for more details).

Knowledge-intensive services
Knowledge-intensive services are primarily characterized by a workforce with an above-average percentage of employees who have tertiary education qualifications.

Labour force
The labour force (or working population) is the subgroup of the potential labour force (cf. ibid) who are gainfully employed or registered as unemployed.

Later stage
'Later stage' describes the financing of business expansion in a young company which is already generating turnover and whose product is ready for the market.

The Lisbon Agenda
The Lisbon Agenda, devised in 2000, is the programmatic strategy of the European Research Area. Its goal was to make the EU the most competitive and dynamic knowledge-based economy in the world by 2010.

Manufacturing
Manufacturing industries are by far the largest part of industry comprising all industrial sectors with the exception of energy and construction. Defining

sectors include the food industry, mechanical engineering, the manufacture of motor vehicles and motor-vehicle parts, the manufacture of metal products, and the chemical industry.

Market failure
Market failure is a situation in which the result of market coordination deviates from the macroeconomically optimum allocation of goods or resources. The reasons for market failure can be the presence of externalities, public goods or information asymmetries.

National accounts
The national accounts (NA) are a set of instruments for observing the economy. They provide a comprehensive, quantitative overall picture of economic activity. The national accounts consist of the calculation of the domestic product, the input-output accounts, national wealth accounts, employment accounts, labour volume accounts and financial accounts.

On demand
On demand means that a product or service is only produced or provided at the direct request of a customer, i.e. at short notice.

Oslo Manual
The OECD's Oslo Manual contains specifications on the statistical gathering of information on innovation activities. This manual goes beyond the R&D definition used by the Frascati Manual (cf. ibid) and distinguishes between different forms of innovation. The Oslo Manual serves as the basis for the Community Innovation Surveys (CIS).

Pact for Research and Innovation
The Pact regulates increases in the funding of Germany's five non-university science and research organizations by the Federal and Länder governments. The science and research organizations in turn have committed themselves to improving the quality, efficiency and performance of their respective research and development activities.

Patent family
A patent family denotes a group of patents or patent applications that are directly or indirectly connected by a common priority, have at least one common priority, or have exactly the same priority or combination of priorities. The 'priority' indicates the seniority of a patent and in this way lays down, inter alia, the state of the art that has to be taken into account when assessing the patentability of the application.

PCT application
The international patent application process was simplified in 1970 with the adoption of the Patent Cooperation Treaty (PCT) under the umbrella of the World Intellectual Property Organization (WIPO, established in 1969). Instead of filing several separate national or regional applications, inventors from PCT countries can submit a single advance patent application to the WIPO, or another registered authority. This enables them to obtain patent protection in all 148 contracting countries. The priority date of the patent is the date on which the application is submitted to the WIPO. The final decision on the countries where patent protection is to be granted must be taken within a period of 30 months (or 31 months at some authorities like the EPA). National or regional patent offices are nevertheless still responsible for the actual granting of patents.

Potential labour force
The potential labour force includes the resident population aged between 15 and 65, i.e. the population of working age. It is made up of employed persons, the unemployed and the so-called 'hidden reserve'. The 'hidden reserve' includes people who are unemployed but are not registered as seeking employment.

Programme allowance
Programme allowances represent the second pillar of the Higher Education Pact (cf. ibid). Prior to the introduction of the Pact, it was the responsibility of the tertiary education institutions to meet the overhead costs of a project's implementation themselves. Now, applicants for projects funded by the German Research Foundation (DFG) receive a programme allowance to cover the indirect, additional and variable costs connected with the funding. The allowance is 22 percent of the accountable direct project costs.

Purchasing power parity
Like the exchange rate between currencies, purchasing power parity makes it possible to make value-based comparisons between different countries or economic areas. Purchasing power parities are determined by comparing prices for a basket of commodities containing comparable goods that are representative of consumer behaviour in the individual countries.

R&D intensity
R&D intensity is defined as expenditure on research and development (R&D) as a percentage of either a company's or a sector's total turnover, or of a country's gross domestic product.

R&D-intensive goods
R&D-intensive goods comprise cutting-edge technology goods (cf. ibid) and high-value technology goods (cf. ibid).

Radical innovation
A radical innovation is a fundamental innovation that leads to entirely new product concepts, technical solutions or services – in contrast to incremental innovation, which refers to the improvement of an existing product or process.

RCA Index
The RCA (revealed comparative advantage) Index describes the relation between exports and imports in a commodity group relative to the total economic relation between exports and imports. For the purpose of mathematical representation, this ratio is logarithmized and the factor multiplied by 100.

Research and development (R&D)
The OECD's Frascati Manual (cf. ibid) defines research and development as systematic, creative work aimed at expanding knowledge – also with the objective of developing new applications.

Research and innovation (R&I)
Research and development (R&D) and R&I are not used synonymously. According to the OECD's Frascati Manual (cf. ibid), the term R&D comprises the three areas of basic research, applied research, and experimental development. Thus, R&D refers to only one aspect of R&I activities. According to the definition given in the OECD's Oslo Manual (cf. ibid), innovations include the introduction of new or essentially improved products (goods and services), processes, and marketing and organizational methods. Innovation expenditure comprises spending on internal and external R&D, machines and materials for innovations, product design, the market launch of new products, and other innovation-related goods and services.

RPA Index
The RPA (revealed patent advantage) Index refers to a country's share in a given technology in relation to this technology's share in global patent applications. The mathematical formulation is analogous to that of the RCA Index in foreign trade.

Seed phase
Cf. Early stage.

Sensorics, sensors
Sensorics is the science and application of sensors for measuring and monitoring changes in technical systems in the vicinity of one or more sensors. Sensors are technical components. For example, there are optical, acoustic and tactile sensors which make it possible to measure changes in the environment.

Social innovations
Social innovations are changes in the way in which technologies are used – or changes in lifestyles, business or financing models, working practices, or forms of organization; in principle they represent changes in social practices. Social innovations can be both complementary to and a consequence of a technological innovation – or be completely independent of such an innovation.

Spillover effects
Spillover effects occur in research and innovation in the form of knowledge transfer, e.g. when company A is able to generate profits on the basis of the R&D activities of another company B.

Start-up
A start-up is a newly founded company with an innovative business idea.

Start-up phase
Cf. Early stage.

Start-up rate
The start-up rate is the number of start-ups in relation to the total number of companies – it is a useful indicator of the degree of renewal of active companies throughout the economy.

Third-party funds/funding
Third-party funding is funding for universities or other research institutions raised from public or private sources in addition to the regular budget (basic or institutional funding).

Three-percent target
In 2002, the European Council decided in Barcelona to increase the EU's R&D expenditure to three

percent of a country's GDP by 2010. In addition, two-thirds of this expenditure was to be financed by the private sector.

Transnational patents

Transnational patent applications are applications in the form of patent families which include at least one application filed with the World Intellectual Property Organization (WIPO) via the Patent Cooperation Treaty (PCT) procedure, or one application filed with the European Patent Office. Such patents are particularly important for the export-based German economy, since they secure the protection of inventions beyond the domestic market.

Value added

Value added is the total of all factor income (wages, salaries, interest, rental and lease income, sales profits) in a given period in the national accounts and is equivalent to national income (national product). In a business sense, value added refers to the production value generated in a given period minus the value of the intermediate inputs received from other companies in the same period.

Venture capital

Venture or risk capital refers to initial capital for start-up entrepreneurs and young enterprises. It also includes funding used to strengthen the equity-capital bases of small and medium-sized enterprises, enabling them to expand and to implement innovative, sometimes very risky projects. Venture-capital investments are also associated with a high risk for the capital investors. This is why venture capital is also referred to as risk capital. Venture capital is often provided by special venture-capital companies (capital-investment companies). A distinction is made between three phases of start-up companies: the seed, start-up and later stage.

Economic sectors in R&D-intensive industries and knowledge-intensive industrial services[413]

D 4

R&D-intensive industrial sectors within the Classification of Economic Activities, 2008 edition (WZ 2008) (4-digit classes)

Cutting-edge technology

20.20 Manufacture of pesticides and other agrochemical products
21.10 Manufacture of basic pharmaceutical products
21.20 Manufacture of pharmaceutical preparations
25.40 Manufacture of weapons and ammunition
26.11 Manufacture of electronic components
26.20 Manufacture of computers and peripheral equipment
26.30 Manufacture of communication equipment
26.51 Manufacture of instruments and appliances for measuring, testing and navigation
26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment
26.70 Manufacture of optical instruments and photographic equipment
29.31 Manufacture of electrical and electronic equipment for motor vehicles
30.30 Manufacture of air and spacecraft and related machinery
30.40 Manufacture of military fighting vehicles

High-value technology

20.13 Manufacture of other inorganic basic materials and chemicals
20.14 Manufacture of other organic basic materials and chemicals
20.52 Manufacture of glues
20.53 Manufacture of essential oils
20.59 Manufacture of other chemical products n.e.c.
22.11 Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres
22.19 Manufacture of other rubber products
23.19 Manufacture and processing of other glass, including technical glassware
26.12 Manufacture of loaded electronic boards
26.40 Manufacture of consumer electronics
27.11 Manufacture of electric motors, generators and transformers
27.20 Manufacture of batteries and accumulators
27.40 Manufacture of electric lighting equipment
27.51 Manufacture of electric domestic appliances
27.90 Manufacture of other electrical equipment
28.11 Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
28.12 Manufacture of fluid power equipment
28.13 Manufacture of other pumps and compressors
28.15 Manufacture of bearings, gears, gearing and driving elements
28.23 Manufacture of office machinery and equipment (excluding computers and peripheral equipment)
28.24 Manufacture of power-driven hand tools
28.29 Manufacture of other general-purpose machinery n.e.c.
28.30 Manufacture of agricultural and forestry machinery
28.41 Manufacture of machine tools
28.49 Manufacture of other machine tools
28.93 Manufacture of machinery for food, beverage and tobacco processing
28.94 Manufacture of machinery for textile, apparel and leather production
28.95 Manufacture of machinery for paper and paperboard production
28.99 Manufacture of other special-purpose machinery n.e.c.
29.10 Manufacture of motor vehicles
29.32 Manufacture of other parts and accessories for motor vehicles
30.20 Manufacture of railway locomotives and rolling stock
32.50 Manufacture of medical and dental instruments and supplies

Knowledge-intensive industrial services WZ 2008 (3-digit classes)

Knowledge-intensive services

Emphasis on finance and assets

411 Development of building projects
641 Monetary intermediation
642 Activities of holding companies
643 Trusts, funds and similar financial entities
649 Other financial service activities, except insurance and pension funding
651 Insurance
652 Reinsurance
653 Pension funding
661 Activities auxiliary to financial services, except insurance and pension funding
663 Fund management activities
681 Buying and selling of own real estate
683 Real estate activities on a fee or contract basis
774 Leasing of intellectual property and similar products, except copyrighted works

Emphasis on communication

611 Leitungsgebundene Telekommunikation
612 Drahtlose Telekommunikation
613 Satellitentelekommunikation
619 Sonstige Telekommunikation
620 Erbringung von Dienstleistungen der Informationstechnologie
631 Datenverarbeitung, Hosting und damit verbundene Tätigkeiten; Webportale
639 Erbringung von sonstigen Informationsdienstleistungen Schwerpunkt technische Beratung und Forschung
711 Architectural and engineering activities and related technical consultancy
712 Technical testing and analysis
721 Research and experimental development on natural sciences and engineering
749 Other professional, scientific and technical activities n.e.c.

Emphasis on non-technical consulting and research

691 Legal activities
692 Accounting, bookkeeping and auditing activities; tax consultancy
701 Activities of head offices
702 Management consultancy activities
722 Research and experimental development on social sciences and humanities
731 Advertising
732 Market research and public opinion polling
821 Office administrative and support activities

Emphasis on media and culture

581 Publishing of books and periodicals; other publishing activities
582 Software publishing
591 Motion picture, video and television programme activities
592 Sound recording and music publishing activities
601 Radio broadcasting
602 Television programming and broadcasting activities
741 Specialised design activities
743 Translation and interpreting activities
823 Organisation of conventions and trade shows
900 Creative, arts and entertainment activities
910 Libraries, archives, museums and other cultural activities

Emphasis on health

750 Veterinary activities
861 Hospital activities
862 Medical and dental practice activities
869 Other human health activities n.e.c.

Recent studies on the German innovation system

D 5

The Commission of Experts for Research and Innovation (EFI) regularly commissions studies on topics that are relevant to innovation policy. These studies can be accessed via the EFI website (www.e-fi.de) in the series 'Studien zum deutschen Innovationssystem' ('Studies on the German innovation system'). The findings are integrated into the report of the Commission of Experts.

1-2018
Gehrke, B.; Kerst, C. (2018): Bildung und Qualifikation als Grundlage der technologischen Leistungsfähigkeit Deutschlands 2018 (Kurzstudie). Studien zum deutschen Innovationssystem. Berlin: EFI.

2-2018
Schasse, U.; Gehrke, B.; Stenke, G. (2018): Forschung und Entwicklung in Staat und Wirtschaft – Deutschland im internationalen Vergleich. Studien zum deutschen Innovationssystem. Berlin: EFI.

3-2018
Bersch, J.; Berger, M; Wagner, S. (2018): Unternehmensdynamik in der Wissenswirtschaft in Deutschland 2016, Gründungen und Schließungen von Unternehmen, Gründungsdynamik in den Bundesländern, Internationaler Vergleich, Wagniskapital-Investitionen in Deutschland und im internationalen Vergleich. Studien zum deutschen Innovationssystem. Berlin: EFI.

4-2018
Neuhäusler, P.; Rothengatter, O.; Frietsch, R. (2018): Patent Applications – Structures, Trends and Recent Developments 2017. Studien zum deutschen Innovationssystem. Berlin: EFI.

5-2018
Helmich, P.; Gruber, S; Frietsch, R. (2018): Performance and Structures of the German Science System 2017. Studien zum deutschen Innovationssystem. Berlin: EFI.

6-2018
Gehrke, B.; Schiersch, A. (2018): FuE-intensive Industrien und wissensintensive Dienstleistungen im internationalen Vergleich. Studien zum deutschen Innovationssystem. Berlin: EFI.

7-2018
Ostertag, K; Neuhäusler, P.; Helmich, P.; Frietsch, R.; Walz, R.; Gehrke, B.; Schasse, U. (2018): FuI-Indikatoren zu Nachhaltigkeit und Klimaschutz: Forschung, Entwicklung, Innovationen und Marktergebnisse. Studien zum deutschen Innovationssystem. Berlin: EFI.

8-2018
Ostertag, K.; Bodenheimer, M.; Neuhäusler, P.; Helmich, P.; Walz, R. (2018): Organisational Innovations, Social Innovations and Societal Acceptability in the Context of Sustainability. Studien zum deutschen Innovationssystem. Berlin: EFI.

9-2018
Rothgang, M.; Dehio, J.; Janßen-Timmen, R.; Stiebale, J. (2018): Sektorfallstudien zu Determinanten der Produktivitätsentwicklung in der Automobilindustrie, im Maschinenbau und bei den Telekommunikationsdienstleistungen. Studien zum deutschen Innovationssystem. Berlin: EFI.

10-2018
Peters, B.; Mohnen, P.; Saam, M.; Blandinières, F.; Hud, M.; Krieger, B.; Niebel, T. (2018): Innovationsaktivitäten als Ursache des Productivity Slowdowns? Eine Literaturstudie. Studien zum deutschen Innovationssystem. Berlin: EFI.

11-2018
Neuhäusler, P.; Schubert, T. (2018): Can Depleting Technological Opportunities Explain the Stagnation of Productivity? Panel Data Evidence for 11 OECD Countries. Studien zum deutschen Innovationssystem. Berlin: EFI.

12-2018
Weber, M.; Rammer, C.; Dinges, M.; Dachs, B.; Hud, M.; Steindl, C. (2018): Erkenntnis- und Wissenstransfer im Kontext europäischer F&I-Politik. Studien zum deutschen Innovationssystem. Berlin: EFI.

13-2018
Dumitrescu, R.; Gausemeier, J.; Slusallek, P.; Cieslik, S.; Demme, G.; Falkowski, T.; Hoffmann, H.; Kadner, S.; Reinhart, F.; Westermann, T.; Winter, J. (2018): Autonome Systeme. Studien zum deutschen Innovationssystem. Berlin: EFI.

D

14–2018
Youtie, J.; Porter, A., Shapira, P.; Woo, S., Huang, Y. (2018): Autonomous Systems: A Bibliometric and Patent Analysis. Studien zum deutschen Innovationssystem. Berlin: EFI.

15–2018
Rammer, C.; Ahmed, R.; Behrens, V. (2018): Lange Datenreihen zu Innovatorenquoten. Studien zum deutschen Innovationssystem. Berlin: EFI.

16–2018
Meurer, P. (2018): Zugang von FH-/HAW-Absolventinnen und -Absolventen zur Promotion, kooperative Promotionen und Promotionsrecht. Studien zum deutschen Innovationssystem. Berlin: EFI.

17–2018
Pötzl, M.; Natterer, M. (2018): Technologietrends in den Bereichen menschenfeindliche Umgebungen, Smart Home, industrielle Produktion und autonome Fahrzeuge. Studien zum deutschen Innovationssystem. Berlin: EFI.

Literature

D 6

A

Acemoglu, D. (2009): Introduction to Modern Economic Growth. Princeton: Princeton Univ. Press.

Acemoglu, D.; Aghion, P.; Bursztyn, L.; Hemous, D. (2012): The Environment and Directed Technical Change. The American Economic Review. 102(1). S. 131–166.

Acemoglu, D.; Akcigit, U.; Hanley, D.; Kerr, W.R. (2016): Transition to Clean Technology. Journal of Political Economy. 124(1). S. 52–104.

Adler, T.; Salvi, M. (2017): Wenn die Roboter kommen. Den Arbeitsmarkt für die Digitalisierung vorbereiten. Zürich: Avenir Suisse.

Aghion, P.; Howitt, P. (2009): The Economics of Growth. Cambridge Mass. u. a.: MIT Press.

AI Index – Artificial Intelligence Index (2017): Annual Report: AI Index.

AI100 – Stone, P.; Brooks, R.; Brynjolfsson, E.; Calo, R.; Etzioni, O.; Hager, G.; Hirschberg, J.; Kalyanakrishnan, S.; Kamar, E.; Kraus, S.; Leyton-Brown, K.; Parkes, D.; Press, W.; Saxenian, A.; Shah, J.; Tambe, M.; Teller, A. (2016): Artificial Intelligence and Life in 2030. One Hundred Year Study on Artificial Intelligence: Report of the 2015-2016 Study Panel: AI100.

Akcigit, U.; Hanley, D.; Serrano-Velarde, N. (2013): Back to Basics: Basic Research Spillovers, Innovation Policy and Growth. Cambridge, MA: National Bureau of Economic Research.

Anderson, J.M.; Samaras, C.; Stanley, K.D.; Kalra, N.; Oluwatola, O.A.; Sorensen, P. (2014): Autonomous Vehicle Technology. A Guide for Policymakers. Santa Monica, CA: Rand Corporation.

Andrews, D.; Criscuolo, C.; Gal, P.N. (2016): The Best versus the Rest: The Global Productivity Slowdown, Divergence across Firms and the Role of Public Policy. OECD Productivity Working Papers. No. 05. Paris: OECD Publishing.

Arthur, W.B. (1989): Competing Technologies, Increasing Returns, and Lock-In by Historical Events. The Economic Journal. 99(394). S. 116–131.

Austrian FP9 Think Tank (2017): Fostering Impact and Sustainable Collaboration in FP9 within a new Common Research, Technology and Innovation Policy. Wien: Bundesministerium für Wissenschaft, Forschung und Wirtschaft.

Autor, D.H.; Levy, F.; Murnane, R.J. (2003): The Skill Content of Recent Technological Change. An Empirical Exploration. The Quarterly Journal of Economics. 118(4). S. 1279–1333.

Autor, D.H.; Salomons, A. (2017): Robocalypse Now – Does Productivity Growth Threaten Employment? Cambridge, MA: National Bureau of Economic Research.

Ayres, R.U.; Van Den Bergh, J. C.; Gowdy, J.M. (1998): Weak versus Strong Sustainability.

B

Bad Wiesseer Kreis – Mitgliedergruppe der Fachhochschulen in der HRK (2014): Bad Wiesseer Eckpunktepapier, Fachhochschulen/Hochschulen für angewandte Wissenschaften und Promotionsrecht. Bad Wiessee: Bad Wiesseer Kreis – Mitgliedergruppe der Fachhochschulen in der HRK.

Barro, R.J.; Sala-i-Martin, X. (2003): Economic Growth. Cambridge Mass. u. a.: MIT Press.

Bartel, A.; Ichniowski, C.; Shaw, K. (2007): How Does Information Technology Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement, and Worker Skills. The Quarterly Journal of Economics. 122(4). S. 1721–1758.

Bartelsman, E.; Dobbelaere, S.; Peters, B. (2013): Allocation of Human Capital and Innovation at the Frontier. Firm-Level Evidence on Germany and the Netherlands. IZA Discussion Paper. No. 7540.

Baumol, W.J. (1967): Macroeconomics of Unbalanced Growth. The Anatomy of Urban Crisis. The American Economic Review. 57(3). S. 415–426.

Baumol, W.J. (2012): The Cost Disease. Why Computers Get Cheaper and Health Care Doesn't. New Haven: Yale University Press.

Bean, C. (2016): Independent Review of UK Economic Statistics. London: HM Treasury, Cabinet Office.

Bersch, J.; Berger, M.; Wagner, S. (2018): Unternehmensdynamik in der Wissenswirtschaft in Deutschland 2016, Gründungen und Schließungen von Unternehmen, Gründungsdynamik in den Bundesländern, Internationaler Vergleich, Wagniskapital-Investitionen in Deutschland und im internationalen Vergleich. Studien zum deutschen Innovationssystem. Nr. 3-2018. Berlin: EFI.

Bertschek, I.; Niebel, T.; Ohnemus, J.; Rasel, F.; Saam, M.; Schulte, P.; Schleife, K.; Stiehler, A.; Ortwein, T.; Heinzl, A. (2014): Produktivität IT-basierter Dienstleistungen: Wie kann man sie messen und steuern? ZEW-Dokumentation. Nr. 14-02.

BITKOM (2016): 51.000 offene Stellen für IT-Spezialisten. Pressemitteilung vom 14. November 2016.

Black, S.E.; Lynch, L.M. (1996): Human-Capital Investments and Productivity. The American Economic Review. 86(2). S. 263–267.

Black, S.E.; Lynch, L.M. (2001): How to Compete. The Impact of Workplace Practices and Information Technology on Productivity. Review of Economics and Statistics. 83(3). S. 434–445.

Blind, K. (2002): Normen als Indikatoren für die Diffusion neuer Technologien. Endbericht für das BMBF. Karlsruhe: Fraunhofer ISI.

Blind, K.; Cremers, K.; Mueller, E. (2009): The Influence of Strategic Patenting on Companies' Patent Portfolios. Research Policy. 38(2). S. 428–436.

Bloom, N.; Jones, C.I.; van Reenen, J.; Webb, M. (2017): Are Ideas Getting Harder to Find? Palo Alto: Stanford University.

BMBF – Bundesministerium für Bildung und Forschung (o.J.): Richtlinie zur Umsetzung der gemeinsamen Initiative des Bundes und der Länder zur Förderung des forschungsbasierten Ideen-, Wissens- und Technologietransfers an deutschen Hochschulen - „Innovative Hochschule". Berlin: BMBF.

BMBF – Bundesministerium für Bildung und Forschung (2014): Horizont 2020 im Blick. Informationen zum neuen EU-Rahmenprogramm für Forschung und Innovation. Bonn: BMBF.

BMBF – Bundesministerium für Bildung und Forschung (2016a): Bildungsoffensive für die digitale Wissensgesellschaft. Strategie des Bundesministeriums für Bildung und Forschung. Berlin: BMBF.

BMBF – Bundesministerium für Bildung und Forschung (2016b): Bundesbericht Forschung und Innovation 2016. Forschungs- und innovationspolitische Ziele und Maßnahmen. Berlin: BMBF.

BMBF – Bundesministerium für Bildung und Forschung (2016c): Europäischer Innovationsrat (EIC). Positionspapier des Bundesministeriums für Bildung und Forschung. Berlin: BMBF.

BMBF – Bundesministerium für Bildung und Forschung (2016d): Forschung an Fachhochschulen, Wie aus praxisorientierter Forschung Produkte und Dienstleistungen werden. Bonn: BMBF.

BMBF – Bundesministerium für Bildung und Forschung (2017a): Berufsbildung 4.0. Den digitalen Wandel gestalten. Programme und Initiativen des BMBF. Berlin: BMBF.

BMBF – Bundesministerium für Bildung und Forschung (2017b): Bundesbildungsministerium baut digitale Talentförderung aus. Pressemitteilung 3. April 2017. Berlin: BMBF.

Böhringer, C.; Jochem, P.E. (2007): Measuring the Immeasurable. A Survey of Sustainability Indices. Ecological Economics. 63(1). S. 1–8.

Bonin, H.; Terry, G.; Zierahn, U. (2015): Übertragung der Studie von Frey/Osborne (2013) auf Deutschland. Kurzexpertise. 57: ZEW.

Bos, W.; Eickelmann, B.; Gerick, J.; Goldhammer, F.; Schaumburg, H.; Schwippert, K.; Senkbeil, M.; Schulz-Zander, R.; Wendt, H. (2014): ICILS 2013. Computer- und informationsbezogene Kompetenzen von Schülerinnen und Schülern in der 8. Jahrgangsstufe im internationalen Vergleich. Münster: Waxmann.

Brand eins (2016): Der Köder. Brand eins 1. Juli 2016.

Breiter, A.; Zeising, A.; Stolpmann, B.E. (2017): IT-Ausstattung an Schulen. Kommunen brauchen Unterstützung für milliardenschwere Daueraufgabe. Gütersloh: Bertelsmann Stiftung.

Brundtland, G.H. (1987): Report of the World Commission on Environment and Development. Our Common Future. New York: United Nations.

Brynjolfsson, E. (1993): The Productivity Paradox of Information Technology. Communications of the ACM. 36(12). S. 66–77.

Brynjolfsson, E.; McAfee, A. (2014): The Second Machine Age. Work, Progress, and Prosperity in a Time of Brilliant Technologies. New York, NY: Norton.

Bundesagentur für Arbeit (2017a): Fachkräfteengpassanalyse. Berichte: Blickpunkt Arbeitsmarkt. 6-2017. Nürnberg: Bundesagentur für Arbeit.

Bundesagentur für Arbeit (2017b): IT-Fachleute. Berichte: Blickpunkt Arbeitsmarkt. 4-2017. Nürnberg: Bundesagentur für Arbeit.

Bundesamt für Güterverkehr (2017): Marktbeobachtung Güterverkehr. Auswertung der Arbeitsbedingungen in Güterverkehr und Logistik 2017-I. Fahrerberufe. BAG - Marktbeobachtung.

Bundesanzeiger (2013): Vereinbarung zwischen Bund und Ländern über die Förderung der angewandten Forschung und Entwicklung an Fachhochschulen nach Artikel 91b des Grundgesetzes, vom 28. Juni 2013. BAnz AT 27. September 2013.

Bundesregierung (2016): Deutsche Nachhaltigkeitsstrategie. Neuauflage 2016.

Bundesregierung (2017a): Leitlinien für das neue EU-Rahmenprogramm für Forschung und Innovation. Positionspapier der Bundesregierung. Berlin: Bundesregierung.

Bundesregierung (2017b): Zwischenevaluierung von Horizont 2020. Positionspapier der Bundesregierung. Berlin: Bundesregierung.

Byrne, D.M.; Reinsdorf, M.B.; Fernald, J.G. (2016): Does the United States Have a Productivity Slowdown or a Measurement Problem? Brookings Papers on Economic Activity. San Francisco: Federal Reserve Bank of San Francisco.

C

Comin, D. (2008): Total Factor Productivity. In: Durlauf, S.; Blume, L.E.: The New Palgrave Dictionary of Economics. Basingstoke: Palgrave Macmillan.

Crass, D.; Peters, B. (2014): Intangible Assets and Firm-Level Productivity. ZEW Discussion Papers. No. 12-120.

D

Danks, D.; London, A.J. (2017): Regulating Autonomous Systems. Beyond Standards. IEEE Intelligent Systems. 32(1). S. 88–91.

David, P. (1990): The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox. The American Economic Review. 80(2). S. 355–361.

David, P.A. (1991): The Modern Productivity Paradox in a Not-Too-Distant Mirror. In: OECD: Technology and Productivity: The Challenge for Economic Policy. Paris: OECD Publishing.

Dechezleprêtre, A.; Martin, R.; Mohnen, M. (2015): Knowledge Spillovers from Clean and Dirty Technologies. Centre for Economic Performance, London School of Economics and Political Science.

Deutsche Akademie der Naturforscher Leopoldina – Nationale Akademie der Wissenschaften (2017): Promotion im Umbruch. Stellungnahme. Halle (Saale): Deutsche Akademie der Naturforscher Leopoldina – Nationale Akademie der Wissenschaften.

Deutscher Bundestag (2013): Schlussbericht der Enquete-Kommission „Wachstum, Wohlstand, Lebensqualität – Wege zu nachhaltigem Wirtschaften und gesellschaftlichem Fortschritt in der Sozialen Marktwirtschaft“. Drucksache 17/13300.

DFG – Deutsche Forschungsgemeinschaft (2014): Merkblatt Projektakademien. Bonn: DFG.

DHV – Deutscher Hochschulverband (2013): Promotionsrecht muss Alleinstellungsmerkmal der Universitäten bleiben. Pressemitteilung vom 27. November 2013.

Dosi, G.; Llerena, P.; Labini, M.S. (2006): The Relationships between Science, Technologies and their Industrial Exploitation. An Illustration through the Myths and Realities of the So-Called ‘European Paradox’. Research Policy. 35(10). S. 1450–1464.

Dumitrescu, R.; Gausemeier, J.; Slusallek, P.; Cieslik, S.; Demme, G.; Falkowski, T.; Hoffmann, H.; Kadner, S.; Reinhart, F.; Westermann, T.; Winter, J. (2018): Autonome Systeme. Studien zum deutschen Innovationssystem. Nr. 13-2018. Berlin: EFI.

E

EFI – Expertenkommission Forschung und Innovation (2010): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2010. Berlin: EFI.

EFI – Expertenkommission Forschung und Innovation (2011): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2011. Berlin: EFI.

EFI – Expertenkommission Forschung und Innovation (2013): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2013. Berlin: EFI.

EFI – Expertenkommission Forschung und Innovation (2014): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2014. Berlin: EFI.

EFI – Expertenkommission Forschung und Innovation (2015): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2015. Berlin: EFI.

EFI – Expertenkommission Forschung und Innovation (2016): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2016. Berlin: EFI.

EFI – Expertenkommission Forschung und Innovation (2017): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2017. Berlin: EFI.

EIT – European Institute of Innovation and Technology (2017): Our Impact from 2010 to 2016. The EIT – Making Innovation Happen. Budapest: EIT.

Elstner, S.; Feld, L.P.; Schmidt, C.M. (2016): Bedingt abwehrbereit. Deutschland im digitalen Wandel. Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung: Arbeitspapier 03/2016.

EOP – Executive Office of the President (2016): Artificial Intelligence, Automation, and the Economy. Washington, D.C.: EOP.

EOP; NSTC – Executive Office of the President; National Science and Technology Council (2016): Preparing for the Future of Artificial Intelligence. Washington, D.C.: EOP; NSTC.

Ermisch, S. (2017): IT-Anbieter werben um Fachkräfte. Handelsblatt 14. April 2017.

Esser, H.; Helmrich, R.; Härtel, M.; Padur, T.; Zinke, G. (2016): Berufsbildung 4.0. Fachkräftequalifikationen und Kompetenzen für die digitalisierte Arbeit von morgen. Bonn: BMBF/BIBB.

Esterházy, Y. (2017): Programmieren in Schulen. So lernen fünfjährige britische Schüler das Programmieren. Wirtschaftswoche 6. Januar 2017.

Ethik-Kommission Automatisiertes und Vernetztes Fahren (2017): Bericht. Berlin: BMVI.

ETH-Rat (2014): Schweiz braucht volle Assoziierung an Horizon 2020. Positionspapier. Zürich: ETH-Rat.

EUA – European University Association (2016): EUA Brexit Factsheet. UK – European Research Collaboration and Student Mobility. Brüssel: EUA.

Europäische Kommission (2016): Factsheet – Beziehungen zwischen der EU und der Schweiz. Brüssel: Europäische Kommission.

Europäische Kommission (2017): Mitteilung der Kommission an das Europäische Parlament, den Rat, den Wirtschafts- und Sozialausschuss und den Ausschuss der Regionen. Stärkung der Innovation in Europas Regionen: Beitrag zu einem widerstandsfähigen, inklusiven und nachhaltigen Wachstum auf territorialer Ebene. Brüssel: Europäische Kommission.

Europäische Union (2005): Ein Neubeginn für die Strategie von Lissabon. Brüssel: Europäische Union.

Europäische Union (2008): Verordnung (EG) No 294/2008 des Europäischen Parlaments und des Rates vom 11. März 2008 zur Errichtung des Europäischen Innovations- und Technologieinstituts. (EG) No 294/2008.

Europäische Union (2013a): Verordnung (EU) Nr. 1291/2013 des Europäischen Parlaments und des Rates vom 11. Dezember 2013 über das Rahmenprogramm für Forschung und Innovation Horizont 2020 (2014-2020) und zur Aufhebung des Beschlusses Nr. 1982/2006/EG.

Europäische Union (2013b): Verordnung (EU) Nr. 1301/2013 des Europäischen Parlaments und des Rates.

Europäische Union (2015): Verordnung (EU) Nr. 2015/1017 des Europäischen Parlaments und des Rates.

European Commission (1995): Green Paper on Innovation.

European Commission (2008): A More Research-Intensive and Integrated European Research Area. Science, Technology and Competitiveness Key Figures Report 2008/2009. Brüssel: European Commission.

European Commission (2016): The Future of the European Institute of Innovation and Technology (EIT). Strategic Issues and Perspectives.

European Commission (2017a): Associated Countries to Horizon 2020. Brüssel: European Commission.

European Commission (2017b): Commission Staff Working Paper on the Interim Evaluation of the European Institute of Innovation and Technology (EIT). Brüssel: European Commission.

European Commission (2017c): Guidance Note. Funding of Applicants from Non-EU Countries and International Organisations. Brüssel: European Commission.

European Commission (2017d): Horizon 2020 Interim Evaluation. Brüssel: European Commission.

European Commission (2017e): LAB – FAB – APP. Investing in the European Future We Want. Report of the Independent High Level Group on Maximising the Impact of EU Research & Innovation Programmes. Brüssel: European Commission.

European Research Council (2017): ERC Starting Grants 2017 Outcome. Indicative Statistics. Brüssel: European Commission.

F

Fabian, G.; Hillmann, J.; Trennt, F.; Briedis, K. (2016): Hochschulabschlüsse nach Bologna. Werdegänge der Bachelor- und Masterabsolvent(inn)en des Prüfungsjahrgangs 2013. Hannover: DZHW.

Fachforum Autonome Systeme – Fachforum Autonome Systeme im Hightech-Forum (2017): Fachforum Autonome Systeme – Abschlussbericht Langversion: Fachforum Autonome Systeme.

Falk, M.; Biagi, F. (2016): Relative Demand for Highly Skilled Workers and Use of Different ICT Technologies. Applied Economics. 49(9). S. 903–914.

Favarò, F.M.; Nader, N.; Eurich, S.O.; Tripp, M.; Varadaraju, N. (2017): Examining Accident Reports Involving Autonomous Vehicles in California. PloS one. 12(9). e0184952.

Feenstra, R.C.; Inklaar, R.; Timmer, M.P. (2015): The Next Generation of the Penn World Table. American Economic Review. 105(10). S. 3150–3182.

Fernald, J.G. (2014): A Quarterly, Utilization-Adjusted Series on Total Factor Productivity. San Francisco: Federal Reserve Bank of San Francisco.

Fernandes, P.; Nunes, U. (2012): Platooning with IVC-Enabled Autonomous Vehicles. Strategies to Mitigate Communication Delays, Improve Safety and Traffic Flow. IEEE Transactions on Intelligent Transportation Systems. 13(1). S. 91–106.

Fichter, K.; Noack, T.; Beucker, S.; Bierter, W.; Springer, S. (2006): Nachhaltigkeitskonzepte für Innovationsprozesse: Fraunhofer-IRB-Verlag.

Fichtl, A.; Piopiunik, M. (2017a): Absolventen von Fachhochschulen und Universitäten im Vergleich: FuE-Tätigkeiten, Arbeitsmarktergebnisse, Kompetenzen und Mobilität. Studien zum deutschen Innovationssystem. Nr. 14-2017. Berlin: EFI.

D

Fichtl, A.; Piopiunik, M. (2017b): Absolventen von Fachhochschulen und Universitäten im Vergleich: FuE-Tätigkeiten, Arbeitsmarktergebnisse, Kompetenzen und Mobilität. Studien zum deutschen Innovationssystem. Nr. 14-2017. Berlin: EFI.

Forth, J.; Mason, G. (2006): Do ICT Skill Shortages Hamper Firms' Performance? Evidence from UK Benchmarking Surveys. NIESR Discussion Paper. No. 281.

Fraunhofer FKIE (2017): FKIE erzielt im Roboterwettbewerb „EnRicH" Auszeichnungen in mehreren Kategorien. Pressemitteilung vom 3. Juli 2017.

Fraunhofer ISE (2017): Aktuelle Fakten zur Photovoltaik in Deutschland: Fraunhofer ISE.

Frey, C.B.; Osborne, M.A. (2017): The Future of Employment. How Susceptible are Jobs to Computerisation? Technological Forecasting and Social Change. 114. S. 254–280.

G

Gehrke, B.; Frietsch, R.; Neuhäusler, P.; Rammer, C. (2013): Neuabgrenzung forschungsintensiver Industrien und Güter – NIW/ISI/ZEW-Listen 2012. Studien zum deutschen Innovationssystem. Nr. 8-2013. Berlin: EFI.

Gehrke, B.; Kerst, C. (2018): Bildung und Qualifikation als Grundlage der technologischen Leistungsfähigkeit Deutschlands 2018 (Kurzstudie). Studien zum deutschen Innovationssystem. Nr. 1-2018. Berlin: EFI.

Gehrke, B.; Schiersch, A. (2018): FuE-intensive Industrien und wissensintensive Dienstleistungen im internationalen Vergleich. Studien zum deutschen Innovationssystem. Nr. 6-2018. Berlin: EFI.

Geyer, A.; Berger, F.; Dudenborstel, T. (2016): Empirische Begleitung des Programms „Forschung an Fachhochschulen", Abschlussbericht. Wien: Technopolis Group.

Gordon, R. (2012): Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds. Cambridge, MA: National Bureau of Economic Research.

Gordon, R.J. (2015): Secular Stagnation: A Supply-Side View. American Economic Review. 105(5). S. 54–59.

Goulder, L.H.; Schneider, S.H. (1999): Induced Technological Change and the Attractiveness of CO_2 Abatement Policies. Resource and Energy Economics. 21(3-4). S. 211–253.

Greaker, M.; Midttømme, K. (2016): Network Effects and Environmental Externalities. Do Clean Technologies Suffer from Excess Inertia? Journal of Public Economics. 143. S. 27–38.

Griffith, R.; Redding, S.; van Reenen, J. (2003): R&D and Absorptive Capacity. Theory and Empirical Evidence. Scandinavian Journal of Economics. 105(1). S. 99–118.

Grömling, M. (2016): Digitale Revolution. Eine neue Herausforderung für die Volkswirtschaftlichen Gesamtrechnungen? Wirtschaftsdienst. 96(2). S. 135–139.

Grunwald, A. (2015): Transformative Wissenschaft. Eine neue Ordnung im Wissenschaftsbetrieb? GAIA – Ecological Perspectives for Science and Society. 24(1). S. 17–20.

Grunwald, A.; Kopfmüller, J. (2012): Nachhaltigkeit. Frankfurt, New York: Campus.

Guellec, D.; van Pottelsberghe de Potterie, B. (2002): The Value of Patents and Patenting Strategies. Countries and Technology Areas Patterns. Economics of Innovation and New Technology. 11(2). S. 133–148.

GWK – Gemeinsame Wissenschaftskonferenz (2016): Bekanntmachung der Verwaltungsvereinbarung zwischen Bund und Ländern gemäß Artikel 91b Absatz 1 des Grundgesetzes zur Förderung des forschungsbasierten Ideen-, Wissens- und Technologietransfers an deutschen Hochschulen – „Innovative Hochschule". Bonn: GWK.

GWK – Gemeinsame Wissenschaftskonferenz (2017): Bund-Länder-Initiative zur Förderung des forschungsbasierten Ideen-, Wissens- und Technologietransfers an deutschen Hochschulen – „Innovative Hochschule", Liste der zur Förderung ausgewählten Hochschulen und Hochschulverbünde. Bonn: GWK.

H

Hachmeister, C.-D. (2017): Die Vielfalt der Studiengänge, Entwicklung des Studienangebotes in Deutschland zwischen 2014 und 2017. Gütersloh: CHE.

Hagsten, E.; Sabadash, A. (2017): A Neglected Input to Production. The Role of ICT-Schooled Employees in Firm Performance. International Journal of Manpower. 38(3). S. 373–391.

Harhoff, D. (2000): R&D Spillovers, Technological Proximity, and Productivity Growth. Evidence from German Panel Data. Schmalenbach Business Review. 52. S. 238–260.

Harhoff, D.; Hall, B.H.; Graevenitz, G. von; Hoisl, K.; Wagner, S. (2007): The Strategic Use of Patents and Its Implications for Enterprise and Competition Policies. Brüssel: European Commission.

Harhoff, D.; Kagermann, H.; Stratmann, M. (Hrsg.) (2018): Impulse für Sprunginnovationen in Deutschland. acatech Diskussion. München: Herbert Utz Verlag.

Helmich, P.; Gruber, S.; Frietsch, R. (2018): Performance and Structures of the German Science System 2017. Studien zum deutschen Innovationssystem. Nr. 5-2018. Berlin: EFI.

Helpman, E.; Trajtenberg, M. (1998): The Diffusion of General Purpose Technologies. In: Helpman, E.: General Purpose Technologies and Economic Growth. Cambridge, MA: MIT Press.

Hessischer Landtag (2017): Kleine Anfrage der Abg. May (Bündnis 90/Die Grünen) und Wolff (CDU) vom 27. Juni 2017 betreffend Promotionszentren an Hochschulen für angewandte Wissenschaften (HAW) und Antwort des Ministers für Wissenschaft und Kunst. Drucksache 19/5030.

Heublein, U.; Ebert, J.; Hutzsch, C.; Isleib, S.; König, R.; Richter, J.; Woisch, A. (2017): Zwischen Studienerwartungen und Studienwirklichkeit, Ursachen des Studienabbruchs, beruflicher Verbleib der Studienabbrecherinnen und Studienabbrecher und Entwicklung der Studienabbruchquote an deutschen Hochschulen. Forum Hochschule. 1/2017. Hannover: DZHW.

Hightech-Forum (2017): Gemeinsam besser – Nachhaltige Wertschöpfung, Wohlstand und Lebensqualität im digitalen Zeitalter. Innovationspolitische Leitlinien des Hightech-Forums. Berlin: Hightech-Forum.

HM Government (2017): Collaboration on Science and Innovation. A Future Partnership Paper. London: HM Government.

Hornstein, A.; Krusell, P. (1996): Can Technology Improvements Cause Productivity Slowdowns? NBER Macroeconomics Annual. 11. S. 209–259.

HRK – Hochschulrektorenkonferenz (2016): Grundsätze für ein nachhaltiges Bund-Länder-Programm zur Gewinnung von Professorinnen und Professoren an Hochschulen für angewandte Wissenschaften (HAW) bzw. Fachhochschulen (FH). Empfehlung des 134. Senats der HRK am 13. Oktober 2016 in Berlin. Berlin/Bonn: HRK.

I

ISO – International Organization for Standardization (2008): The ISO System, The Trusted Partner, Annual Report 2007. Genf: ISO.

J

Jaffe, A.B.; Newell, R.G.; Stavins, R.N. (2005): A Tale of Two Market Failures. Technology and Environmental Policy. Ecological Economics. 54(2-3). S. 164–174.

Jaradat, M.A.; Bani-Salim, M.; Awad, F. (2017): A Highly-Maneuverable Demining Autonomous Robot. An Over-Actuated Design. Journal of Intelligent & Robotic Systems. 15(2). S. 589.

K

Kalkuhl, M.; Edenhofer, O.; Lessmann, K. (2012): Learning or Lock-In. Optimal Technology Policies to Support Mitigation. Resource and Energy Economics. 34(1). S. 1–23.

Kehl, C.; Sauter, A. (2015): Was kostet die Natur? Wert und Inwertsetzung von Biodiversität. Baden-Baden: Nomos.

Kelly, E.; Alho, I. (2017): Macron Wants to Set up 'EU Agency on Disruptive Innovation'. Science Business 26. September 2017.

Klepper, S. (1996): Entry, Exit, Growth, and Innovation over the Product Life Cycle. The American Economic Review. 86(3). S. 562–583.

Klepper, S. (1997): Industry Life Cycles. Industrial and Corporate Change. 6(1). S. 145–182.

Klepper, S. (2002): Firm Survival and the Evolution of Oligopoly. The RAND Journal of Economics. 33(1). S. 37–61.

KMK – Kultusministerkonferenz (1999): Strukturvorgaben für die Einführung von Bachelor-/Bakkalaureus- und Master-/Magisterstudiengängen. Beschluss der Kultusministerkonferenz vom 5. März 1999. Bonn: KMK.

KMK – Kultusministerkonferenz (2003): Ländergemeinsame Strukturvorgaben gemäß § 9 Abs. 2 HRG für die Akkreditierung von Bachelor- und Masterstudiengängen. Beschluss der Kultusministerkonferenz vom 10. Oktober 2003. Darmstadt: KMK.

KMK – Kultusministerkonferenz (2010): Ländergemeinsame Strukturvorgaben für die Akkreditierung von Bachelor- und Masterstudiengängen. Beschluss der Kultusministerkonferenz vom 10. Oktober 2003 i. d. F. vom 4. Februar 2010. Bonn: KMK.

Konigs, J.; Vanormelingen, S. (2010): The Impact of Training on Productivity and Wages. Firm Level Evidence. IZA Discussion Paper. No. 4731.

KPMG; Center for Automotive Research (2012): Self-Driving Cars. The Next Revolution: KPMG; CAR.

Kreuchauff, F.H. (2015): Fraktale Doppel-Boom-Zyklen und Querschnittstechnologien. Dissertation. Karlsruhe: Karlsruher Institut für Technologie.

Kuri, J. (2017): Fachkräftemangel. Weiter steigender Bedarf an IT-Fachkräften. Heise Online 19. September 2017.

L

Le Monde Economie (2017): Pour „une initiative européenne sur l'innovation de rupture“. Le Monde Economie 18. Oktober 2017.

Lehnert, P.; Pfister, C.; Backes-Gellner, U. (2017): The Effect of an Education-Driven Labor Supply Shock on Firms' R&D Personnel. Leading House Working Paper. No. 141.

Lindiger, M. (2016): Das Europäische GPS ist gestartet. Frankfurter Allgemeine Zeitung 21. Dezember 2016.

Lindner, R.; Goos, K.; Güth, S.; Som, O.; Schröder, T. (2016): „Responsible Research and Innovation“ als Ansatz für die Forschungs-, Technologie- und Innovationspolitik. Hintergründe und Entwicklungen. TAB-Hintergrundpapier. Nr. 22.

Lindner, R.; Kuhlmann, S. (2016): Responsible Research and Innovation und die Governance von Forschung & Innovation. Herausforderungen und Prinzipien. Forschung: Politik – Strategie – Management. 9(1). S. 22–27.

Lindsey, B. (2015): Understanding the Growth Slowdown. Washington, D.C.: Cato Institute.

Loecker, J. de; Eeckhout, J. (2017): The Rise of Market Power and the Macroeconomic Implications. Cambridge, MA: National Bureau of Economic Research.

Loecker, J. de; Warzynski, F. (2012): Markups and Firm-Level Export Status. The American Economic Review. 102(6). S. 2437–2471.

Lorenz, R.; Bos, W.; Endberg, M.; Eickelmann, B.; Grafe, S.; Vahrenhold, J. (2017): Schule digital – der Länderindikator 2017. Schulische Medienbildung in der Sekundarstufe I mit besonderem Fokus auf MINT-Fächer im Bundesländervergleich und Trends von 2015 bis 2017. Münster: Waxmann.

M

Mayer, A.L. (2008): Strengths and Weaknesses of Common Sustainability Indices for Multidimensional Systems. Environment international. 34(2). S. 277–291.

Meller, P.; Hudson, R.L.; Lau, T. (2006): Barroso Boost for European Institute of Technology. Science Business 1. März 2006.

Menge-Sonnentag, R. (2017): Entwickler verzweifelt gesucht. Stack-Overflow-Studie zur Lage bei IT-Fachkräften. Heise Online 23. August 2017.

Messner (2016): Stellungnahme Öffentliches Fachgespräch zum Thema „Forschung und Innovation in Deutschland: Stand und Perspektiven – einschließlich Zwischenbilanz der Hightech-Strategie“. Ausschuss für Bildung, Forschung und Technikfolgenabschätzung, Deutscher Bundestag. Ausschussdrucksache 18(18)245 a.

Meurer, P. (2018): Zugang von FH-Absolventinnen und -Absolventen zur Promotion, kooperative Promotionen und Promotionsrecht. Studien zum deutschen Innovationssystem. Nr. 16-2018. Berlin: EFI.

Mitgliedergruppe der Fachhochschulen/Hochschulen für Angewandte Wissenschaften in der HRK (2017): Vorschlag zur Gründung einer Deutschen Transfergemeinschaft (DTG) 2017.

Moedas, C. (2015): Open Innovation, Open Science, Open to the World. Speech of the Commissioner for Research, Science and Innovation at "A new start for Europe: Opening up to an ERA of Innovation“ Conference. Brüssel: European Commission.

Mozur, P. (2017): Beijing Wants A.I. to Be Made in China by 2030. New York Times 20. Juli 2017.

Mozur, P.; Markoff, J. (2017): Is China Outsmarting America in A.I.? New York Times 27. Mai 2017.

Müller, B.; Bersch, J.; Niefert, M.; Rammer, C. (2013): Unternehmensdynamik in der Wissenswirtschaft in Deutschland 2011, Gründungen und Schließungen von Unternehmen, Beschäftigungsbeitrag von Gründungen, Vergleich von Datenquellen mit Informationen zu Gründungen. Studien zum deutschen Innovationssystem. Nr. 4-2013. Berlin: EFI.

Müller, B.; Gottschalk, S.; Niefert, M.; Rammer, C. (2014): Unternehmensdynamik in der Wissenswirtschaft in Deutschland 2012, Gründungen und Schließungen von Unternehmen, Gründungsdynamik in den Bundesländern, Internationaler Vergleich. Studien zum deutschen Innovationssystem. Nr. 3-2014. Berlin: EFI.

N

Nelson, R.R. (1959): The Simple Economics of Basic Scientific Research. Journal of Political Economy. 67(3). S. 297–306.

Neuhäusler, P.; Rothengatter, O.; Frietsch, R. (2018): Patent Applications – Structures, Trends and Recent Developments 2017.

D

Studien zum deutschen Innovationssystem. Nr. 4-2018. Berlin: EFI.

Nill, J.; Kemp, R. (2009): Evolutionary Approaches for Sustainable Innovation Policies. From Niche to Paradigm? Research Policy. 38(4). S. 668–680.

Nilsson, N.J. (2010): The Quest for Artificial Intelligence. A History of Ideas and Achievements. Cambridge: Cambridge University Press.

NKR – Nationaler Normenkontrollrat (2017): Bürokratieabbau. Bessere Rechtsetzung. Digitalisierung. Erfolge ausbauen – Rückstand aufholen, Jahresbericht 2017 des Nationalen Normenkontrollrates. Berlin: NKR.

Nordhaus, W.D. (2008): Baumol's Diseases. A Macroeconomic Perspective. The B.E. Journal of Macroeconomics. 8(1).

Nourry, M. (2008): Measuring Sustainable Development. Some Empirical Evidence for France from Eight Alternative Indicators. Ecological Economics. 67(3). S. 441–456.

NSTC – National Science and Technology Council (2016): The National Artificial Intelligence Research and Development Plan. Washington, D.C.: NSTC.

O

o.V. (2009): The Lund Declaration. Europe Must Focus on the Grand Challenges of Our Time.

OECD – Organisation for Economic Cooperation and Development (2016): New Skills for the Digital Economy. Measuring the Demand and Supply of ICT Skills at Work. OECD Digital Economy Papers. No. 258. Paris: OECD.

OECD - Organisation fpr Economic Cooperation an Development (2018): Main Science and Technology Indicators. OECD Science, Technology and R&D Statistics (database).

Onut, V.; Aldridge, D.; Mindel, M.; Perelgut, S. (2010): Smart Surveillance System Applications. In: Ng, J.; Couturier, C.; Müller, H.A.; Ryman, A.: Proceedings of the 2010 Conference of the Center for Advanced Studies on Collaborative Research. Toronto, Canada.

P

Partha, D.; David, P.A. (1994): Toward a New Economics of Science. Research Policy. 23(5). S. 487–521.

Perez, C. (2002): Technological Revolutions and Financial Capital the Dynamics of Bubbles and Golden Ages. Cheltenham: Edward Elgar Publishing.

Peters, B.; Licht, G.; Kladobra, A.; Crass, D. (2009): Soziale Erträge der FuE-Tätigkeit in Deutschland. Studien zum deutschen Innovationssystem. Nr. 15-2009. Berlin: EFI.

Peters, B.; Mohnen, P.; Saam, M. Blandinières, F.; Hud, M.; Krieger, B.; Niebel, T. (2018): Innovationsaktivitäten als Ursache des Productivity Slowdowns? Eine Literaturstudie. Studien zum deutschen Innovationssystem. Nr. 10-2018. Berlin: EFI.

Pfister, C.; Rinawi, M.; Harhoff, D.; Backes-Gellner, U. (2017): Regional Effects of Applied Research – Universities of Applied Sciences and Innovation. Swiss Leading House Working Paper. No. 117.

Pillarisetti, J.R.; van den Bergh, J.C. (2013): Aggregate Indices for Identifying Environmentally Responsible Nations. An Empirical Analysis and Comparison. International Journal of Environmental Studies. 70(1). S. 140–150.

Pötzl, M.; Natterer, M. (2018): Technologietrends in den Bereichen menschenfeindliche Umgebungen, Smart Home, industrielle Produktion und autonome Fahrzeuge. Studien zum deutschen Innovationssystem. Nr. 17-2018. Berlin: EFI.

R

Rammer, C.; Ahmed, R.; Behrens, V. (2018): Lange Datenreihen zu Innovatorenquoten. Studien zum deutschen Innovationssystem. Nr. 15-2018. Berlin: EFI.

Rammer, C.; Berger, M.; Doherr, T.; Hud, M.; Iferd, Y.; Krieger, B.; Peters, B.; Schubert, T.; Burg, J. von der (2018): Innovationen in der deutschen Wirtschaft, Indikatorenbericht zur Innovationserhebung 2017, Innovationsaktivitäten der Unternehmen in Deutschland im Jahr 2016, mit einem Ausblick für 2017 und 2018. Studie im Auftrag des BMBF. Mannheim: ZEW.

Rammer, C.; Hünermund, P. (2013): Innovationsverhalten der Unternehmen in Deutschland 2011 – Aktuelle Entwicklungen – Europäischer Vergleich. Studien zum deutschen Innovationssystem. Nr. 3-2013. Berlin: EFI.

Rennings, K. (2000): Redefining Innovation. Eco-Innovation Research and the Contribution from Ecological Economics. Ecological Economics. 32(2). S. 319–332.

Rosenberg, N. (2009): Why Do Firms Do Basic Research (With Their Own Money)? In: Rosenberg, N.: Studies on Science and the Innovation Process: World Scientific.

Rothgang, M.; Dehio, J.; Janßen-Timmen, R.; Stiebale, J. (2018): Sektorfallstudien zu Determinanten der Produktivitätsentwicklung in der Automobilindustrie, im Maschinenbau und bei den Telekommunikationsdienstleistungen. Studien zum deutschen Innovationssystem. Nr. 9-2018.

S

Sachverständigenrat deutscher Stiftungen für Integration und Migration (2017): Neuordnung der Einwanderungspolitik, Ein Einwanderungsgesetzbuch für Deutschland. Berlin: Sachverständigenrat deutscher Stiftungen für Integration und Migration.

Sachwald, F. (2015): Europe’s Twin Deficits. Excellence and Innovation in New Sectors. Policy Paper by the Research, Innovation, and Science Policy Experts (RISE). Brüssel: European Commission.

SAE International (2016): Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. J3016.

Schasse, U.; Gehrke, B.; Stenke, G. (2018): Forschung und Entwicklung in Staat und Wirtschaft – Deutschland im internationalen Vergleich. Studien zum deutschen Innovationssystem. Nr. 2-2018. Berlin: EFI.

Schiller, J.; Aicher, C.; Feresin, E. (2016): Weiße Biotechnologie. Stand und Perspektiven der industriellen Biotechnologie: Umwelt- und Nachhaltigkeitspotenziale. TAB-Arbeitsbericht. Nr. 169.

Schlütter, K. (2017): Vorschlag für eine deutsch-französische Innovationsagentur. Kooperation International 23. Oktober 2017.

Schneider, J.; Stenke, G. (2015): Männlich – Deutsch – MINT. Diversität als Chance für Forschung und Entwicklung in Unternehmen. Essen: Wissenschaftsstatistik GmbH im Stifterverband.

Schneidewind, U.; Singer-Brodowski, M. (2013): Transformative Wissenschaft. Klimawandel im deutschen Wissenschafts- und Hochschulsystem. Marburg: Metropolis.

Schot, J.; Steinmüller, E. (2016): Framing Innovation Policy for Transformative Change. Innovation Policy 3.0: Science Policy Research Unit (SPRU) University of Sussex.

Schütte, G. (2016): Interaction between National and European Research and Innovation Funding. Keynote Speech by the State Secretary to the Federal Minister of Education and Research in Oslo, Norway, at the Science Europe's ERA High-Level Workshop 2016.

D

Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, Referat IV C (2012): Vorausberechnung der Studienanfängerzahlen 2012-2025 – Fortschreibung – (Stand: 24. Januar 2012). Bonn: KMK.

SGD – Studiengemeinschaft Darmstadt (2017): Weiterbildungstrends in Deutschland 2017. Darmstadt: SGD.

Shea, C.M.; Grinde, R.; Elmslie, B. (2011): Nanotechnology as General-Purpose Technology. Empirical Evidence and Implications. Technology Analysis & Strategic Management. 23(2). S. 175–192.

Smitten, S. in der; Sembritzki, T.; Thiele, L.; Kuhns, J.; Sanou, A.; Valero-Sanchez, M. (2017): Bewerberlage bei Fachhochschulprofessuren (BeFHPro). Forum Hochschule. 3/2017. Hannover: DZHW.

Soldt, R. (2018): Die Informatiklehrer fehlen. Wieder ein neues Fach im Südwesten. F.A.Z. Plus 11. Januar 2018.

Solow, R. (1987): We'd Better Watch Out. New York Times Book Review July 12, 1987.

Statistisches Bundesamt (2003): TOP 2.1.1, Einführung der Vorjahrespreisbasis. Sitzung des Fachausschusses Volkswirtschaftliche Gesamtrechnungen am 26. November 2003.

Statistisches Bundesamt – Statistisches Bundesamt (2016): Verkehr. Verkehrsunfälle. Fachserie 8 Reihe 7. Wiesbaden: Statistisches Bundesamt.

Statistisches Bundesamt (2017): Produzierendes Gewerbe. Indizes der Produktion und der Arbeitsproduktivität im Produzierenden Gewerbe. Wiesbaden: Statistisches Bundesamt.

Strohschneider, P. (2014): Zur Politik der Transformativen Wissenschaft. In: Brodocz, A.; Herrmann, D.; Schmidt, R.; Schulz, D.; Schulze Wessel, J.: Die Verfassung des Politischen: Festschrift für Hans Vorländer. Wiesbaden: Springer Fachmedien Wiesbaden.

SVR – Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung (2015): Zukunftsfähigkeit in den Mittelpunkt. Jahresgutachten 2015/16. Wiesbaden: SVR.

SVR – Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung (2017): Für eine zukunftsorientierte Wirtschaftspolitik, Jahresgutachten 17/18. Wiesbaden: SVR.

Syverson, C. (2017): Challenges to Mismeasurement Explanations for the US Productivity Slowdown. Journal of Economic Perspectives. 31(2). S. 165–186.

T

The Royal Society (2016): UK Research and the European Union. The Role of the EU in International Research Collaboration and Research Mobility. London: The Royal Society.

Turing, A. (1950): Computing Machinery and Intelligence. Mind.(236). S. 433–460.

U

U15 (2014): U15: „Promotionsrecht für Fachhochschulen verwischt Profile der Hochschularten und ihre Aufgaben“. Berlin: U15.

Unruh, G.C. (2000): Understanding Carbon Lock-In. Energy Policy. 28(12). S. 817–830.

Utterback, J.M.; Abernathy, W.J. (1975): A Dynamic Model of Process and Product Innovation. Omega. 3(6). S. 639–656.

V

van Ark, B. (2016): The Productivity Paradox of the New Digital Economy. International Productivity Monitor. 31. S. 3–18.

VDA – Verband der Automobilindustrie (2015): Automatisierung. Von Fahrerassistenzsystemen zum automatisierten Fahren. Berlin: VDA.

W

Watt, N. (2006): European Institute 'to Rival MIT'. The Guardian 22. Februar 2006.

WBGU – Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (2016): Sondergutachten. Entwicklung und Gerechtigkeit durch Transformation: Die vier großen I. Berlin: WBGU.

Weber, M.; Rammer, C.; Dinges, M.; Dachs, B.; Hud, M.; Steindl, C. (2018): Erkenntnis- und Wissenstransfer im Kontext europäischer F&I-Politik. Studien zum deutschen Innovationssystem. Nr. 12-2018. Berlin: EFI.

Wilson, J.; Tyedmers, P.; Pelot, R. (2007): Contrasting and Comparing Sustainable Development Indicator Metrics. Ecological Indicators. 7(2). S. 299–314.

Witwicki, S.; Castillo, J.C.; Messias, J.; Capitan, J.; Melo, F.S.; Lima, P.U.; Veloso, M. (2017): Autonomous Surveillance Robots. A Decision-Making Framework for Networked Multiagent Systems. IEEE Robotics & Automation Magazine. 24(3). S. 52–64.

WR – Wissenschaftsrat (2002): Empfehlungen zur Entwicklung der Fachhochschulen. Drs. 5102/02. Berlin: WR.

WR – Wissenschaftsrat (2010): Empfehlungen zur Rolle der Fachhochschulen im Hochschulsystem. Drs. 10031-10. Berlin: WR.

WR – Wissenschaftsrat (2016): Empfehlungen zur Personalgewinnung und -entwicklung an Fachhochschulen. Drs. 5637-16. Weimar: WR.

Y

Youtie, J.; Porter, A.; Shapira, P.; Woo, S.; Huang, Y. (2018): Autonomous Systems. A Bibliometric and Patent Analysis. Studien zum deutschen Innovationssystem. Nr. 14-2018. Berlin: EFI.

D 7 Endnotes

1 Cf. in the following EFI (2017: 28f.).
2 In this regard and in the following, cf. EFI (2017: 29).
3 In this regard and in the following, cf. EFI (2017: 28 and 102).
4 In this regard, cf. also NKR (2017: 35ff.).
5 In this regard and in the following, cf. EFI (2017: chapter B 7).
6 In this regard and in the following, cf. EFI (2017: 84ff.).
7 Cf. EFI (2017: 84ff.) and https://www.kfw.de/KfW-Konzern/Newsroom/Pressematerial/Themen-kompakt/Beteiligungsfinanzierung/ and https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2017/20170802-machnig--schub-fuer-wagniskapitalfinanzierung.html (last accessed 17 January 2018).
8 In this regard and in the following, cf. EFI (2017: 25 and 84ff.).
9 In this regard and in the following, cf. EFI (2017: 24f. and 84ff.).
10 In this regard and in the following, cf. EFI (2017: 82f.).
11 In this regard and in the following, cf. EFI (2017: 18f.).
12 In this regard and in the following, cf. EFI (2017: 26 and 90ff.).
13 The concept of radical innovation is a technical term from the field of innovation economics; its narrower interpretation distinguishes incremental (small-step) technical progress from changes that can enable an innovator to establish a monopoly position. In a broader sense, the term 'radical innovation' is used for innovations that lead to far-reaching changes in markets, organizations and societies.
14 Cf. Harhoff et al. (2018). Cf. also http://www.deutschlandfunk.de/praesident-der-max-planck-gesellschaft.676.de.html?dram:article_id=409092 (last accessed 24 January 2018).
15 The Expert Council of German Foundations on Integration and Migration (Sachverständigenrat deutscher Stiftungen für Integration und Migration) proposes changing the rules on labour-related migration when a uniform legal code is drawn up in the field of migration. Cf. Sachverständigenrat deutscher Stiftungen für Integration und Migration (2017).
16 Cf. Sachverständigenrat deutscher Stiftungen für Integration und Migration (2017) and SVR (2017: 387f.).
17 In this regard and in the following, cf. EFI (2017: 27 and 93ff.). In 2013, the Competence Centre for Innovative Procurement (Kompetenzzentrum innovative Beschaffung, KOINNO) was set up in Germany as a central political initiative; it is now becoming networked at the European level as part of a project funded by the European Commission. Cf. https://www.koinno-bmwi.de/ (last accessed on 17 January 2018) and information provided by BMWi on 19 December 2017. Apart from the establishment of KOINNO, no major initiatives to promote innovation-oriented procurement have been launched. In this regard and in the following, cf. EFI (2016: 27 and 93ff.).
18 Cf. in the following EFI (2017: 16f.).

A 2

19 Cf. https://sustainabledevelopment.un.org/sdgs (last accessed on 17 January 2018).
20 "European research must focus on the Grand Challenges of our time, moving beyond current rigid thematic approaches." Cf. unknown author (2009)
21 Cf. WBGU (2016: 7).
22 Cf. Messner (2016).
23 Cf. Hightech-Forum (2017: 6).
24 The call for greater participation shares common ground with the controversial debate on transformative science, which is not pursued further here. Cf. in this regard i.a. Schneidewind and Singer-Brodowski (2013); Strohschneider (2014); Grunwald (2015).
25 Cf. Brundtland (1987).
26 Cf. Bundesregierung (2016).
27 Cf. Fraunhofer ISE (2017).
28 Cf. Fichter et al. (2006) and Schiller et al. (2016).
29 Cf. Grunwald and Kopfmüller (2012).
30 Furthermore, direct improvements, e.g. reducing the consumption of fossil energy resources by improving energy efficiency, can be overcompensated by such indirect effects as increased energy demand, income effects or changes in behaviour (so-called rebound effect).
31 Sustainability indices aggregate selected indicators in the three sustainability fields mentioned to form a one-dimensional ratio.
32 Cf. for example Böhringer and Jochem (2007); Wilson et al. (2007); Nourry (2008); Mayer (2008); Pillarisetti and van den Bergh (2013).
33 In macroeconomic cost-benefit analysis, price signals in a market-economy system serve as fundamental indicators of how to assess scarcity relations of resources. If markets or price signals are lacking or distorted, then market externalities – e.g. in the case of climate damage – can be internalized through taxes or subsidies into a societal cost-benefit calculation. The extreme ecological case of strong sustainability – i.e. natural capital is not substitutable, and mere existence has a value in itself (existence value) – can be integrated in the form of ecological guard rails. Cf. for example Ayres et al. (1998). The dimension of social justice can also be depicted by taking into account explicit inequality aversion and resultant social policy via tax and/or transfer policies.
34 Cf. Kehl and Sauter (2015).
35 Cf. for example Nill and Kemp (2009); Lindner et al. (2016); Schot and Steinmüller (2016).
36 The Responsible Research and Innovation approach aims to adapt the alignment and effects of research and development to societal values and needs by ensuring the

early involvement of different groups of actors (groups of stakeholders, users and citizens). Cf. for example Lindner and Kuhlmann (2016).

37 In the Horizon 2020 research framework programme, the approach is being promoted in the programme section 'Science with and for Society' and as a cross-cutting theme. Cf. https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation (last accessed on 17 January 2018). The Dutch research community (NWO) has developed the 'Responsible Innovation' programme (Maatschappelijk Verantwoord Innoveren, MVI), which funds projects in which social and ethical implications are taken into consideration early on during the development phase. One mandatory element, among others, is a so-called 'Valorisation Panel', which accompanies the entire project and is made up of potential users and other relevant societal stakeholders. In the United Kingdom, the largest research community, the Engineering and Physical Science Research Council (EPSRC), stipulates that an RRI approach be integrated into the project in certain invitations to tender (e.g. on geoengineering), although it does not lay down more precise specifications.

38 Cf. https://www.bmbf.de/de/innovations-und-technik analysen-ita-937.html (last accessed on 17 January 2018).

39 Cf. EFI (2013); EFI (2016).

40 Cf. for example Goulder and Schneider (1999), Rennings (2000) and Jaffe et al. (2005) on the so-called double dividend of environmental innovations. Another theoretical justification put forward for increasing the R&D funding of clean innovations is that they suffer more from market failure in the innovation process than 'dirty' innovations. Such market-failure effects include path dependencies in the innovation orientation (Acemoglu et al. 2012; Acemoglu et al. 2016), positive network effects (Greaker and Midttømme 2016), lock-ins (Unruh 2000; Kalkuhl et al. 2012), and above-average knowledge externalities (Dechezleprêtre et al. 2015).

A 3

41 In the 2016/17 winter semester, three-quarters of the tertiary education institutions in Germany were universities and UASs. A total of 428 tertiary education institutions existed. These included 106 universities, six teacher-training colleges, 16 theological colleges, 53 art colleges, 217 UASs and 30 administrative colleges. Cf. https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/BildungForschungKultur/Hochschulen/Tabellen/HochschulenHochschularten.html (last accessed on 17 January 2018).

42 The specific tasks of the UASs differ in the individual Länder. Cf. Meurer (2018).

43 Cf. EFI (2014: chapter A 3).

44 Cf. https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/BildungForschungKultur/Hochschulen/Tabellen/HochschulenHochschularten.html (last accessed on 17 January 2018), cf. also WR (2016: 16f.).

45 Cf. https://www.destatis.de/DE/ZahlenFakten/-GesellschaftStaat/BildungForschungKultur/Hochschulen/Tabellen/StudierendeInsgesamtHochschulart.html;jsessionid=06871D7EB36C739C80531DA2A0C93AEA.cae1 (last accessed on 17 January 2018).

46 Cf. (WR 2016: 16).

47 Cf. (WR 2016: 87). Training in new, increasingly specialized occupations is becoming more and more established at UASs, for example in health and nursing sciences. This development, among other things, has resulted in a very large number of study programmes (more than 6,000 in 2017). Cf. Hachmeister (2017: 7) on the development of the range of study programmes in Germany.

48 The German Council of Science and Humanities (Wissenschaftsrat) notes that "up until the 1990s [the higher education acts of the Länder] took account of the differentiation between the education and research mandates by making a clear distinction between the types of higher education institutions". WR (2002: 6), own translation.

49 Cf. Meurer (2018) and WR (2016: 81f.). The task of UASs to conduct R&D varies between the different Länder. Most of the Länder higher education acts name application-oriented or practice-oriented research as an independent task. In several Länder, the R&D activities are linked to teaching. Individual higher education acts also implicitly allow basic research, since the catalogue of tasks of tertiary education institutions has not been finally formulated therein – as, e.g., in Berlin. Some higher education acts do not distinguish between basic research and applied or practice-oriented research – e.g. North Rhine-Westphalia. Bremen makes no distinctions between the types of tertiary education institutions when it comes to their tasks – and this also applies to research. Some Länder higher education acts explicitly assign the task of scientific further training to the UASs. Cf. WR (2016: 21 and footnote 14). However, in most Länder the UASs are not entrusted with the task of promoting the next generation of scientists. In this regard and in the following, cf. WR (2016: 82).Three Länder have higher education acts through which they assign this task to tertiary education institutions in general. According to Berlin's higher education act, the Land and the UASs are to gradually develop ways of promoting young scientists. In Hesse, according to the Hessian higher education act, UASs participate in training future young scientists in the context of cooperative doctoral studies.

50 The goal of the 1999 Bologna Declaration of the European Ministers of Education was to create a study system that ensures an internationally comparable, high-quality education customized to individual needs by introducing a three-stage model – Bachelor's degree, Master's degree, Doctorate – in successive, interlinked sequences. Cf. http://www.europa.clio-online.de/quelle/id/artikel-3230 (last accessed on 17 January 2018) and EFI (2010: 53). According to a resolution passed by the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany (Kultusministerkonferenz, KMK), Bachelor's and Master's degree study programmes can be set up in Germany "both at universities and equivalent tertiary education institutions, and at universities of applied sciences, without calling into question the different educational objectives of these types of higher education". KMK (2010) and KMK

(1999), own translation. Furthermore, Master's degrees acquired at universities and UASs entitle each graduate to study for a doctorate on principle, according to the KMK. Cf. KMK (2003) and KMK (2010).

51 The German Council of Science and Humanities notes: "Their application-oriented teaching as well as numerous transfer services and collaborations in applied research and development make the universities of applied sciences regional innovation drivers and first-rate networking centres". In the opinion of the German Council of Science and Humanities, the UASs have used the growth phase of the past few years, "to increasingly forge specialized and structural profile features and thus drive both the recommended differentiation of the UAS sector and the internal differentiation of the institutions". WR (2016: 6), own translation.

52 Cf. Pfister et al. (2017). The exact mechanisms have not yet been examined for Switzerland, but initial analyses by Lehnert et al. (2017) suggest that the newly created availability of UAS graduates has led to an increase in R&D personnel in local companies, so that the newly available human capital in the respective region has contributed significantly to patenting activities. It should be borne in mind, however, that UASs in Switzerland have particularly strong complementarities with vocational education and training.

53 A study carried out on behalf of the Commission of Experts on the basis of the National Educational Panel (Nationales Bildungspanel, NEPS) has examined the regional mobility of UAS students. In this regard and in the following, cf. Fichtl and Piopiunik (2017a: 45ff.). In the 2010/11 winter semester, 51 percent of UAS students studied in the district in which they had acquired their higher-education entrance qualification; in the case of first-year students at universities, the figure was 41 percent. The average distance from the school district to the district in which first-year students received their higher education was 59 kilometres in the case of UASs and 95 kilometres in the case of universities. However, the higher average distances from the school to the university district may be partly due to the smaller number of universities.

54 Cf. in the following Fichtl and Piopiunik (2017b: 23ff.). The analysis was based on the microcensus, since it focuses on the respondents' main activity at the workplace and on the company departments in which they work. Although the categories of the survey are not tailored exactly to R&I activities, they are close. The microcensus surveys from the years 2000, 2004, 2007 and 2011 were used for the ifo study, since only these surveys asked the relevant questions on the respondents' main activity at the workplace and the company departments where they work. The study looked only at employed graduates who financed their living mainly through their own employment. In order to establish systematic comparability between the graduates of UASs and universities, only UAS and university graduates in comparable fields of study were included. This meant, for example, that medical doctors and lawyers were excluded.

55 The proportion of both UAS graduates and university graduates working in 'development, construction, research, design, prototyping' departments was 16 percent, respectively. Fewer than 12 percent of the UAS graduates and university graduates worked in 'development, construction, research, design, prototyping' departments and practised mainly R&I activities. Cf. Fichtl and Piopiunik (2017b: 23ff.). The proportion of both UAS and university graduates who worked in a research establishment was also about equally high at 38 percent and 40 percent, respectively, as analyses of the LIAB data show. In this regard and in the following, cf. Fichtl and Piopiunik (2017a: 16ff.). The linked-employer-employee (LIAB) data set consists of a combination of establishment data from the annual IAB Establishment Panel and individual data from the Federal Employment Agency (Bundesagentur für Arbeit). The surveys conducted in 1998, 2004 and 2009 were used, since the questions asked in these years focused on the establishments' R&D activities. The comparison covered UAS and university graduates of German nationality practising the same profession (which meant that medical doctors and lawyers, for example, were excluded).

56 In this regard, cf. Schneider and Stenke (2015: 39ff.). The study is based on a special survey of scientific research staff conducted by the Stifterverband Wissenschaftsstatistik in the context of the 2013 R&D survey. A study conducted by the German Centre for Higher Education Research and Science Studies (Deutsches Zentrum für Hochschul- und Wissenschaftsforschung, DZHW) examined the average amount of time taken by graduates to find employment (2013 academic year; survey conducted up to approx. one and a half years after graduation), a period that sometimes already begins before graduation. UAS graduates with a Bachelor's degree seeking employment took 3.5 months, Master's graduates 3.7 months. University graduates with a Bachelor's degree seeking employment took 3.5 months, Master's graduates 3.3 months. Cf. Fabian et al. (2016: 119).

57 A number of Länder higher education acts formulate the task of teaching at UASs in this or a similar way (e.g. Baden-Württemberg). A uniform description of tasks by all Länder higher education acts does not exist.

58 Cf. WR (2016: 7), own translation. In the context of its recommendations made in 2010 on the role of the UASs in the higher education system, the German Council of Science and Humanities points out that it considers a 65 percent share of UAS graduates among the final examinations in the higher education system to be adequate. Cf. WR (2010: 43). In this regard, cf. also WR (2002: 90ff.).

59 Cf. Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, Referat IV C (2012).

60 The German Council of Science and Humanities notes: "The preeminence of teaching at UASs is still reflected in a greater density of teaching staff or smaller core groups than at universities; most teaching is carried out by professors, with the result that they have larger teaching loads." WR (2016: 20), own translation.

61 The student drop-out rate among German Bachelor's degree students at UASs was 19 percent for first-year students in 2006/2007, 23 percent for first-year students in 2008/2009, and 27 percent for first-year students in 2010/2011. Cf. Heublein et al. (2017: 263ff.). The student drop-out rate among German Master's degree students at UASs was 7 percent for first-year students in 2010 and 19 percent for first-year students in 2012. Cf. Heublein et al. (2017: 267ff.). Cf. Heublein et al. (2017: 17ff.) on the motives.

62 A study carried out by Technopolis on behalf of the BMBF also polled UAS managements, among others. 77 percent of the UAS managements regarded basic teaching (e.g. BSc, BEng) as a particular strength of their own UAS – the figure for postgraduate teaching (e.g. MSc, MEng) was 39 percent. Furthermore, when asked about other special strengths of their own UASs, 54 percent of UAS managements mentioned cooperation with partners in the local economy or the region, 46 percent cited applied R&D, 37 percent cooperation with SMEs, and 27 percent the transfer of knowledge and technology. In this regard, cf. Geyer et al. (2016: 6ff.).

63 In this regard and in the following, cf. Statistisches Bundesamt, Fachserie 11, Reihe 4.3.2 and 4.5, as well as written information provided by the Federal Statistical Office on 15 December 2017.

64 In this regard and in the following, cf. Geyer et al. (2016: 41ff.).

65 Asked about measures with great potential for sustainably improving framework conditions for research at UASs, 83 percent of UAS managements mentioned increasing basic financing for research, 81 percent improving facilities for research, and 76 percent reducing professors' teaching commitments. Approval ratings of over 50 percent were also given to the following measures: more participation opportunities for UASs in funding programmes of the Federal Government (69 percent), more participation opportunities for UASs in DFG funding programmes (67 percent), independent right to grant doctoral degrees in UAS-typical subjects with a high research component (65 percent), more participation opportunities for UASs in Länder funding programmes, and the appointment of research professors with reduced teaching commitments. Cf. Geyer et al. (2016: 68ff.).

66 The qualifications required for appointment are stipulated in the German Higher Education Framework Act (section 44) and in the Länder higher education acts.

67 In this regard, cf. also WR (2016: 28ff.). The German Council of Science and Humanities points out that, in this respect, the UASs are also competing with universities in certain subjects, e.g. in engineering sciences. Cf. WR (2016: 29f.).

68 According to a BMBF-funded study conducted by the DZHW, only 57 percent of the professorships advertised between July 2013 and June 2015 were filled after the first round. However, the ratio was increased to 84 percent by means of multiple alerts (16 percent of the professorships at UASs thus remained unoccupied; the corresponding percentage among universities is not known since comparable figures are not available). Ongoing processes are excluded in this study. If they are included, the picture after the first job advertisement is as follows: 53 percent of positions were filled, 39 percent could not be filled, and 8 percent of the appeal proceedings were still ongoing at the time of the analysis. The status of the processes at the time when the data collected were analysed – where necessary after repeated job ads – was as follows: 71 percent of positions were filled, 14 percent of positions could not be occupied, and 16 percent of the appeal proceedings were still ongoing at the time of the analysis. A lack of practical (non-tertiary) experience was mentioned in about half of the excluded applications. Cf. Smitten et al. (2017).

69 In 1992, the BMBF launched a programme called 'Application-oriented research and development at universities of applied sciences' (Anwendungsorientierte Forschung und Entwicklung an Fachhochschulen) with the aim of enabling UASs to start engaging in research. In 2004, the programme 'Applied research at universities of applied sciences in cooperation with business UAS3' (Angewandte Forschung an Fachhochschulen im Verbund mit der Wirtschaft FH3) followed, in which the focus was on research collaborations with companies. The programme called 'Research at universities of applied sciences' began in 2006. Cf. BMBF (2016d: 6).

70 Cf. Bundesanzeiger (2013).

71 Cf. Bundesanzeiger (2013).

72 Cf. https://www.foerderinfo.bund.de/de/forschung-an-fachhochschulen-956.php (last accessed on 17 January 2018). The programme 'Research at universities of applied sciences' includes several lines of funding: FHprofUnt (research at universities of applied sciences with companies), IngenieurNachwuchs (cooperative doctoral studies), FH-Sozial (quality of life through social innovation), FHInvest (promotion of strategic investments at universities of applied sciences, FH-Impuls (strong universities of applied sciences – stimulus for the region), EU-Antrag-FH and EU-Strategie-FH.

73 Cf. https://www.bmbf.de/de/forschung-an-fachhochschulen-543.html (last accessed on 17 January 2018).

74 https://www.bmbf.de/en/innovative-hochschule-3367.html (last accessed on 17 January 2018). According to the agreement between the Federal Government and the Länder, the key goals of the Innovative University funding initiative are to "strengthen the strategic role of tertiary education institutions in the regional innovation system" and to "support tertiary education institutions that already have a coherent strategy for their interaction with business and society, as well as structures and experience with the transfer of ideas, knowledge and technology – in raising their profile in the transfer of ideas, knowledge and technology either throughout the entire institution or in selected thematic areas of the institution". GWK (2016), own translation.

75 GWK (2016), own translation. The agreement between the Federal and Länder governments mentions strategic measures, structural measures and implementation projects as possible ideas for cooperation with business, culture and society. In this context, the guidelines on the

implementation of the agreement between the Federal and Länder governments mention possible projects for funding, although this should not be regarded as an exhaustive list. Cf. BMBF (o.J.).

76 Cf. GWK (2016).
77 Cf. GWK (2016).
78 Cf. BMBF (o.J.).
79 Cf. GWK (2017) on the projects selected for funding.
80 In this regard and in the following, cf. DFG (2014).
81 Project academy participants can apply to the DFG for the 'Stand-in' module, which enables them to be freed from teaching and administrative tasks for a limited period of time. Cf. DFG (2014).
82 In the following, cf. WR (2016).
83 The holders of special-focus professorships take on specialized assignments in defined performance areas. According to the German Council of Science and Humanities, special-focus professorships are to be awarded for a limited period and to be dependent on performance. Cf. WR (2016).
84 In the case of tandem programmes, personnel-development measures are to be drawn up jointly by one or more UASs and several companies and/or institutions and offered to a selected group of employees from outside academia. Cf. WR (2016).
85 The idea behind cooperation platforms is that they should represent the institutional, financial and legal basis for transfer processes between the UASs, universities and non-university partners. Cf. WR (2016).
86 In this regard and in the following, cf. HRK (2016).
87 In this regard and in the following, cf. Meurer (2018) and the literature cited there.
88 In this regard and on individual points, cf. Meurer (2018).
89 Cf., for example, https://www.tu9.de/tu9/6425.php (last accessed on 17 January 2018), U15 (2014), DHV (2013), and Deutsche Akademie der Naturforscher Leopoldina – Nationale Akademie der Wissenschaften (2017). The German Council of Science and Humanities postulates that the universities' right to grant doctoral degrees involves an obligation to cooperate with institutions that do not have an independent right to grant doctoral degrees, but do participate in the qualification of young scientists. Cf. recently WR (2016: 57).
90 In the United Kingdom and the USA, a distinction is made between a PhD and a professional doctorate. The National Academy of Sciences Leopoldina (Nationale Akademie der Wissenschaften Leopoldina), the acatech – German Academy of Science and Engineering (acatech – Deutsche Akademie für Technikwissenschaften) and the Union of the German Academies of Sciences and Humanities (Union der deutschen Akademien der Wissenschaften) point out that, in the UK, the value of a doctorate depends to a larger extent than in other countries on the institution that awards the title and on the type of doctoral degree. Cf. Deutsche Akademie der Naturforscher Leopoldina – Nationale Akademie der Wissenschaften (2017: 30ff.).
91 In this regard and on individual points, cf. Meurer (2018).
92 Two doctoral centres – 'Social sciences focusing on globalization, European integration and interculturality' and 'Public health' are located at Fulda University of Applied Sciences. The 'Social work' doctoral centre is organized jointly by the RheinMain, Frankfurt and Fulda universities of applied sciences. The 'Applied computer science' doctoral centre is run by the Darmstadt (HDA), Frankfurt, Fulda and RheinMain universities of applied sciences. Cf. Hessischer Landtag (2017); also based on information provided by telephone on 22 November 2017 by the Hessian Ministry for Science and the Arts.
93 Bad Wiesser Kreis – Mitgliedergruppe der Fachhochschulen in der HRK (2014), own translation.
94 DHV (2013), own translation.
95 In a statement on doctoral studies in transition, the National Academy of Sciences Leopoldina, the acatech – German Academy of Science and Engineering, and the Union of the German Academies of Sciences and Humanities note: "It would be unfortunate if the value of a doctoral degree were to become dependent on the issuing institution or on special legal regulations that apply in individual Länder." Deutsche Akademie der Naturforscher Leopoldina – Nationale Akademie der Wissenschaften (2017: 46), own translation.
96 Cf. EFI (2017); EFI (2013).
97 For example, the UASs group in the HRK has recommended forming a German transfer company (DTG). The DTG would support technology transfer based on application-oriented research and, in addition to project funding, also promote business start-ups and the establishment of cooperation structures. Cf. Mitgliedergruppe der Fachhochschulen/Hochschulen für Angewandte Wissenschaften in der HRK (2017).

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98 Cf. http://www.cebit.de/de/news-trends/news/data-scientists-erobern-unternehmen-und-universitaeten-1443 (last accessed on 17 January 2018).
99 Cf. EFI (2016: 79).
100 The KldB 2010 was developed by the Federal Employment Agency and has been in use since 1 January 2011. Assignment to an occupation or profession depends on the type of activity that is executed. For example, an employed person with a degree in computer science who works as a managing director is statistically not listed under computer scientists but under corporate management. Cf. Bundesagentur für Arbeit (2017b: 16) and https://statistik.arbeitsagentur.de/Navigation/Statistik/Grundlagen/Klassifikation-der-Berufe/KldB2010/KldB2010-Nav.html (last accessed on 17 January 2018).
101 The number of persons employed in the occupational group 'computer science, information and communication technology' totalled 655,900 in 2015. Cf. http://bisds.iab.de/Default.aspx?beruf=BHG43&region=1&qualifikation=0 (last accessed on 17 January 2018).
102 In 2013, the ICIL study was the first to compare the information literacy and computer skills of eighth grade students worldwide. In Germany, the tests and surveys were carried out at 142 schools in all Länder with a total sample of 2,225 pupils. The International Association for the Evaluation of Educational Achievement (IEA) is responsible for ICILS – as well as for PISA, IGLU

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and TIMSS. Cf. Bos et al. (2014): Computer- und informationsbezogene Kompetenzen von Schülerinnen und Schülern in der 8. Jahrgangsstufe im internationalen Vergleich (Computer and Information Literacy of Grade 8 Students in Germany and by International Comparison). Cf. Bos et al. (2014: 12).

103 Cf. Bos et al. (2014: 105).

104 The ICILS author team uses the English-German term Literacy-Ansatz (literacy approach). Cf. Bos et al. (2014: 10).

105 Cf. Bos et al. (2014: 10), own translation.

106 Cf. Bos et al. (2014: 10).

107 Cf. http://kw.uni-paderborn.de/institut-fuer-erziehungswissenschaft/arbeitsbereiche/schulpaedagogik/forschung/forschungsprojekte/computational-thinking/ (last accessed on 17 January 2018).

108 Survey conducted by the Federal Association for Information Technology, Telecommunications and New Media (Bundesverband Informationswirtschaft, Telekommunikation und neue Medien, BITKOM) in November 2016. Cf. BITKOM (2016). In June 2017, the Federal Employment Agency diagnosed bottlenecks with regard to the availability of skilled workers in its so-called 'Skilled Workers Shortage Analysis' (based on the average period in days that a job subject to social insurance contributions remains vacant after an employee leaves) for the following technical occupations: plumbing, sanitary, heating, air-conditioning (156 days); energy engineering (148 days); software development and programming (144 days); automotive engineering (139 days); construction (130 days). Bottlenecks were also diagnosed for the following health and nursing professions: geriatric nursing (167 days); physiotherapy (144 days); healthcare and nursing (140 days); human medicine (128 days). Average vacancy time for all occupations: 100 days. Cf. Bundesagentur für Arbeit (2017a: 7).

109 According to Adecco recruitment agency. Cf. Kuri (2017).

110 Cf. Ermisch (2017).

111 According to the Federal Employment Agency, there is a particularly high demand for experts in software development and IT-application consulting whose knowledge corresponds to a degree in computer science taking at least four years. Cf. Bundesagentur für Arbeit (2017b).

112 The survey was carried out by the operator of the Stack Overflow internet platform. Another 53.6 percent of respondents said that a larger supply of skilled labour would be welcome. Only 5.8 percent of the respondents stated that they could find enough candidates for vacant positions. As far as developers are concerned, full-stack web developer Java is top of the list with 47.1 percent, followed by web developer Backend with 43.9 percent and Frontend with 37.4 percent. Cf. Menge-Sonnentag (2017).

113 Due to the country's federal structure, education policy in Germany is the responsibility of the Länder. Computer science is only taught as a compulsory subject in schools in four Länder (Bavaria, Baden-Württemberg, Mecklenburg-Western Pomerania, and Saxony starting at the lower secondary stage). To the Commission of Experts' knowledge, there are no official tabular overviews on the current teaching of computer science as a school subject in Germany.

114 The most recent ICILS international comparative study conducted in 2013 states on this topic that in German schools attended by eighth grade students, the pupil-computer ratio is 11.5 to 1, which is around the mean value of the EU Member States that took part in the 2013 ICILS (11.6:1). However, the ratio is significantly more favourable in other countries, e.g. Norway (2.4:1). About 40 percent of eighth grade teachers in Germany rate the existing technical facilities at their schools as obsolete or indicate that internet access at the school is limited. Tablets for teaching or learning are available to only 6.5 percent of eighth grade pupils in Germany. This percentage is lower than that of the reference group EU (15.1 percent), and also markedly lower than that of other countries such as Australia (63.6 percent). Cf. Bos et al. (2014: 18). Cf. Lorenz et al. (2017) on the slightly positive trend of the last few years.

115 The ICILS international comparative study shows that the percentage of teachers in Germany who attended further training on the use of digital media in the classroom in the two years prior to data collection (2013) is consistently below 20 percent in various areas of training. This result is below the international average. Cf. Bos et al. (2014: 19).

116 Cf. Esterházy (2017).

117 Cf. Brand eins (2016).

118 Cf. https://www.raspberrypi.org/resources/teach/ (last accessed on 17 January 2018).

119 The corresponding project is funded by the BMWi. In the past there have also been similar BMBF projects.

120 Cf. Breiter et al. (2017).

121 The Digital Pact for Schools between the Federal Government and Länder proposed by the BMBF originally provided for federal investment amounting to €5 billion over five years. Cf. BMBF (2016a). However, these funds were not yet taken into account in financial planning.

122 Cf. Adler and Salvi (2017: 64) and Soldt (2018).

123 Cf. EFI (2016: 56).

124 The four core vocational training occupations in IT include 'IT specialist' (with the two subfields 'application development' and 'systems integration'), 'IT officer', 'IT systems electronics technician', and 'IT systems support specialist'. A fifth occupation ('mathematical-technical software developer') is often added to the IT field. The percentage of completed training contracts in the IT field grew from just under 4 percent in 2006 to around 5.2 percent in 2016. According to own calculations based on DIHK data.

125 The project commissioned jointly by the BMWi and the BMBF was accompanied, among others, by an advisory board of BITKOM and the Federal Association for SMEs in the IT sector (Bundesverband IT-Mittelstand, bitmi), the Coordinating Association of German Industry for Vocational Education (Kuratorium der deutschen Wirtschaft für Berufsbildung), and the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder (Kultusministerkonferenz, KMK). Cf. Esser et al. (2016).

126 More than 30 percent of respondents respectively agreed ("more or less applicable"/"fully applicable") with the statement that the name of their IT profession was less attractive to female potential trainees. Cf. Esser et al. (2016: 97).
127 Cf. Esser et al. (2016: 95).
128 Cf. EFI (2014: 30ff.).
129 Cf. Bundesagentur für Arbeit (2017b).
130 Overall, approximately 194,000 students (not including teacher training) studied computer science in the 2015/2016 academic year. That was 12,000 or 7 percent more than in the previous year. Women made up 20 percent. The number of graduates in computer science has also grown steadily since the turn of the millennium. Approximately 24,500 computer scientists successfully concluded their studies in 2015, an increase of 9 percent compared to the previous year.
131 According to own calculations based on data from the Federal Employment Agency.
132 However, in the same period there were also stagnating or even regressive developments in other subjects that interact with IT, and this is a cause for concern. For example, the share of first-year students in bioinformatics fell from 0.14 to 0.09 percent; in computational engineering/computer engineering the share stagnated at just under 0.6 percent. Medical informatics, on the other hand, doubled its share from 0.07 to 0.15 percent. Cf. Bundesagentur für Arbeit (2017b).
133 Cf. https://data.berkeley.edu/education (last accessed on 17 January 2018).
134 Cf. http://www.oec.uzh.ch/de/studies/general/regulations.html (last accessed on 17 January 2018).
135 Cf. EFI (2015: 50ff.).
136 Cf. SGD (2017: 7).
137 A random sample of 100 prime standard companies on the Frankfurt Stock Exchange with headquarters in Germany on 1 November 2017 was drawn (exception: AirBerlin based in the UK and Airbus in the Netherlands).
138 The following study and vocational training programmes were taken into account: computer science, information economy, software development, computational engineering/computer engineering, communications engineering, telecommunications, electronics specializing in communications technology, communications electronics and business informatics. The sample did not contain any management board members with a background of training in bioinformatics, computational linguistics, media informatics, medical informatics or business informatics. Of the 23 identified managing directors, the following have a computer-science background; 3 from the field of computer science; 2 from engineering with a computer-science focus; 2 from mathematics with subsidiary computer science; 2 from communications engineering; 2 from business informatics; and 2 with MBAs specializing in computer science. The other fields each had only one representative. The fact that areas like communications engineering were included shows that the figure of 5.1 percent is quite a conservative estimate.
139 In its New Skills Agenda for Europe, the European Union has also defined a number of education-policy priorities in 2016, among other things relating to the subject field of digital skills. Cf. http://ec.europa.eu/social/main.jsp?catId=1223 and https://www.na-bibb.de/themen/skills-agenda/ (last accessed on 17 January 2018).
140 In addition, pilot projects in eight competence centres and their networking are funded. Project teams are studying the effects of digitalization on inter-company vocational training in various occupations and developing innovative concepts for vocational training. These will be tested in the training courses and subsequently disseminated. Cf. BMBF (2017a).
141 Cf. https://www.qualifizierungdigital.de/de/programm-23.php (last accessed on 17 January 2018).
142 Cf. http://www.esf.de/portal/DE/Startseite/inhalt.html (last accessed on 17 January 2018).
143 The funding programme JOBSTARTER plus was launched in 2014 as part of the European Social Fund (ESF) 2014–2020 funding period and succeeded the JOBSTARTER programme, which had been running since 2006. The main topics are derived, among other sources, from the Alliance for Initial and Further Training 2015–2018, which was launched in December 2014 by the Federal Government, the central associations of German industry, the trade unions, the Federal Employment Agency and the Länder. The BMBF and the ESF are providing approximately €108 million for the programme. Cf. https://www.jobstarter.de/de/wer-wir-sind-97.php (last accessed on 17 January 2018).
144 Cf. Esser et al. (2016).
145 Cf. BMBF (2016a).
146 Cf. https://hpi.de/open-campus/hpi-initiativen/schul-cloud.html (last accessed on 17 January 2018).
147 The competition targets pupils and students of all ages who want to demonstrate initial knowledge of algorithmic thinking and programming. In the context of the competition, children and young people will be offered many learning opportunities – usually online and free of charge. Cf. BMBF (2017b).
148 Cf. BMBF (2016a).

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149 Cf. e.g. Gordon (2012) or Lindsey (2015).
150 Cf. for example Bertschek et al. (2014).
151 Countries near the technology frontier/Community Innovation Surveys (CISs) countries plus Switzerland.
152 In the following, cf. Peters et al. (2018).
153 The USA is regarded as the best-studied country in terms of national productivity development. Since the Second World War, a distinction has frequently been made with regard to productivity growth between four periods (calculated on the basis of labour productivity):
– 1947 to 1973: average of 2.7 percent per year
– 1974 to 1994: average of 1.5 percent per year
– 1995 to 2004: average of 2.8 percent per year
– 2005 to 2015: average of 1.3 percent per year,

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The first decline in productivity growth is regarded as well-studied. However, there is still a debate about its causes; cf. Bloom et al. (2017) on the basis of data from the US Bureau of labour Statistics. According to Fernald (2014), the second decline (from 2005) began before the major recession and is not related to burst bubbles on the real-estate and financial markets in 2008. Each of the group differences is statistically significant. Cf. Bloom et al. (2017).

154 The TFP measure here is based specifically on a production function that takes the input factors capital, labour and human capital into account. Labour corresponds to the number of persons employed in an economy. It is weighted with the human capital variable generated from the average number of school years and the assumed returns on education. The capital variable is estimated on the basis of a country's investment, and GDP is used as the measure of output. TFP is calculated according to the method used by Feenstra et al. (2015). Cf. Peters et al. (2018: 22).

155 Cf. Peters et al. (2018: 23), calculations are based on Penn World Table 9.0 data.

156 The reason for the development between 1990 and 1994 was probably that in East Germany, with an almost fully depreciated capital stock, positive output was produced.

157 The OECD uses the term multi-factor productivity (MFP) differently to make it clear that not all factors influencing productivity can be measured. Cf. https://stats.oecd.org/glossary/detail.asp?ID=3091 (last accessed on 17 January 2018).

158 The way it changes over time is determined indirectly by a process known as growth accounting by comparing the growth contributions of the other input factors to overall growth (Solow growth accounting). In this context, the contribution of an input factor to overall growth is weighted with the respective input elasticity of the output. This weighting can be determined directly by growth accounting. In the case of linear-homogeneous production functions (like the Cobb-Douglas production function) and competitive factor markets, the sought input elasticities correspond to the respective income shares of the associated input factors (which can be measured empirically as wage income and capital returns in relation to total income), since the factor prices are a result of the respective marginal productivities. Cf. for example Acemoglu (2009: 77ff.).

159 TFP growth is the amount left over from growth accounting, is referred to in the literature as Solow residual.

160 Cf. Comin (2008). This interpretation is, however, dependent on various assumptions. These include, in particular, constant economies of scale (i.e. if all input factors are doubled, the output is also exactly doubled), efficient production, and competitive factor markets (i.e. wages correspond to the (value-based) marginal productivity of the input factor labour, and the return on capital corresponds to the (value-based) marginal productivity of the input factor capital). However, many of these assumptions only hold up partially in reality.

161 For a summary, cf. for example Acemoglu (2009), Aghion and Howitt (2009), or Barro and Sala-i-Martin (2003).

162 Cf. Elstner et al. (2016). In the case of the production factor capital, an additional distinction is made between ICT capital and non-ICT capital. Cf. Elstner et al. (2016: 5).

163 Cf. EFI (2017).

164 The knowledge-based economy encompasses R&D-intensive industries and knowledge-intensive services. In this regard and on individual points, cf. chapter D 4.

165 In the same period, the closure rates in the knowledge-based economy have remained constant. Cf. EFI (2017).

166 The exact definition of the innovator ratio is the number of companies that have introduced at least one product or process innovation within a three-year reference period as a percentage of all companies. Cf. Rammer et al. (2018: 6).

167 The Community Innovation Surveys (CISs) are a series of statistical surveys conducted by national institutions in the Member States of the European Union, as well as in Norway and Iceland. The EU-wide surveys are harmonized on the basis of the so-called Oslo Manual; they are used to depict and analyse innovation activities. In addition, there are surveys in non-EU countries that also follow the stipulations of the Oslo Manual. Cf. Rammer et al. (2018: 6).

168 Moreover, the percentage of companies with marketing and organizational innovations decreased noticeably from 2006 to 2016, i.e. product and process innovations were not offset by marketing and organizational innovations. In the opinion of the ZEW, new innovation trends therefore have no effects on the innovation rate. According to written information provided by the ZEW.

169 The data shown also include the first CIS survey (reference period 1990 to 1992), which is only available for Germany. The first CIS survey did not publish any internationally comparable results. Cf. Rammer et al. (2018: 6).

170 These are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden and United Kingdom.

171 The decline took place mainly between 1996 and 2000 and between 2008 and 2012. From 2000 to 2008, the innovation rate remained stable at approx. 40 percent.

172 Cf. Bloom et al. (2017). The fact that, despite everything, there was comparatively stable growth in the USA's overall economy is attributed to the strong growth in research activities, which offset the decline in research efficiency.

173 It remains unclear which researchers were incorporated and, in particular, whether researchers at tertiary education institutions were included, whose knowledge output is difficult to measure.

174 In disaggregated studies at the industry level, Bloom et al. (2017) replace this indicator, for example, by the change in the number of transistors per chip or the ratio of additional years of life for people aged 55 to 64.

175 Cf. Peters et al. (2018: 38).

176 These include other intangible assets, spillover, a possible misallocation of resources, and the age and quality of the stock of physical capital used. Approaches for estimating the rate of return on R&D, by contrast, make it possible

either to check for these influences or at least to include them statistically in the error term. Cf. Peters et al. (2018: 37ff.). Furthermore, neither knowledge accumulation nor the depreciation of knowledge is taken into account in the above approach.

177 Cf. the Glossary for the definition of transnational patents.

178 According to written information provided by Fraunhofer ISI on 24 November 2017.

179 Another cause that is not discussed in depth here relates to economic structural change, i.e. the way in which the respective shares of employment, value-added or production shares shift between sectors of the economy. Cf. Baumol (1967) and Baumol (2012). This is seen as the reason why productivity growth is lower during structural change. The hypothesis is that, as income and the international division of labour increase, demand shifts away from industry to other sectors such as the service sector, where there are fewer technological possibilities for innovation and productivity gains. At the same time, structural shifts take place within services in the course of digitalization. In Germany, in addition to the factors discussed here that have a global effect, further country-specific effects have contributed to the decline in productivity growth since 2005. Cf. for example Elstner et al. (2016). For example, the relocation abroad of labour-intensive or unproductive value-adding stages between 1995 and 2005 led to macroeconomically positive productivity effects. However, the relocation of manufacturing abroad largely came to a standstill in 2009. Cf. SVR (2015: 282). At the same time, starting from 2005, there was a successful, progressive integration of low-skilled workers into the labour market, leading to a fall in labour productivity. The latest productivity developments in other countries are partially influenced by completely different effects. These include, among other things, the extent to which a country was affected by the 2008/2009 financial crisis, or e.g. one-off events such as the Brexit discussion in the United Kingdom (which was anticipatory from today's perspective); in the meantime, this discussion has led to a decline in growth from 3.1 percent in 2014 to 1.8 percent in 2016. Cf. Peters et al. (2018: 105). In France, undesirable developments on the labour market, among other things, contributed to the once unmatched level of productivity growth in the 1960s (which saw an approximately 5.5 percent average annual growth of labour productivity on the basis of technological drivers in the fields of electricity, internal combustion engines and chemicals) falling markedly to less than one percent in recent years. Cf. Peters et al. (2018: 117ff.).

180 For a topical methodological overview of challenges faced by national accounts, cf. in particular Syverson (2017) and Byrne et al. (2016), as well as Bean (2016).

181 Nordhaus (2008), for example, expects digitalization to dramatically accelerate productivity growth in the coming years and decades ('singularity hypothesis').

182 The notion of the productivity paradox dates back to Robert M. Solow, who wrote in 1987: "You can see computers everywhere but in the productivity statistics." Cf. Solow (1987).

183 Cf. in particular Brynjolfsson and McAfee (2014) and the 'evolutionary economics' view of the ICT transformation in the work of Perez (2002), according to whom digitalization is only in its "installation phase" [...] "Creative destruction is taking place right now." Cf. also van Ark (2016).

184 For a summary, cf. Peters et al. (2018), Shea et al. (2011) and Kreuchauff (2015: 13f.).

185 Cf. for example Forth and Mason (2006).

186 Cf. OECD (2016).

187 Cf. for example Bartel et al. (2007), OECD (2016), Autor et al. (2003), Falk and Biagi (2016).

188 In general, various empirical studies show that human capital has a positive effect on productivity. For example, corporate expenditure on further training has been shown to have a positive influence on productivity by Black and Lynch (1996) in America, Konigs and Vanormelingen (2010) in Belgium, and Crass and Peters (2014) in Germany. In a similar way, this is shown for the ratio of highly qualified employees, for example, by Black and Lynch (2001) for American companies, Crass and Peters (2014) for German companies, and Bartelsman et al. (2013) for Dutch and German companies. Specifically in relation to IT skills, there are some econometric studies that indirectly measure the possible productivity effects of the shortage of skilled IT professionals or the lack of IT knowledge and skills among employees. Cf. for example Hagsten and Sabadash (2017). In the meantime, efforts are being made at the international level to assess the (IT) skills of employees better. The OECD Programme for the International Assessment of Adult Competencies (PIAAC) and the CEDEFOP European Skills and Jobs (ESJ) survey are examples of broad-based surveys on this general topic. Cf. Peters et al. (2018: 89).

189 Often, for example, intermediate products first have to be researched and produced at high cost in terms of resources and time, which at the same time leads to lower investment in other parts of the economy, cf. Helpman and Trajtenberg (1998). The argument is based on David (1990) and David (1991), among others.

190 Cf. EFI (2017).

191 Cf. in particular Griffith et al. (2003). Empirical findings from earlier waves of digitalization can be found, for example, in Hornstein and Krusell (1996).

192 Similar results are found by Guellec and van Pottelsberghe de la Potterie (2002), for example, on the interaction between domestic R&D and knowledge from abroad, and by Harhoff (2000) and Peters et al. (2009) in relation to the interplay between internal and external R&D knowledge capital..

193 Cf. EFI (2017).

194 Cf. Andrews et al. (2016).

195 This observation is even more clear-cut in the services sector.

196 For example, gross domestic product is called into question by several authors as a primary measure of prosperity, quality of life and societal progress. There is no doubt that gross domestic product does not take social and ecological aspects sufficiently into account. Cf. Deutscher Bundestag (2013: 23).

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197 The legal reason for the introduction of the 'previous year's price basis' in the German national accounts was the Commission's Decision 98/715/EC of 30 November 1998 (clarifying Annex A to Council Regulation (ESA) no. 2223/96 on the principles for measuring prices and volumes). This legislative act lays down in Principle 3: "Volume measures derived at the elementary level of aggregation shall be aggregated using weights derived from the previous year." Cf. Federal Statistical Office (2003).

198 The chain index determines individually for each year how much products sold in the previous year cost in the current year. In this way, the underlying basket of goods changes from year to year – new goods are taken into consideration more quickly. Cf. Rothgang et al. (2018). As a result, the current price relations are always taken into account, the aim being to ensure a more precise calculation of the 'real' rates of change. In terms of calculations, in the case of the 'previous year's price basis' method, annual results are initially determined as measures at the previous year's prices; these measures form comparable time series by chain-linking each individual trait. Cf. Statistisches Bundesamt (2017: 3).

199 Cf. Statistisches Bundesamt (2017).

200 Cf. Syverson (2017) and Byrne et al. (2016). For information on possible measurement problems and the shift to non-market production, with a focus on Germany, cf. for example Grömling (2016).

201 Cf. Syverson (2017).

202 Cf. Syverson (2017).

203 Cf. Syverson (2017).

204 Cf. Gordon (2015) and Bloom et al. (2017).

205 Cf. Akcigit et al. (2013), Nelson (1959), Rosenberg (2009) and Partha and David (1994).

206 Cf. Loecker and Eeckhout (2017). See Loecker and Warzynski (2012) on the method of calculating markups. It should be borne in mind that the analysis only includes publicly traded companies. There are relatively few of these in the USA. However, they do account for a high proportion of turnover.

207 Cf. e.g. Harhoff et al. (2007) and Blind et al. (2009).

208 Cf. Klepper (1996); Klepper (1997); Klepper (2002).

209 Cf. Klepper (1996); Klepper (2002) in connection with Utterback and Abernathy (1975).

210 Cf. Andrews et al. (2016).

211 Positive network effects (on the user side) are usually responsible for this. Cf. Arthur (1989).

212 Cf. Solow (1987) and Brynjolfsson (1993) on the productivity paradox in the field of information technology.

213 Pursuing the example of the automotive industry, productivity growth there increased between 2005 and 2014. Total factor productivity (annual average: +3.1 percent) grew markedly faster than the overall average in the economy (annual average: +0.5 percent). The value chain was marked by continuous increases in efficiency, driven by the high competitive pressure in vehicle construction. At present, it is impossible to predict the extent to which the current upheavals relating to alternative drive systems and autonomous driving (cf. chapter B 3 on autonomous systems) will lead to a global shift in value-creation structures. For example, electric engines are much less complex to manufacture than combustion engines. Were this drive technology to win large market shares in the future, the knowledge base of the German original equipment manufacturers (OEMs) would be devalued in terms both of the technology itself and of systems integration. Cf. Rothgang et al. (2018: 38).

214 Cf. EFI (2017: chapters A1 and A2).

215 Cf. https://www.bmbf.de/foerderungen/bekanntmachung-1302.html (last accessed on 17 January 2018).

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216 Cf. http://www.europarl.europa.eu/summits/lis1_de.htm (last accessed on 17 January 2018).

217 Cf. https://www.bmbf.de/de/der-europaeische-forschungsraum-gemeinsam-forschen-gemeinsam-wachsen-279.html (last accessed on 17 January 2018).

218 With Galileo, Europe introduced the first global satellite navigation and positioning system under civilian control; it is open to international cooperation and operated commercially. Galileo aims to guarantee European independence from the two military-controlled systems GPS (USA) and GLONASS (Russia). The satellite navigation system has been available to the general public since 15 December 2016. At the end of 2017, 22 of the planned 30 satellites were in orbit. The plan is for the remaining satellites to be shot into space in the course of 2018. Originally, Galileo's services were to be available as early as 2008. However, there were repeated delays due to disputes between the satellite manufacturers, disagreements between the governments on where the satellite-control centres should be located, and technical difficulties. Instead of the original €3 billion, in the meantime a total of €13 billion is earmarked for the development and operation of Galileo until 2020. Cf. Lindiger (2016) and http://www.esa.int/ger/ESA_in_your_country/Germany/Galileo_Europas_U-nabhaengigkeit_und_Kooperation and https://www.gsc-europa.eu/news/new-galileo-quartet-successfully-launched (last accessed on 17 January 2018).

219 Cf. Bundesregierung (2017b).

220 Cf. Europäische Union (2013a).

221 Funding programmes:
The research programme of the Research Fund for Coal and Steel (RFCS) is an independent programme supplementing the Horizon 2020 research framework programme. It covers all aspects of coal and steel as well as the use and conversion of resources, safety at the workplace and environmental protection. About €300 million is available for the period from 2014 to 2020. Cf. http://www.foerderdatenbank.de/Foerder-DB/-Navigation/Foerderrecherche/suche.html?get=views;document&doc=2514 (last accessed on 17 January 2018).
The European Atomic Energy Community (EURATOM) was founded in 1957. EURATOM funds research and training in the field of nuclear energy. EURATOM's research and training programme runs from 2014 to 2018 and has a budget of €1.6 billion. Furthermore, the EU

is participating via EURATOM in the development of the International Thermonuclear Experimental Reactor (ITER). Also taking part in the ITER project, apart from the EU, are Russia, Japan, China, India, South Korea and the United States. The European Commission is providing €2.9 billion in funding for ITER over the period 2014 to 2020. Cf. EFI (2011).
CERN is one of the first joint European projects and was founded in 1954. It is a large-scale international, intergovernmental research facility for basic research in physics. CERN is funded by the 20 Member States. The budget for 2016 totalled approximately €1 billion. Cf. Weber et al. (2018: 25).
The COSME programme is a continuation of the promotion of SMEs by the 2007–2013 Competitiveness and Innovation Framework Programme. COSME aims to improve the competitiveness of SMEs, among other things by taking measures to facilitate access to funding, and to improve the framework conditions for competitiveness. The budget for the period from 2014 to 2020 amounts to around €2.3 billion. Cf. http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=views;document&doc=11701, and https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/europaeische-mittelstandspolitik3.html (last accessed on 17 January 2018).
The European Space Agency (ESA) is an international organization to which 22 European countries belong. It acts as an intergovernmental organization independent of the EU, although it maintains close ties with the Union via an ESA-European Community framework agreement. The ESA's task consists in designing and implementing the European space programme. ESA's budget for 2017 amounted to €5.75 billion. Cf. Weber et al. (2018: 25).
Copernicus and Galileo bundle the European Union's space activities connected with satellite navigation and terrestrial observation. Cf. Weber et al. (2018: 26).
Financial instruments:
The European Investment Bank (EIB) is part of the EIB Group, which also includes the European Investment Fund (EIF). The EIB is owned by the Member States of the EU. The EIF's shareholders are the EIB (66 percent), the European Commission (25 percent) and other European financing institutions (9 percent). The EIB raises funds on the financial markets and makes these available on favourable terms, usually in the form of loans and venture capital for projects. In 2016, the capital subscribed by the EIB amounted to €243 billion; the EIF's capital totalled €4.4 billion. The EIF's support operations in cooperation with the EIB primarily target SMEs and their access to funding sources. Cf. http://www.eib.org/about/key_figures/data.htm (last accessed on 17 January 2018).
The European Fund for Strategic Investments (EFSI) set up in 2015, also known as the Juncker Plan, is a joint initiative of the EIB Group and the European Commission. It is equipped with guarantees worth €21 billion, with which investments of at least €315 billion are to be mobilized. The EFSI's priorities lie in the promotion of education, research, development and innovation, as well as supporting SMEs. Cf. European Union (2015) and http://www.eib.org/efsi/what-is-efsi/index.htm (last accessed on 17 January 2018).
In addition, there are the Health and Life programmes, which are financed via the respective sectoral budgets and will promote applications of solutions with a high degree of innovation. Weber et al. (2018: 26).

222 Cf. European Commission (1995).

223 Dosi et al. (2006) argue that Europe is behind the USA in scientific terms when the EU's publication output is standardized to the population or the research personnel. Cf. Dosi et al. (2006). In her study, Sachwald (2015) finds that European publications are cited less frequently than American ones, and draws the conclusion that European publications are of lower quality than American publications. Cf. Sachwald (2015).

224 Cf. http://www.eubuero.de/ausweitung.htm (last accessed on 17 January 2018).

225 Cf. http://www.eubuero.de/ausweitung.htm (last accessed on 17 January 2018).

226 Cf. BMBF (2014).

227 Cf. Bundesregierung (2017b).

228 Examples of this include the Competitiveness and Innovation Framework Programme (CIP) and the European Institute of Innovation and Technology.

229 Cf. European Commission (2017d).

230 Cf. BMBF (2014).

231 The European Research Council is a science-led institution set up by the European Commission to support excellent scientists with ground-breaking research projects.

232 The Marie Skłodowska-Curie actions aim to promote the cross-border and intersectoral mobility and career development of researchers and R&I personnel, and to make careers in science more attractive.

233 E.g. for ICT, nanotechnology and biotechnology.

234 Horizon 2020's financial facilities include the credit facility and the participation facility.

235 Cf. Weber et al. (2018).

236 Teaming measures: partnerships between excellent research institutions and regions that are weak in research, development and innovation. The aim of teaming is to create new (or comprehensively upgrade existing) centres of excellence in regions or Member States that are weak in research, development and innovation.
Twinning measures: partnerships between research institutions with the aim of substantially strengthening a certain research area in an up-and-coming institution through connections with at least two internationally leading institutions in this field.

237 Cf. http://www.horizont2020.de/einstieg-programmstruktur.htm (last accessed on 17 January 2018).

238 Research and/or innovation actions support R&I projects that are carried out in association with partners from different countries. The aim of these measures is to develop new knowledge, technologies, processes, products and services. They are supplemented by network-oriented innovation actions which aim to promote demonstration and market-implementation projects. Coordination and support actions are measures that accompany research. They support networking between project partners,

e.g. with the help of conferences, seminars or common initiatives. In the case of co-financing measures, national or regional funding institutions administrating research and innovation programmes are given financial support with individual programmes or invitations to tender. In this way, Horizon 2020 emphasizes and supports public-private partnerships (PPPs) and public-public partnerships (P2Ps). These PPPs and P2Ps aim to improve interaction between national and regional activities and to increase the involvement of industry. Cf. http://www.horizont2020.de/einstieg-instrumente.htm (last accessed on 17 January 2018) and BMBF (2014).

239 Volume at current prices.

240 However, in 2015, the budget of Horizon 2020 was reduced in favour of the European Fund for Strategic Investments (EFSI, also known as the Juncker Plan). At present, the financial framework of Horizon 2020 amounts to a maximum of €74.8 billion at current prices (European Union, 2015, Annex 1). As Article 9 of the Regulation says, however, the EFSI can also fund projects that correspond to the objectives of Horizon 2020, so that the actual level of cuts will probably not be known until after completion of the programme. Cf. Weber et al. (2018: 16).

241 This is a significant increase over the 6th and 7th framework programmes (4.2 and 5.5 percent respectively).

242 Parts of the Competitiveness and Innovation Framework Programme (CIP) are being continued within Horizon 2020 in the thematic pillar Industrial Leadership. Similarly, the European Institute of Innovation and Technology (EIT) has been integrated into Horizon 2020. Cf. Weber et al. (2018).

243 For example, the funds of the European Research Council (ERC) almost doubled to €13 billion, and the resources of the Marie Skłodowska-Curie initiative (formerly Marie Curie initiative) rose by about 30 percent. Similarly, the funding of several thematic programmes within the three pillars was significantly improved. The budget for energy in the Societal Challenges pillar tripled from €1.8 billion in FP7 to €5.7 billion in Horizon 2020. Funding for transport rose to €6.1 billion, almost €4 billion more than in FP7. Other areas are difficult to compare because Horizon 2020 funds societal challenges that can extend across several fields of technology. Cf. Weber et al. (2018: 17).

244 The increase in funding for Horizon 2020 compared to FP7 is 73 percent in the Excellent Science pillar. In the Societal Challenge pillar, funding for Horizon 2020 was 55 percent higher than for FP7.

245 The ESI Funds are made up of the European Regional Development Fund (ERDF), the European Social Fund (ESF), the Cohesion Fund (CF), the European Agricultural Fund for Rural Development (EAFRD), and the European Maritime and Fisheries Fund (EMFF).

246 Cf. BMBF (2016b: 292).

247 Cf. European Commission (2008: 114).

248 Cf. Europäische Union (2013a).

249 Cf. http://www.eubuero.de/ausweitung.htm (last accessed on 17 January 2018).

250 Cf. https://cohesiondata.ec.europa.eu/funds/erdf (last accessed on 17 January 2018).

251 Cf. Europäische Union (2013b).

252 Cf. https://cohesiondata.ec.europa.eu/funds/eafrd (last accessed on 17 January 2018).

253 Cf. Europäische Kommission (2017).

254 Cf. Weber et al. (2018: 86).

255 Compared to Horizon 2020, funds from FP7 made up 3.82 percent of total government R&D funding in the case of tertiary education institutions and 4.2 percent in the case of AUFs. Cf. Weber et al. (2018: 40).

256 Compared to Horizon 2020, funds from FP7 made up 13.02 percent of total government R&D funding for companies. Cf. Weber et al. (2018: 40).

257 The correlation value, which describes the linear relationship between two characteristics, amounts to 0.94 for the sector shares listed in table B 2-5 (taking into account 56 two-digit sectors of the WZ 2008 classification of economic activities, average for 2006 to 2014). If the correlation value were 1.0, the respective shares of sectors funded by the EU Framework Programme and the BMBF Specialized Programmes would be identical. In the case of BMWi funding, the correlation with the EU Framework Programme funding, at 0.85, is less pronounced than in the case of BMBF funding; the correlation for Länder funding is 0.88. The correlation of the sector shares is lowest for the group of companies that received exclusively EU Framework Programme funding (0.72). This is due to the high percentage of companies in the field of other services (22 percent), and the sectors manufacturing and processing materials – particularly glass/ceramics/stone products, rubber/plastics and chemicals. The EU Framework Programme evidently offers funding opportunities for R&D activities in these sectors that are not available in this form in the federal and Länder programmes. The EU Framework Programme seems to play a unique role here compared to the funding offered by the Federal Government and the Länder. Cf. Weber et al. (2018: 63f.).

258 Other services: 22 percent; chemicals/materials: 18 percent.

259 SMEs made up a significantly higher share (90 percent) of the BMWi's Central Innovation Programme for SMEs (ZIM). Cf. Weber et al. (2018: 85).

260 Cf. Weber et al. (2018: 83).

261 According to information provided by KUKA AG on 5 December 2017.

262 The share in the case of Horizon 2020 programmes is 51.4 percent. The share in the case of federal Specialist Programme projects is 56.3 percent.

263 Cf. Weber et al. (2018: 74f.).

264 Cf. Europäische Union (2008).

265 Cf. EIT (2017: 8f.) and European Commission (2017b).

266 Cf. European Commission (2016).

267 Cf. EIT (2017: 19).

268 Cf. Moedas (2015) and http://www.eubuero.de/fet-eic.htm (last accessed on 17 January 2018).

269 Cf. Sachwald (2015).

270 Cf. Weber et al. (2018: 93).

271 Among other things, the EIC is supposed to act as a one-stop shop and thus offer some orientation in the European funding jungle. At the same time, it is expected to support companies in generating disruptive innovations. In addition, the topic of 'open innovation' is supposed to be

given special attention in the EIC. Cf. Weber et al. (2018: 93f.).

272 Cf. Weber et al. (2018) and Austrian FP9 Think Tank (2017).

273 Plans for the establishment of an EIC are criticized from various sides. For example, the BMBF argues that there is no gap in the funding system at the European level that could be filled by an EIC. Cf. Schütte (2016). Furthermore, the BMBF calls for an expansion of the focus to include universities and public research institutions. Cf. BMBF (2016c). The question is also raised as to how excellent innovations with disruptive, market-opening potential can be identified at all. Finally, there are references to the risk of overlap with the EIT, which also aims to strengthen European innovation activities. Cf. Weber et al. (2018: 92).

274 These instruments include the European Fund for Strategic Investments (EFSI), the European Institute of Innovation and Technology (EIT) and the SME Instrument in Horizon 2020. It is also unclear whether EIC promotion should be provided by means of loans or the allocation of funding.

275 Cf. http://www.horizont2020.de/einstieg-eit.htm (last accessed on 17 January 2018).

276 Cf. Weber et al. (2018: 94).

277 Cf. http://ec.europa.eu/research/eic/index.cfm?pg=home (last accessed on 17 January 2018).

278 The concept of radical innovation is a technical term from the field of innovation economics; its narrower interpretation distinguishes incremental (small-step) technical progress from changes that can enable an innovator to establish a monopoly position. In a broader sense, the term 'radical innovation' is used for innovations that lead to far-reaching changes in markets, organizations and societies. The term breakthrough innovation has also become established in this context.

279 For example, EIC Horizon Prizes.

280 FET Open: FET Open funds unconventional new research ideas at an early stage – ideas geared towards fundamental breakthroughs for new technologies – by questioning existing paradigms and enabling research to be conducted at the frontier of knowledge. Cf. http://www.eubuero.de/fet-open.htm (last accessed on 17 January 2018).
SME Instrument: SME Instrument targets innovative and ambitious SMEs with European and global ambitions, enabling them to develop specific innovations to market maturity. The instrument combines fast funding decisions, funding without restrictions on research topics, and a three-phase approach. Funding of individual SMEs is possible. Cf. http://www.nks-kmu.de/foerderung-kmu-instrument.php (last accessed on 17 January 2018).
Innovation prizes: the prizes (inducement prizes) under the umbrella of the EIC pilot in Horizon 2020 include ambitious targets without dictating how these are to be achieved. The prize is awarded to those who have met the challenge in the most effective manner. Cf. http://www.nks-kmu.de/foerderung-preise.php (last accessed on 17 January 2018).
Fast Track to Innovation: Fast Track to Innovation (FTI) offers a springboard for applicants to quickly transfer relatively mature, pioneering new technologies, concepts and processes into market-ready products, processes, services, business models, etc. The emphasis is on interdisciplinary and cross-sectoral approaches. FTI targets technological breakthroughs and service innovations. Cf. http://www.nks-kmu.de/teilnahme-fti.php (last accessed on 17 January 2018).

281 Cf. Weber et al. (2018: 97f.).

282 Cf. European Commission (2017e).

283 Cf. Bundesregierung (2017a: 13).

284 Cf. Bundesregierung (2017a: 19).

285 Cf. Bundesregierung (2017a: 19).

286 Cf. Bundesregierung (2017a: 19).

287 Cf. Harhoff et al. (2018). Cf. also http://www.deutschlandfunk.de/praesident-der-max-planck-gesellschaft.676.de.html?dram:article_id=409092 (last accessed on 24 January 2018).

288 Cf. Harhoff et al. (2018). Cf. also http://www.deutschlandfunk.de/praesident-der-max-planck-gesellschaft.676.de.html?dram:article_id=409092 (last accessed on 24 January 2018).

289 The initiative is not a proposal by the French Government. However, the initiators are taking up the demands for a European innovation agency made by French President Emmanuel Macron in his Sorbonne speech on 26 September 2017. Cf. Kelly and Alho (2017) and Le Monde Economie (2017).

290 Cf. Schlütter (2017).

291 Furthermore, British institutions coordinate a fifth of all Horizon 2020 projects. Spanish and German institutions follow in second and third place with 13 percent or 11 percent of the project coordinations respectively. Cf. EUA (2016).

292 Cf. HM Government (2017).

293 Taking the twelve main EU countries into account, the number of co-publications is approximately 453.000. Cf. The Royal Society (2016: 11)

294 Cf. The Royal Society (2016: 8).

295 There are 37 British, 48 French and 65 German ERC grant holders. Cf. European Research Council (2017: 3ff).

296 "… forging a more ambitious and close partnership with the EU than any yet agreed between the EU and a non-EU country" (HM Government 2017: 8).

297 Cf. Europäische Kommission (2016).

298 Cf. European Commission (2017c) and http://www.horizont2020.de/einstieg-international.htm (last accessed on 17 January 2018).

299 For further examples see e.g. https://www.timeshighereducation.com/news/brexit-could-uk-join-european-union-eu-research-system-as-associated-country (last accessed on 17 January 2018).

300 Cf. https://www.sbfi.admin.ch/sbfi/de/home/themen/in-ternationale-forschungs--und-innovations zusammenarbeit/forschungsrahmenprogramme-der-europaeischen-union/horizon-2020/h2020.html (last accessed on 17 January 2018).

301 The Swiss government had refused to ratify the protocol extending the free movement of persons to include Croatia. The EU regarded the non-ratification as a violation of the 2002 bilateral agreement between the EU and Switzerland on freedom of movement

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for workers and the freedom to provide services. According to a provisional agreement between the EU and Switzerland, the latter was able to participate in Horizon 2020 from September 2014 to December 2016 as a partially associate partner. Only when Switzerland recognized the free movement of persons for Croatia was its full association status restored at the beginning of 2017. Cf. Europäische Kommission (2016) and ETH-Rat (2014); European Commission (2017a) and https://www.sbfi.admin.ch/sbfi/de/home/themen/internationale-forschungs--und-innovationszusammenarbeit/forschungsrahmenprogramme-der-europaeischen-union/horizon-2020/h2020.html (last accessed on 17 January 2018).

302 Cf. https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-60389.html (last accessed on 17 January 2018).

303 In the case of third countries, a distinction is made between industrialized countries (e.g. Australia, Japan, South Korea, USA, etc.) and International Cooperation Partner Countries (developing countries, EU accession countries and countries of the European Neighbourhood Policy). While the participation of institutions from IPC countries in the research framework programmes is funded, partners from industrialized countries can take part in the research framework programmes but generally receive no financial support for their participation. Cf. http://www.horizont2020.de/projekt-beteiligungsregeln.htm and http://www.kowi.de/kowi/horizon-2020/internationale-kooperation/internationale-zusammenarbeit.aspx (last accessed on 17 January 2018).

304 Cf. European Commission (2017c) and Weber et al. (2018: 105).

305 Cf. Weber et al. (2018: 105) and http://www.horizont2020.de/einstieg-international.htm (last accessed on 17 January 2018).

306 Cf. http://www.europarl.europa.eu/summits/lis1_de.htm (last accessed on 17 January 2018).

307 This objective was taken up again in the 'Europe 2020' strategy adopted in 2010, and declared one of the five main objectives for 2020. Cf. Europäische Union (2005) and https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy--coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy_de (last accessed on 17 January 2018).

308 Cf. Watt (2006) and Meller et al. (2006).

309 Cf. EFI (2011: 58).

310 The expectations formulated in the context of the establishment of the EIC are so diverse and comprehensive, that they could hardly be met by a single institution. The EIC is expected not only to identify and promote excellent innovations with disruptive, market-opening potential, but simultaneously correct erroneous developments within European R&I policy and deficits in existing institutions.

B 3

311 For example, in June 2017 the European Robotics Hackathon was held at the Zwentendorf nuclear power plant – see http://enrich.european-robotics.eu/ (last accessed on 17 January 2018) – during which robots from the participating teams created radiation maps and 3D maps of the interior, and searched for and manipulated radioactive material. In some cases, semi-autonomous functions were used, cf. Fraunhofer FKIE (2017). An autonomous robot for mine-clearance operations is described, for example, in Jaradat et al. (2017).

312 Autonomous systems are also called learning systems (for example, on the 'Learning Systems' platform, cf. https://www.plattform-lernende-systeme.de/home.html (last accessed on 17 January 2018).

313 Cf. Statistisches Bundesamt (2016).

314 Cf. Anderson et al. (2014). However, the accident frequency of the autonomous vehicle prototypes currently being tested is significantly higher than that of human drivers. Cf. Favarò et al. (2017).

315 Cf. SAE International (2016).

316 In 1965, John McCarthy organized the Dartmouth Summer Research Project on Artificial Intelligence. The term artificial intelligence was already used in the previous year in the corresponding proposal, cf. http://raysolomonoff.com/dartmouth/boxa/dart564props.pdf (last accessed on 17 January 2018).

317 Cf. Turing (1950). The famous Turing test for the recognition of artificial intelligence is also formulated here.

318 Cf. EOP and NSTC (2016). However, there is no uniform definition of AI.

319 Cf. AI100 (2016).

320 This is also referred to as the 'AI winter'. Cf. Nilsson (2010: 305-330).

321 Cf. on this also https://towardsdatascience.com/the-ai-winter-is-over-heres-why-1001e6b7bb0 (last accessed on 17 January 2018).

322 The victory of the Deep Blue chess computer over the then world champion Garri Kasparov in 1997 may be called a milestone. It is important to note in this context that although computers can be superior to humans when it comes to very clearly defined tasks, even here cooperation between humans and machines leads to a substantial improvement in the results as a rule. For example, a modern chess computer can be beaten by a team made up of a human and a weaker chess computer. Cf. EOP and NSTC (2016).

323 Cf. AI100 (2016).

324 Cf. https://devblogs.nvidia.com/nvidia-ibm-cloud-support-imagenet-large-scale-visual-recognition-challenge/# (last accessed on 17 January 2018).

325 Cf. EOP and NSTC (2016).

326 Cf. Dumitrescu et al. (2018).

327 These functions are of great importance, even in deployment areas of autonomous systems that do not require direct interaction with people. For example, exact environment recognition, communication and precise

execution of actions also play a major role underwater, e.g. when investigating coral reefs or in archaeological investigations.

328 The different sensors carry out different tasks. Cameras read traffic signs, radar ensures that there are no collisions, and lidar supports vehicle guidance. Another particularly important function is sensor fusion, i.e. integrating these different sensor data. On the other hand, different sensors can be used in different areas of application. Underwater, for example, sensors are used to determine the direction and velocity of currents.

329 Self-regulation is a cross-cutting function that ensures independent task performance and adaptation to changing environments and situations. The core of self-regulation is continuous learning from successful or unsuccessful actions. Based on what has been learned, systems can self-optimize, enabling them to autonomously adapt system targets and system behaviour. Cf. Dumitrescu et al. (2018).

330 One advantage lies in the fact that computers can acquire and share knowledge very quickly and efficiently, and AI is able to process data such as texts, from which it has hardly been possible to automatically extract knowledge up to now.

331 Cf. Dumitrescu et al. (2018).

332 These indicators are generated by aggregating the survey results for a finer breakdown of technologies within the respective environmental and core technologies. For the purpose of aggregation, the arithmetic mean of the experts' assessment of the technologies is calculated within a core or environmental technology.

333 The potential benefits presented here can be regarded as conservative estimates. The disruptive potential of autonomous systems and of AI may lead to more than such adjustments in existing processes and business models. However, predictions of more radical disruptive upheavals in life habits and markets involve a high degree of uncertainty.

334 Owners of facilities or items of information that are essential for the provision of a service (essential facilities) may be obliged to grant rights of use to other market participants for an appropriate fee. The aim behind enforcing such an obligation to contract is to ensure that market competition is achieved. Hitherto, the essential-facilities doctrine has been applied primarily to physical infrastructures such as supply and communication networks.

335 Test sites that are equipped with sensors are of great importance for collecting data in the area of application of autonomous vehicles; they make it possible to validate the environmental data collected by the vehicle. In Germany, test sites can be found e.g. in the cities of Berlin, Braunschweig, Dresden, Düsseldorf, Hamburg, Ingolstadt, Munich and Karlsruhe, as well as on the A9, A93, A2, A7 and A39 motorways. Cf. Dumitrescu et al. (2018: 40). The Test Area for Autonomous Driving Baden-Württemberg offers facilities for all kinds of traffic, not only to research institutions – private companies can also test technologies and services. Cf. https://taf-bw.de/ (last accessed on 17 January 2018).

336 Furthermore, policy makers can use the legislative regulation of data protection to influence how companies may use data for their value-added processes. With its General Data Protection Regulation, the European Union has a data-protection approach that is restrictive by international comparison. The aim is for citizens to be better protected from the misuse of their data. However, more difficult access to data also involves a competitive disadvantage for local companies.

337 Cf. Danks and London (2017).

338 Cf. final report of the Ethics Commission (Ethik-Kommission Automatisiertes und Vernetztes Fahren 2017).

339 Surveys of experts commissioned by the Commission of Experts have revealed that data protection and the discussion of ethical issues are further developed in Germany than in other countries. Nevertheless, the level of development is also low in Germany. Cf. Dumitrescu et al. (2018).

340 User-generated online entries on the topic of autonomous driving were analysed using IBM's Watson Analytics for Social Media. The data pool is made up of approx. 26,000 German-language and about 239,000 English-language posts between 1 January 2017 and 31 August 2017.

341 Another study shows that views on AI expressed online are also predominantly positive. Cf. AI Index (2017).

342 Estimates that assume that half of all jobs will be lost as a result of further automation are exaggerated and sharply criticized in more recent studies. In the view of many experts (Bonin et al. 2015; Autor and Solomon 2017), the study by Frey and Osborne (2017), which was first presented in 2013, is based on extremely simplified assumptions. In particular, studies of this kind cannot include complementarity and augmentation effects from the future use of autonomous systems and AI systems. Cf. also box B 2-6 in EFI (2016).

343 At present, several autonomous submarines are being deployed in parallel to continue the search for the missing flight MH370, cf. https://www.economist.com/news/science-and-technology/21733399-swarm-submarine-drones-will-scour-depths-plane-fantastical-ship (last accessed on 17 January 2018).

344 At Cebit 2017, the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (IOSB) presented the autonomous excavator IOSB.BoB, which could be deployed in environments that are hostile to humans. Cf. Fachforum Autonome Systeme (2017).

345 Cf. Witwicki et al. (2017) and examples mentioned therein, such as IBM's Smart Surveillance System. Cf. Onut et al. (2010).

346 A demonstrator for interoperability in the smart home field was presented by ZVEI at Cebit 2017. Cf. Fachforum Autonome Systeme (2017).

347 Cf. https://www.kuka.com/de-de/technologien/mensch-roboter-kollaboration (last accessed on 17 January 2018).

348 Cf. https://www.kuka.com/de-de/branchen/loesungsdatenbank/2016/07/solution-systems-bsh (last accessed on 17 January 2018).

349 Cf. Anderson et al. (2014). For example, estimates suggest that digitally linked autonomous vehicles can achieve a

five-fold increase a road lane's capacity. Cf. Fernandes and Nunes (2012), cited in KPMG and Center for Automotive Research (2012).

350 Cf. Bundesamt für Güterverkehr (2017).

351 Cf. http://www.zeit.de/news/2018-01/07/jahreswechsel-busfahrer-fuer-betriebe-nur-noch-schwer-zu-finden-07085802 (last accessed on 17 January 2018).

352 To ensure this, it will be necessary to complete the internal data market within the EU. Cf. https://ec.europa.eu/germany/news/europ%C3%A4ische-datenwirtschaft-eu-kommission-stellt-konzept-f%C3%BCr-daten-binnenmarkt-vor_de (last accessed on 17 January 2018).

353 The conferences covered are: Conference on Neural Information Processing Systems (NIPS), Principles and Practice of Knowledge Discovery and Data Mining (PKDD), Conference on Artificial Intelligence and Statistics (AISTAT), Annual Conference on Computational Learning Theory (COLT), International Conference on Knowledge Discovery and Data Mining (SIGKDD), Uncertainty in Artificial Intelligence (UAI), and International Conference for Machine Learning (ICML). The term basic research is applicable to the majority of the conference contributions. In individual cases, applications are also presented in the conference proceedings.

354 For the conference contributions in the years 2005 to 2016, data from Scopus were used on citation frequency, author affiliation and the location of the research institutions.

355 An evaluation of all the recorded publications on artificial intelligence since 1996 shows that their number has increased nine-fold in the meantime. This means that growth in the AI field exceeds the increase in the number of publications in computer science in general (a six-fold increase since 1996). Cf. AI Index (2017: 10).

356 It should be pointed out at the same time that the results of this form of analysis are highly dependent on the search strategy and data pool used. Cf. Youtie et al. (2018).

357 A complete set of data was not yet available for 2017.

358 Cf. Figs. 2.1, 3.1, 4.1 and 5.1 in Youtie et al. (2018).

359 A publication is assigned to a country if at least one of the authors is affiliated to an organization in that country. In cases of international co-authorship, publications are thus assigned to several countries.

360 The number of publications by the front-runner in each dimension is also stated. For example, 912 of all publications in the smart home area of application can be assigned to China. However, the USA is in the lead with 135 top publications. The positions of the reference countries are shown for each dimension and for every area of application relative to the respective front-runner.

361 Cf. tables 4.1 and 4.5 in Youtie et al. (2018).

362 Cf. tables 2.1 and 2.5 in Youtie et al. (2018).

363 Cf. tables 3.1 and 3.5 in Youtie et al. (2018).

364 Cf. tables 5.1 and 5.5 in Youtie et al. (2018).

365 Cf. Youtie et al. (2018) and Pötzl and Natterer (2018). While Youtie et al. (2018) worked with classic keyword-search procedures, Pötzl and Natterer (2018) used semantic processes to check the robustness of the results obtained in this way.

366 The term transnational patent families is used if there is at least one EPA application or one PCT application within the family.

367 An analysis of the patent applicant by country leads to similar results to the analysis of the inventor by country.

368 See table 2 in Dumitrescu et al. (2018) for an overview, albeit one with uncertainties.

369 Various funding databases and information pages were searched. Projects launched from 2012 onwards were studied in the databases. Cf. Dumitrescu et al. (2018).

370 Cf. Dumitrescu et al. (2018), who state that autonomous driving made up 65 percent of the project volume of German projects launched between 2012 and 2017.

371 Cf. Dumitrescu et al. (2018). who state that autonomous driving made up 91 percent of the project volume of European projects launched between 2012 and 2017.

372 For a list of the ongoing DFG priority programmes, see http://www.dfg.de/gefoerderte_projekte/programme_und_projekte/listen/index.jsp?id=SPP (last accessed on 17 January 2018). For information on the collaborative research centres, see http://gepris.dfg.de/gepris/projekt/54371073 and http://gepris.dfg.de/gepris/projekt/13634853 (last accessed on 17 January 2018).

373 The funding will total €1.5 million over four years. Cf. https://www.volkswagenstiftung.de/unsere-foerderung/unser-foerderangebot-im-ueberblick/kuenstliche-intelligenz-ihre-auswirkungen-auf-die-gesellschaft-von-morgen.html?tx_itaofundinginitiative_itaofundinginitiativelist%5Bcontroller%5D=FundingInitiative&cHash=29d4f3d9556a5d7f02d3a438b7a91ac7 (last accessed on 17 January 2018).

374 Cf. http://cyber-valley.de/de (last accessed on 17 January 2018).

375 When it comes to tapping potential sources of value creation (value added) from new technologies, start-ups can play a decisive role when established companies are too slow to open up to these technologies. There has already been an enormous increase in the number of AI start-ups in the USA: their number has risen fourteen-fold since 2000 (AI Index 2017: 16). This increase in start-ups coincided with a sixfold increase in venture-capital investment since 2000. Cf. AI Index (2017: 17).

376 Cf. http://english.gov.cn/policies/latest_releases/2017/07/20/content_281475742458322.htm (last accessed on 17 January 2018).

377 Cf. https://www.datainnovation.org/2017/08/how-governments-are-preparing-for-artificial-intelligence/ (last accessed on 17 January 2018).

378 $5 billion .

379 Cf. Mozur (2017).

380 One trillion South Korean won.

381 Cf. https://aiimpacts.org/funding-of-ai-research/ (last accessed on 17 January 2018).

382 Cf. https://www.datainnovation.org/2017/08/how-governments-are-preparing-for-artificial-intelligence/ (last accessed on 17 January 2018).

383 Cf. on this EOP (2016), EOP and NSTC (2016), and NSTC (2016). However, the 2018 US budget, for example, shows a 10-percent fall in National Science Foundation

D

expenditure in the field of 'intelligent systems' to just under €150 million. Cf. Mozur and Markoff (2017).

384 The Federal Government funds research in the field of AI, e.g. via the programmes 'IT Research 2006' and 'ICT 2020', and by supporting the German Research Centre for Artificial Intelligence (DFKI). In addition, the BMBF supports projects linking research with training and further education in the field of machine learning, and funds the Berlin Big Data Center, the Competence Center for Scalable Data Services and Solutions (in Dresden and Leipzig), and the Smart Data Innovation Lab in Karlsruhe. Up to now, the Federal Government has supported strategy development on AI within the framework of the High-Tech Strategy, particularly in the specialist forum on 'Autonomous Systems', and has supported it since spring 2017 via the Learning Systems platform.

385 Cf. section 19(4) no. 4 of the German Act Against Restraints of Competition (GWB).

C

386 The systematic selection of international reference countries is based i.a. on the size of the economies and on the national R&D intensity in the OECD and BRICS countries.

C 1

387 This section and the following figures are based on Gehrke and Kerst (2018).

C 2

388 This section and the following figures are based on Schasse et al. (2018).

389 Last year, R&D intensity for 2015 was initially quantified at 2.99 percent of gross domestic product. However, this value later had to be corrected to 2.92 percent.

C 3

390 In this regard and in the following, cf. Rammer and Hünermund (2013).

391 In this regard, cf. also Rammer et al. (2018).

392 Cf. Blind (2002).

393 Cf. ISO (2008: 15) and http://www.iso.org/iso/home/about/iso_members.htm (last accessed on 17 January 2018).

C 4

394 This section and the following figures are based on Bersch et al. (2018).

395 Internal financing is rarely an option, as these companies initially generate little or no turnover with which to fund investment and pay for current expenditure. Borrowing outside capital in the form of bank loans is also difficult, as it is not easy for banks to assess the companies' success prospects.

396 Invest Europe is the European Association of Private Equity & Venture Capital Investors. Together with the European Data Cooperative (EDC), it runs a platform that collects data on private equity and venture capital. Invest Europe regularly supplies updated data on venture-capital investment based on the information in the EDC database and data from Eurostat and the International Monetary Fund. The data supplied is based on information from the national venture-capital associations, which receive their information from member surveys. The harmonized acquisition and processing of data ensures good international comparability.

397 This is the case when investing market participants are not registered as members of Invest Europe, or if an investor comes from outside Europe.

398 The Zephyr M&A database contains information on mergers and acquisitions (M&A), categorized according to private-equity, venture-capital and business-angel investments. The information includes the investment sum, the company being invested in (portfolio company), and the investor. Since the Zephyr M&A Database primarily contains major investments, information from this database is complemented by the Majunke transaction database. It is made available by Majunke Consulting and covers venture-capital investment in Germany, Austria and the German-speaking part of Switzerland. It also contains information on the investment sum, the portfolio company and the investor, and also includes small investments. Since both databases also contain many other investments in companies in addition to venture-capital investments, each transaction is checked to determine with reasonable likelihood whether it is indeed a venture-capital investment. For this purpose, information from the Mannheim Enterprise Panel (MUP) is used about the (natural and legal) persons participating in a company.

399 Atypical investors are all those market participants who enter into direct venture-capital holdings, but whose core business is another. They may include, for example, asset managers, funds of funds, banks and insurers, as well as established companies.

C 5

400 This section and the following figures are based on Bersch et al. (2018).

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401 However, the data from the individual countries are not fully comparable. For more details on this, cf. Müller et al. (2014).
402 In this regard and on individual points, cf. Müller et al. (2013).
403 In this regard and in the following, cf. Bersch et al. (2018).
404 An original, newly formed company is created when a business activity not exercised before is begun and provides at least one person with their main source of income. A company closure is when a company no longer exercises any business activity and no longer offers products on the market.
405 The MUP has a much narrower definition of economically active companies, market entries and market exits, so that relatively small entrepreneurial activities are not covered in the MUP.
406 In this regard and in the following, cf. Bersch et al. (2018).
407 In this regard and in the following, cf. Bersch et al. (2018).
408 In the following, cf. Bersch et al. (2018).

C 6

409 This section and the following figures are based on Neuhäusler et al. (2018).

C 7

410 This section and the following figures are based on Helmich et al. (2018).

C 8

411 This section and the following figures are based on Gehrke and Schiersch (2018).
412 Cf. Gehrke and Schiersch (2018: 74) for a methodological explanation of the RCA indicator.

D 4

413 Cf. Gehrke et al. (2013).

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