FOCUS:
OPENNESS OF
INNOVATION SYSTEMS

Innovation Indicator

BDI
The Voice of
German Industry

Fraunhofer
ISI

ZEW
Zentrum für Europäische
Wirtschaftsforschung GmbH
Centre for European
Economic Research

Contents

Preface

Fourth place in the overall ranking – that is the result of the current BDI Innovation Indicator which compares Germany's innovation performance with a further 34 countries. While at first glance this is the same rank as last year for our country, there is a significant difference: the gap to the leaders is increasing. China's innovation performance grows at about three times the pace of the EU's. Small and medium-sized enterprises in particular have to participate intensively in the innovation process again, in order not to fall behind. In addition, innovation processes at universities, research organizations and enterprises must become more open and more innovative start-ups with strong growth must prosper in Germany. In short, we need more dynamism than our competitors.

The Innovation Indicator clearly shows where changes must be made: the German government must finally introduce tax incentives for research and expand the digital infrastructure. The key for the success of digitalization is the combination of our industrial strength with the possibilities offered by artificial intelligence (AI). Only significantly more investments in innovative AI applications can increase the effectiveness of AI for industry. The government should also promote the support for high-tech company foundings and accelerate the technology transfer towards mid-sized companies.

It is important to support the cultural change towards open innovation processes, for example, via the so-called "transfer via heads" – the personal professional exchange across the boundaries of disciplines and companies. For this to happen, existing barriers in labor and social law, which impede temporary moves between science and business, need to be dismantled in both directions.

More freedom is needed to conquer new fields of technology and their value creation potentials: experimental spaces or living labs in which pioneers test novelties and prepare them for use in the market. Many companies would be helped by the agency announced by the German government to promote springboard innovations.

The researchers at the Fraunhofer Institute for Systems and Innovation Research (ISI) and the Centre for European Economic Research (ZEW) who compiled the Innovation Indicator see the relative decline in the innovative strength of the German economy as the biggest shortcoming. Whereas Germany was still among the top three locations in the sub-indicator industry in 2012, it now only reaches place 9. Since then, a number of countries, whose economies have developed more dynamically than ours, have passed us by. Belgium, Israel and Ireland, for example, have moved ahead. The continuously poorer performance in this country is definitely cause for concern. This trend must be stopped. We want to get back to the top – with successful innovations that find new customers in the world markets.

Neither insight nor implementation plans are lacking. Policy-makers must not lose any more time now and must set the course for future innovations – these mean growth and prosperity, bring opportunities for advancement and participation, secure and create employment.

I wish you a stimulating read.

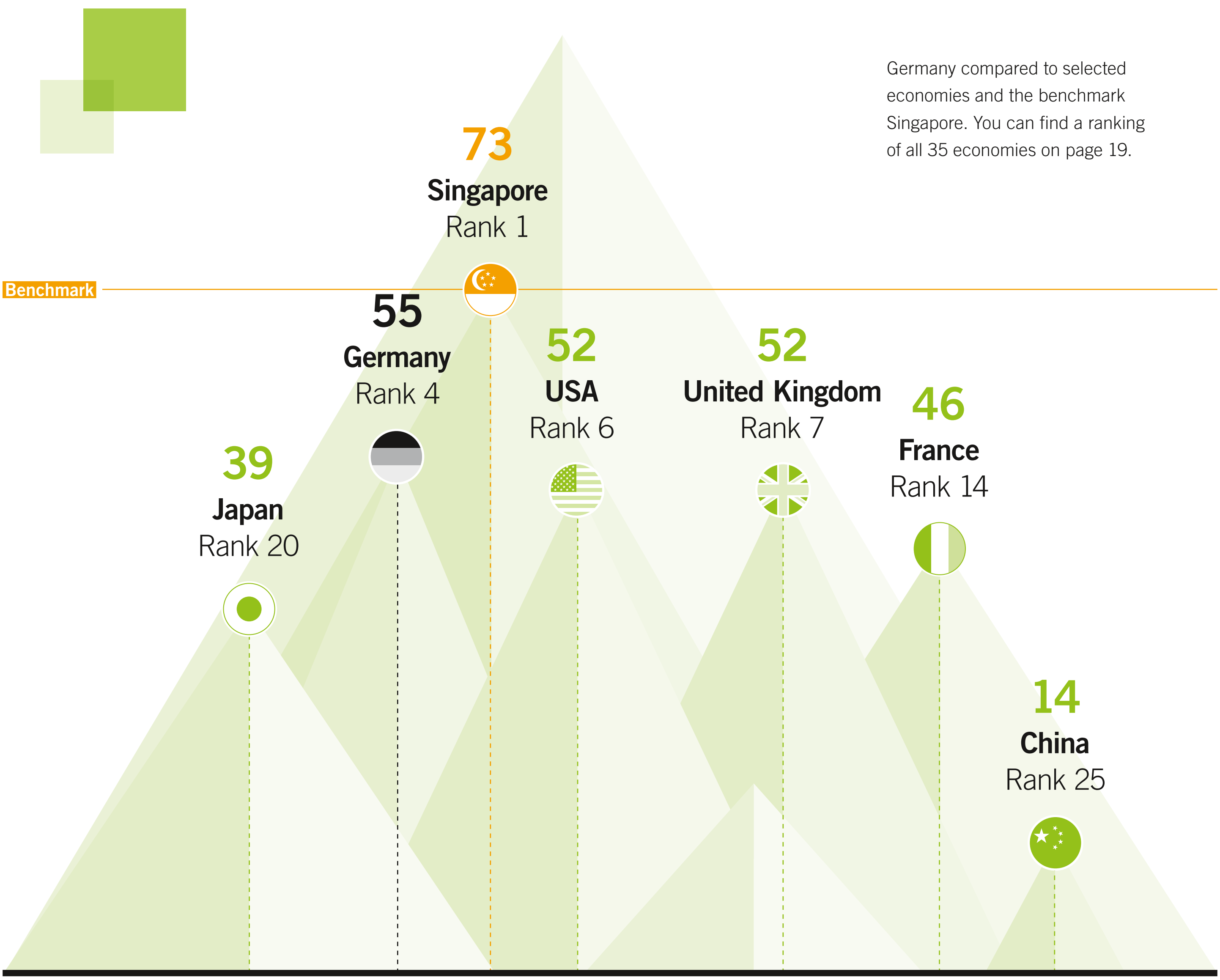
Prof. Dieter Kempf
President
Federation of German Industries

At a glance

Key findings

Innovation Indicator

Germany is one of the most innovative countries in the world and with an index value of 55 reaches the fourth place in the Innovation Indicator, unchanged from last time. However, the German innovation system does not achieve top marks in any of the five sub-areas examined: industry, science, education, state and society.

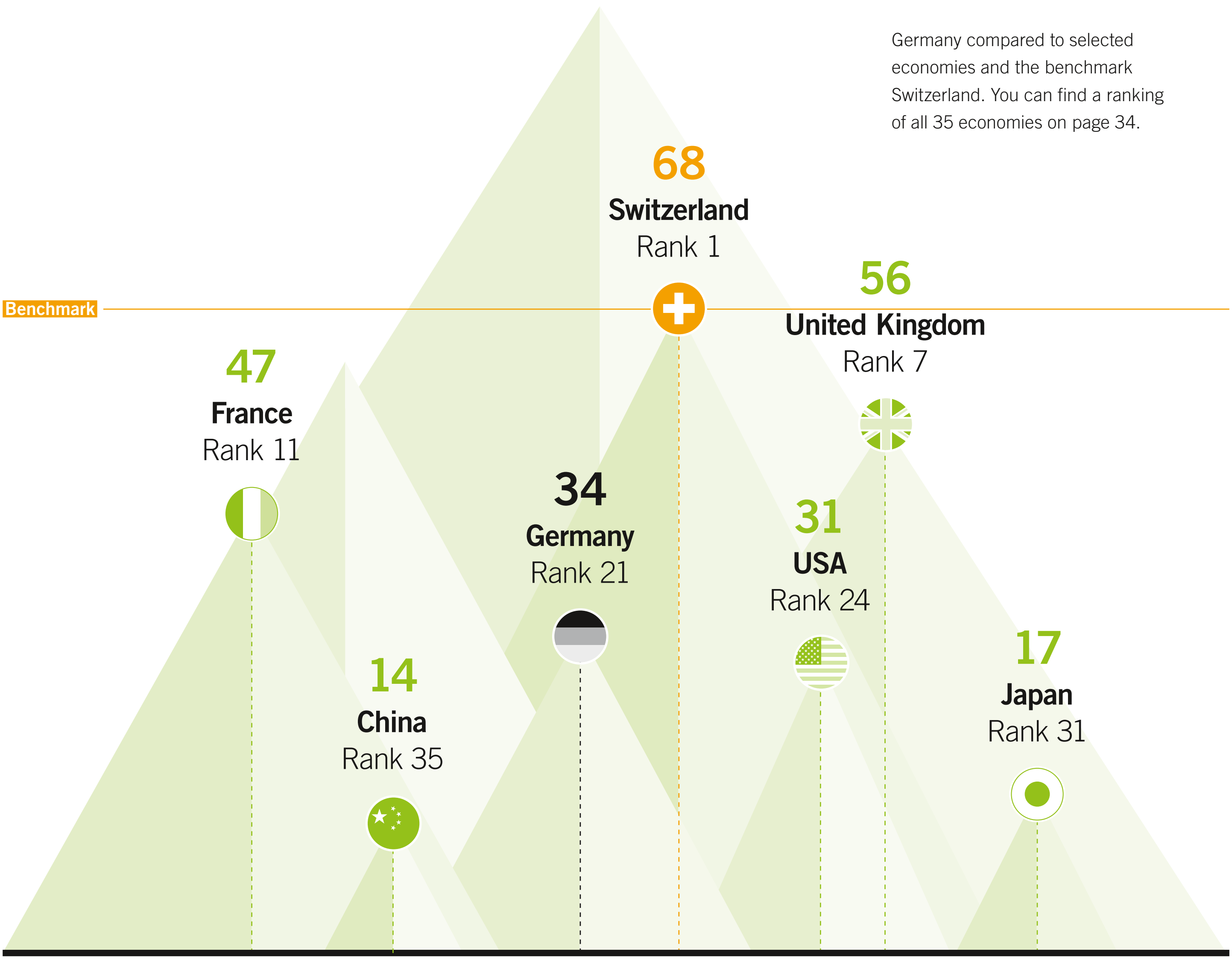


Germany compared to selected economies and the benchmark Singapore. You can find a ranking of all 35 economies on page 19.

Openness indicator

Germany's innovation system has the highest degree of openness among the world's largest economies. However, in the overall comparison Germany only lands far behind in position 21. Switzerland is doing better: while having lost its top spot in the Innovation Indicator it lies ahead in the openness indicator.

Germany compared to selected economies and the benchmark Switzerland. You can find a ranking of all 35 economies on page 34.



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Summary

As one of the most innovative countries in the world, Germany defends the fourth place – but again does not achieve a top position in any of the sub-areas of industry, science, education, state and society.

- Singapore takes over the top spot, for the first time, overtaking Switzerland. Singapore achieves 73 points in this year's Innovation Indicator, one point more than Switzerland.

- Germany with 55 points remains in fourth place behind Belgium. The distance to the small neighbor to the west has now grown to five points. The reason for the larger gap to the top is the lacking dynamics in some sub-indicators. In the sub-indicator industry for example Germany only reaches place 9.

- The BRICS countries, for which a golden future was still foretold back in the 2000s, still occupy the lowest positions in the Innovation Indicator. China, which reaches place 25 out of 35 countries, scores best of this group.

- The USA was able to improve to place 6 after years of decline. It is unclear to what extent this improvement has to do with the current political situation or the delayed positive effects of Obama's ambitious innovation policy.

- For Austria, the catching-up process of recent years seems to have stopped for the time being. In the ranking of the Innovation Indicator, the Alpine republic fell from place 9 to 11. As far as the sub-systems are concerned, Austria has a similar structure to Germany, as it achieves solid, but not peak values in all sub-systems.

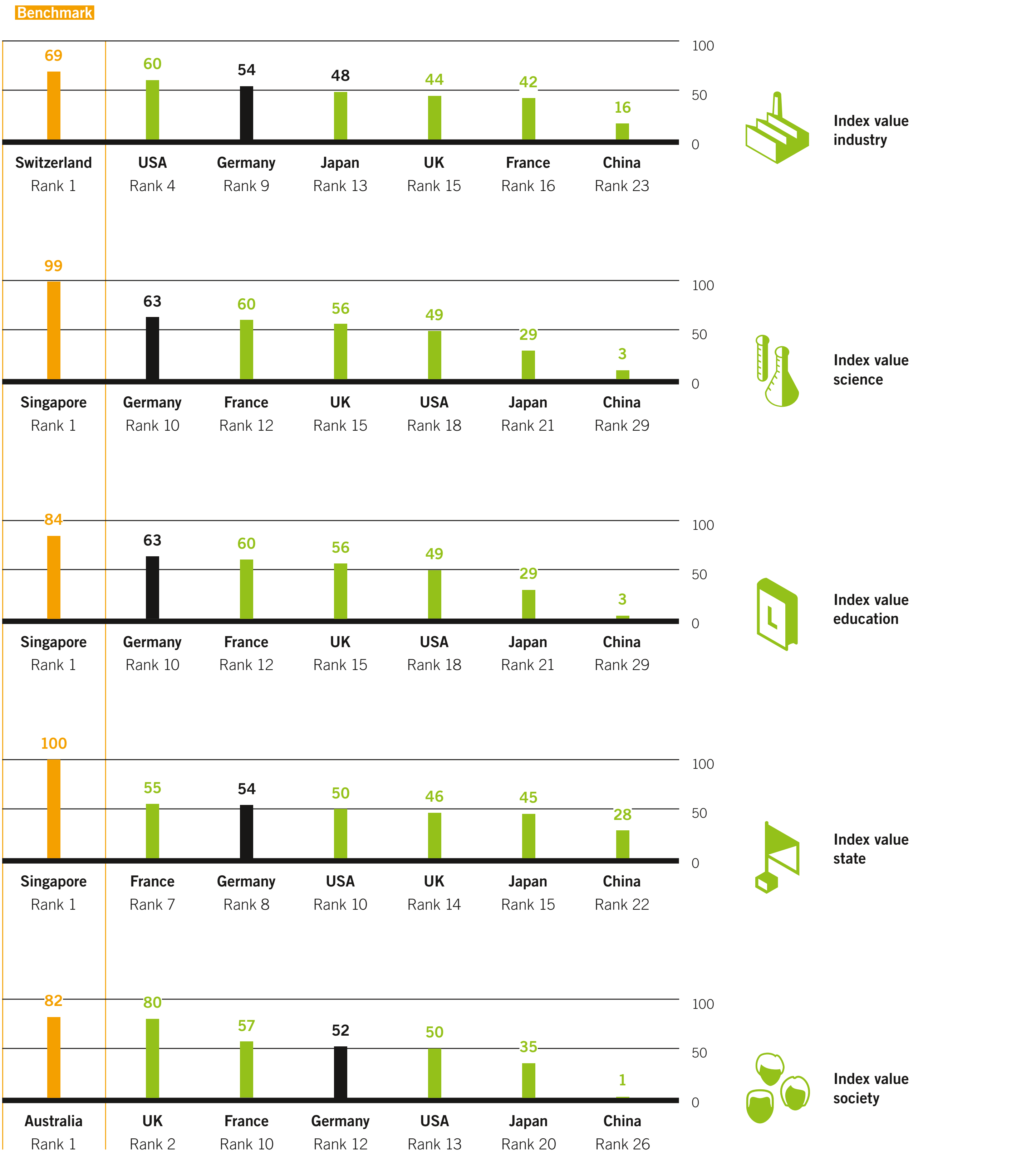
- Norway falls behind in the Innovation Indicator and, with its 17th place, only achieves a lower position. The raw material-rich Scandinavian country is aware of the lack of sustainability of its oil-based economic structure and has introduced political measures to realign its economy. So far, however, these measures have not borne fruit.

- After losses in the past years, Sweden, with 54 points behind Germany in fifth place, manages to improve again. The country attains good marks most of all in the sub-indicator society (71 points) and in the sub-indicator science (75 points). Sweden's biggest weakness lies in the area of education, where it only achieves 40 points. There is by now an urgent need for action by the Scandinavians in this area.

- There is little movement to be seen in the case of the southern Euro countries, which were strongly affected by the Euro crisis. Italy gains two ranks – now at place 24 – but still lags behind Portugal (rank 22) and Spain (rank 23), which have not changed. Greece remains at rank 29 with 5 points.

- Ireland manages to clearly improve by three positions and now ranks ninth. The former crisis state now boasts good values in the sub-system industry (55 points). Ireland's

Sub-areas of the Innovation Indicator
Germany and selected economies in comparison



German science policy has always been based on cooperation and exchange.

results for the state sub-indicator and the society sub-indicator are less good.

- The sub-indicator industry is led by Switzerland with 69 points. In the sub-indicators science, education and state Singapore takes the top spots with 99, 84 and 100 points respectively. Australia heads the sub-indicator society with 82 points.

- The exchange across institutional and national borders is a means to meet the strongly growing need for more and more complex knowledge in the innovation process. Open innovation systems make this exchange possible. They also increasingly determine the performance of innovation systems. The Innovation Indicator therefore compares the openness of innovation systems.

- While open science and open data are important building blocks of an open innovation system, they are not synonymous with openness.

- As far as the openness indicator is concerned, Switzerland (68 points) and Ireland (67 points) are the leaders followed by the Netherlands, Austria, Singapore, Sweden, the United Kingdom, Belgium and Denmark.

- Small economies are basically forced into openness. This is the case especially when they specialize in certain areas and therefore do not cover all fields of knowledge and innovation. Larger economies are often able and willing to cover the entire spectrum of science disciplines and innovation topics and therefore face less pressure to acquire external knowledge.

- Regarding the overall indicator, it can be seen that Germany, compared with the four largest economies in the world – apart from Germany these are the USA, Japan and China – achieves the highest degree of openness over the entire time period, with the exception of 2013.

- German science policy has always been based on cooperation and exchange. These policy measures are derived from the German government's strategy for the internationalization of education, science and research. However, Germany only ranks at position 21 and, like the USA and Australia for example, therefore finds itself in the lower midfield. Compared to 2007, Germany has lost seven index points and six places in the ranking. Other countries are obviously even more committed to openness.

- The German science system ranks in the lower half of the distribution, despite a high share of international co-publications. Compared to that, German industry is fairly open. Here, Germany achieves place 17, its best ranking in the sub-systems.

- Overall, the results suggest the conclusion that openness in Germany can still be significantly improved in all sub-areas of the innovation system. For a radical opening, a cultural change is necessary in many areas.

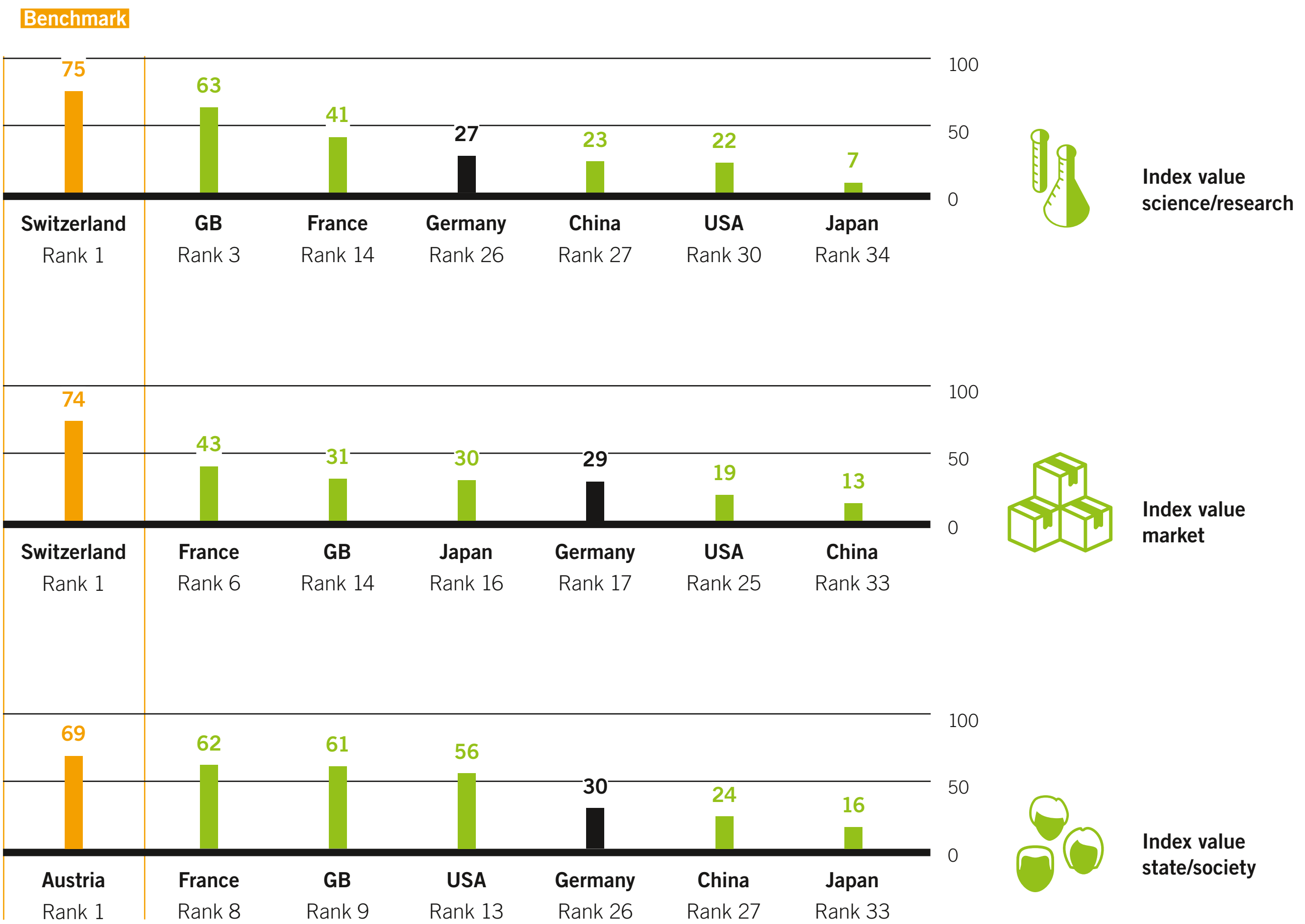
- The analyses show that open innovation systems are overall more economically successful, respectively that successful innovation systems have a higher degree of openness. However, there seems to be hardly any link between openness and scientific performance.

- The Chinese innovation system has changed faster and more intensively than any other in the years since 2001. The opening of the system was an important contribution to this.

- The development of the openness index shows declining values for China, meaning: the openness of the country regarding science, industry and also society decreases over the course of time. The entire breadth of the indicators used here points towards a further closing off or isolating of the country.

- While opening and international exchange are announced in numerous policy papers and programs, deeds addressing these aspects are still lacking or are currently not sufficient to reverse the negative trend in this evaluation.

Sub-areas of the openness indicator
Germany and selected economies in comparison



02

Recommendations for policy-makers

Achieve the 3.5 percent goal faster

The German government has set itself the goal of increasing the overall economic expenditure on research and development to 3.5 percent of the gross domestic product by 2025. Achieving this goal would be an important contribution towards bringing Germany closer to the top group of the most innovative countries. The new High-Tech Strategy 2025 sets the framework for achieving this target. It contains important and correct starting points, such as orientation towards major societal challenges, a broad view of the necessary framework conditions – in particular, the skilled labor base – and new impetus for research and innovation. It is crucial that implementation is rapid and dynamic, otherwise the goal will not be reached:

- The promotion of cutting-edge research and scientific excellence must not be squandered on small-scale projects. Global visibility requires large investments in selected top institutions.
- The innovation dynamics of the economy are currently being slowed down by the mid-sized companies. Sufficiently funded tax incentives for research and development, combined with effective project promotion, can provide the necessary impulses.
- The transfer of knowledge and insights between science and industry is already well established in Germany. New initiatives must therefore address the few weak points: high-tech start-ups from science, integration of small and medium-sized enterprises (SMEs), transfer via heads.
- Innovations in the area of societal challenges not only need research funding for new technologies, but also the right legal and political framework conditions. Technology promotion must therefore go hand in hand with the promotion of innovative markets and user acceptance of innovation.

Take excellence in science seriously

Despite not inconsiderable reform efforts, positive dynamics in the field of science can hardly be discerned. Although Germany achieves a tolerable value with 63 points in the sub-indicator science, Germany is only in 10th place. An important step towards improving the science system was the implementation of the Excellence Initiative 2005/2006 and its extension from 2011/2012. From 2019 it will be replaced by the Excellence Strategy. At 2.7 billion euros, the funds spent in the Excellence Initiative initially appear to be substantial. However, this picture is put into perspective very quickly if one takes into account that these funds relate to the entire period from 2012 to 2017. Compared with ETH Zurich's annual budget of approximately 1.6 billion euros or MIT's annual budget of approximately 2.9 billion euros, the total funding volume appears very small-scale. Some studies seem to prove that the funding from the Excellence Initiative has substantially increased the quantity, but not the quality, of the research activities in the funded universities.[1] This is not enough for a program that has set itself the goal of creating globally visible lighthouses. Improvements that go significantly beyond maintaining the current level will only be achievable if there is a significant increase in the volume of funding. The stronger differentiation of higher education institutions also according to their performance, in particular should be more strongly emphasized in this context. It can be assumed that the continuous expansion of the number of so-called “Excellence Universities” to 11 in the last funding period had a counterproductive effect on this objective. At any rate, lighthouses cannot be created this way.

Inspire new dynamism in the economy

The innovation performance of the German economy has lost momentum in recent years. In 2010, the index value of the industry sub-system still was 59, but by 2017 it had fallen to 54 points. This puts the German enterprise sector in 9th place in the global innovation comparison. In 2012 it was still one of the top three locations in the world. The decline has many causes. One is the decreasing inclination among SMEs to innovate, which in turn is due to a shortage of skilled labor, limited internal financing and low founding figures for growth-oriented innovative start-ups. At the same time, there are weaknesses in particularly dynamic fields of innovation, such as digital services and digital business models outside industry. Innovation policy in Germany is aware of these challenges. What is lacking, however, is courageous implementation and the provision of adequate resources that can actually achieve the necessary change of direction.

- The tax incentives for R & D that have been discussed for many years must finally be introduced, and to an extent that also leads to noticeable effects. Homeopathic dosages do not counteract the decline in innovation among mid-sized companies or the weak research and development dynamics of SMEs.

- Innovation promotion must more strongly address the development and diffusion of business models up to the establishment of entirely new market segments or markets. The radical innovations approach in combination with a demand-oriented innovation policy promises new impulses here.

- Regulations in public procurement and in legally specified standards and norms should be made more innovation-friendly, i. e. more flexible. Project funding should also be brought closer to the market, whether through demonstration schemes, pilot or model projects.

- Founding companies is another important way to develop new topics and markets. The focus should be on promoting growth-oriented innovative start-ups. The support instruments for company foundings should be focused on this group of start-ups.

Promote incentives for knowledge and technology transfer

The exchange between science and industry in the innovation process is generally well developed in Germany. In the Innovation Indicator, the indicators concerning interactions between companies and public research are among Germany’s strengths.

- In science, stronger incentives for transfer activities must be created. In addition to research excellence and teaching activities, transfer activities must also be prominently incorporated into the evaluation of institutions and the determination of the funding of chairs and institutes.

- The involvement of SMEs in transfer activities often fails, due to insufficient human and time resources in the SMEs and an innovation strategy that does not focus enough on fundamental innovations for which cooperation with science would be necessary. The transfer capability of SMEs should therefore be specifically increased.

- Increasing the number of high-tech start-ups from science requires models that accompany the transition from research to business start-ups. New initiatives are needed here to build on the experience of previous programs in the field of higher education and non-university institutions.

There must finally be tax incentives for R & D.

- The transfer via heads is regarded as the most effective mode of knowledge exchange. To advance this exchange, existing barriers in labor and social law hindering a temporary move between science and industry should be dismantled in both directions.

Risk more openness

The exchange of knowledge and ideas in support of one's own innovation processes and for exploiting innovations by others (open innovation) will be even more decisive for the success and failure of enterprises and entire innovation systems in the future. For many companies, open innovation processes offer new market opportunities through greater innovative strength and a faster pace of innovation.

Open innovation should not be confused with open source. Open innovation is not a plea for an uncontrolled and, above all, unwanted outflow of knowledge. On the contrary, cooperation is based on clear rules and protection of intellectual property. Efficient and target-oriented cooperation is only possible if the rights of ownership, use and exploitation are clear from the outset. The state is a decisive actor in defining and monitoring these rules. A strong system for the protection of intellectual property and a reliable regulatory system, as a whole, which is already the case in Germany, are important prerequisites. However, adaptations to the existing system are worth considering. For example, a grace period in German patent law could allow knowledge to diffuse more quickly without impairing the possibilities of protection.

Open access to publications of research results (open access) and also access to research data (open data) to increase reproducibility, verifiability and efficiency in the science system, but also citizen participation in scientific processes (citizen science) are building blocks on the path to an open innovation culture in Germany. But it is much more important to effectuate a cultural change among all players in the innovation process and thus make the give and take of knowledge and technological solutions faster and easier across institutional boundaries.

A cultural change towards open innovation processes can only be achieved through trust and thus through explanatory and confidence-building measures. The reservations of SMEs, in particular, must best be dispelled by positive experiences in concrete cooperation and exchange processes. On the one hand, platforms and co-creation labs, which can be realized both as state-organized or by the private sector, can make significant contributions here. On the other hand, the experiences of joint projects between scientific institutions and SMEs are almost entirely positive. Particularly with a view to open innovation processes, the German government should also intensively promote larger collaborative projects with several industrial and, if necessary, several scientific partners. Bilateral and international collaborative projects (2+2) are also essential for the exchange of knowledge and offer further potentials for the future.

Open innovation is an opportunity to re-involve more strongly those companies – especially SMEs – that have withdrawn from innovation activities in recent years. Many companies that do not themselves have internal formalized R&D activities have process knowledge that can be crucial for the implementation and diffusion of knowledge and ideas. With open innovation, they can contribute this knowledge on the one hand, and on the other hand, participate in knowledge that they alone could not maintain or develop. Therefore, research funding, especially of collaborative and cooperation projects, should somewhat relax the narrow technological focus of research and development and support the development of business models and services more strongly.

Co-creation labs, idea contests and open-theme programs are essential features of a mission-oriented innovation policy. The promotion of interdisciplinarity and opportunities for people with different views beyond the scientific and technological mainstream in public funding programs are examples of measures that offer political and entrepreneurial starting points for opening up the innovation system. Existing measures such as the Research Campus or the Leading-Edge Cluster Competition (recently renamed Future Clusters) are at their core already measures to promote open innovation processes. They could, however, be extended even more specifically to include aspects of the opening of processes and involving other actors and groups.

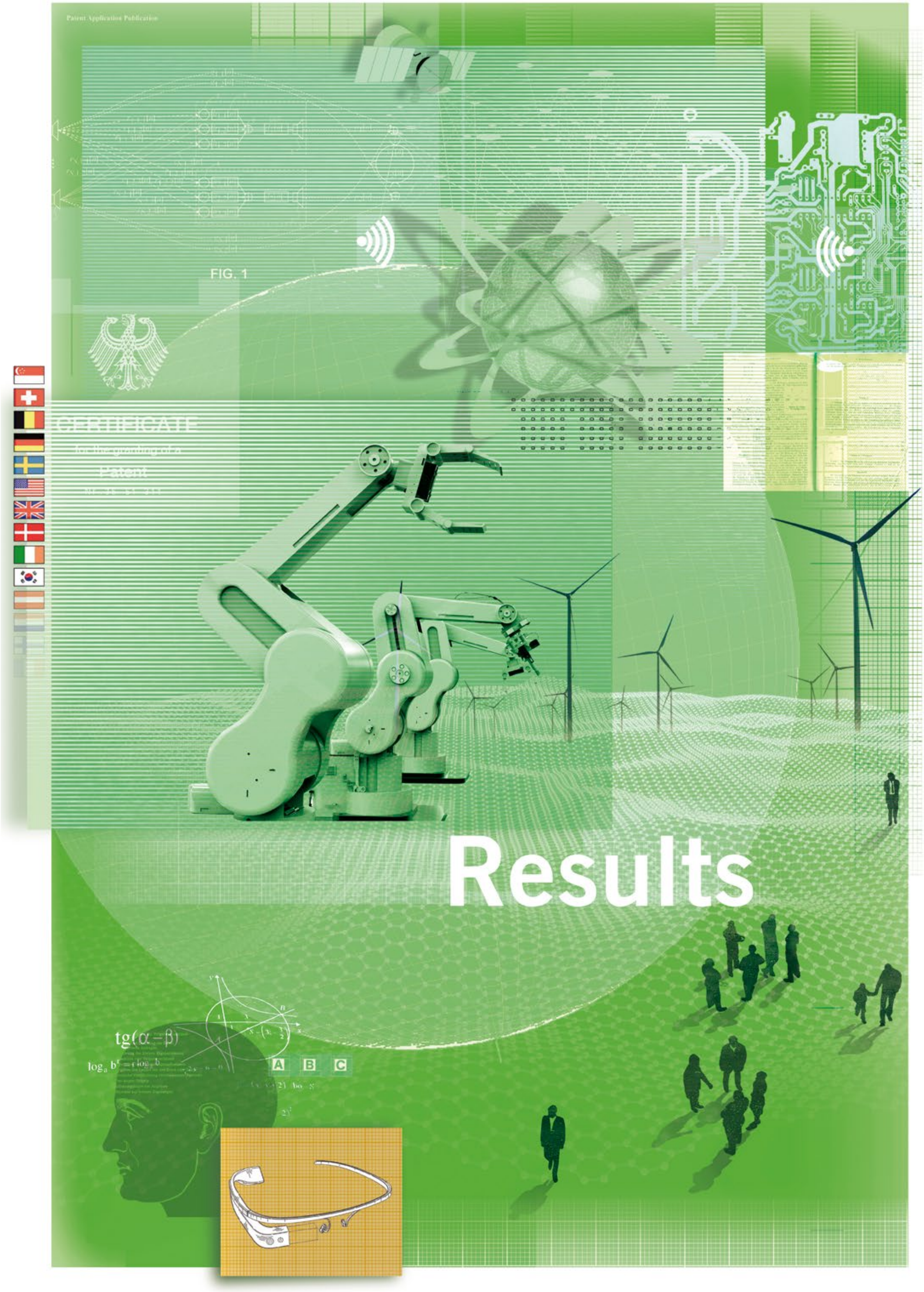
The analyses have also shown that, compared to other countries, Germany is less able to attract foreign talent and integrate foreign employees into the labor market and society. A clear strategy in this respect and a knowledge- and innovation-oriented perspective of migration and labor market policy are long overdue.

Open systems do not end at national borders. Knowledge and exploitation processes today are characterized by an international division of labor as never before in world history. The collection and dissemination of knowledge are not limited to scientific cooperation but include the mutual exploitation and use of knowledge. Isolated markets and protectionist procedures are detrimental to this mutual exchange. Countries such as China and the USA must therefore be bound by their own promises and commitments under international treaties such as the WTO. And there are convincing arguments for this, because open (economic) systems tend to be more successful innovation systems, as this year's studies in the Innovation Indicator show, among others. Government consultations at the highest political level as well as small-scale research and collaborative projects are ways of approaching international partners. The formulation of one's own interests – the opening of markets and access to knowledge are among these interests – and the development of strategies to achieve these interests are important and legitimate prerequisites.

Open innovation systems offer new market opportunities.

1 Frietsch, R.; Schubert, T.; Rothengatter, O. (2017): An Analysis of the Excellence Initiative and its Effects on the Funded Universities, Studien zum deutschen Innovationssystem, Berlin: EFI.

Results


Patent Application Publication
FIG. 1
CERTIFICATE
for the granting of a
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03

About the Innovation Indicator

New products, processes and services that prevail in markets, or also improving the quality of existing products and processes, are referred to as innovations in an economic sense. Innovations are the key to competitiveness and growth for most companies and entire industries. Germany is especially reliant on innovations to secure the growth of its economy and prosperity, as well as the public sector's capacity to act in the face of demographic change.

From an economic perspective, a variety of factors and influences promote private innovation actions or even render them possible in the first place. There are also numerous players – companies, research institutions, funding agencies, educational institutions, but also innovation financiers and buyers and users of innovations, who often improve and adapt services and products themselves – these are the so-called user-led innovations. The interplay of these factors, influences and actors constitute the national innovation system.

A well-functioning innovation system allows companies to be innovative, and thus secures jobs and prosperity. However, the companies as providers of innovative goods and services face competition – and this is therefore also true in a broader sense for innovation systems. It is important that companies and organizations as well as politics or public organizations can assess and pinpoint Germany's position in the global innovation competition. Only then can they take measures to secure or improve the situation. For this purpose, a differentiated analysis and international comparisons are indispensable.

The Innovation Indicator has exactly this goal. On behalf of the Federation of German Industries (BDI), 35 national economies are examined to determine how innovation-oriented and -capable they are. The Innovation Indicator is created by the Fraunhofer Institute for Systems and Innovation Research (ISI) in Karlsruhe in cooperation with the Centre for European Economic Research (ZEW) in Mannheim. It compares the innovation performance of 35 countries based on 38 individual indicators.

Basic principles of the Innovation Indicator are:

1. Model-based approach to the selection of indicators: each of the 38 indicators was selected based on its statistically verified explanatory value for the national innovation performances. In this way, both clarity and the relevance of the results are ensured.
2. Sub-division of the indicators according to input/output and sub-systems (industry, education, science, state, society): this allows a detailed analysis of the strengths and weaknesses of individual countries and thus targeted recommendations for action.
3. Incorporating hard and soft indicators: innovation activities depend not only on directly measurable factors, such as the available financial and human resources, but also on rather soft, not directly measurable factors such as societal attitudes. The Innovation Indicator also collects relevant data of these soft factors to reflect innovation systems in their

35 economies at a glance: How competitive, fast-growing and innovative are they? This study provides an answer.

entirety. This sets it apart from many similar indicator systems.

4. Timeliness of the results by using forecasting and extrapolation methods (now-casting) for the individual indicators: all indicators relate to 2017.

The Innovation Indicator is a so-called composite indicator, in which individual sub-indicators, relevant for the innovation system, are condensed by weighting to a summary measure. The Innovation Indicator uses an equal weighting to keep the calculation transparent and comprehensible. However, other weighting methods would also

List of the individual indicators of the Innovation Indicator

Description	Player/Sub-system	Source
Share of foreign students in all students	Education	OECD
Employees with at least upper secondary education, excluding tertiary degrees as a proportion in all employees	Education	ILO
Holders of doctoral degrees (ISCED 6) in STEM subjects as a percentage of the population	Education	OECD
Tertiary graduates in relation to highly qualified employees aged 55+	Education	ILO
Share of employees with tertiary education in all employees	Education	ILO
Annual expenditure on education (tertiary level incl. R&D) per student	Education/State	OECD
Quality of the education system (scale from 1 to 7 based on expert assessments)	Education/State	World Economic Forum
Quality of mathematical and scientific education (scale from 1 to 7 based on expert assessments)	Education/State	World Economic Forum
PISA Index: science, reading skills, mathematics (on open scale with mean 500 and standard deviation 100)	Education/State	PISA/OECD
Share of postmaterialists (Inglehardt) in the population	Society	World Value Survey; Flash Eurobarometer
Life expectancy	Society	OECD
Labor market participation of women	Society	Worldbank
News about R&D	Society	LexisNexis
State demand for advanced technological products (scale from 1 to 7 on the basis of expert assessments)	State	World Economic Forum
Companies' demand for technological products (scale from 1 to 7 based on expert assessments)	Industry	World Economic Forum
Venture capital employed for the early phase in relation to gross domestic product	Industry	Invest Europe, OECD, various national sources
Extent of marketing (scale from 1 to 7 based on expert assessments)	Industry	World Economic Forum
Share of international co-patents in all applications for transnational patents	Industry	EPO – PATSTAT
Share of value added in high-tech fields in total value added	Industry	WIOD
Share of employees in knowledge-intensive services in all persons employed	Industry	WIOD
Intensity of domestic competition (scale from 1 to 7 based on expert assessments)	Industry	World Economic Forum
Gross domestic product (GDP) per capita of the population	Industry	Weltbank/WDI
Transnational patent applications per inhabitant	Industry	EPO – PATSTAT
Patent applications to the USPTO per inhabitant	Industry	EPO – PATSTAT
Value added per hour worked (in constant PPP-$)	Industry	OECD/STAN
Balance of trade in high-tech areas as measured against population	Industry	UN – COMTRADE
Share of higher education R&D expenditure financed by enterprises	Industry	OECD/MSTI
Internal R&D expenditure of enterprises as a percentage of GDP	Industry	OECD/MSTI
B index of R&D tax incentives: share of R&D expenditure of companies financed by R&D tax incentives.	Industry/State	OECD
Share of state-funded R&D expenditure of enterprises in GDP	Industry/State	OECD/MSTI
Number of researchers in full-time equivalents per 1,000 employees	Science	OECD/MSTI
Number of scientific-technical articles in relation to population	Science	Clarivate – WoS, World Bank
Quality of scientific research institutions (scale from 1 to 7 based on expert assessments)	Science	World Economic Forum
Number of citations per scientific-technical publication	Science	Clarivate – WoS
Number of patents from public research per inhabitant	Science	EPO – PATSTAT
Share of international co-publications in all scientific-technical articles	Science	Clarivate – WoS
R&D expenditure in state research institutions and higher education institutions as a percentage of GDP	Science/State	OECD/MSTI
Share of a country in the 10 percent most frequently cited scientific and technical publications	Science	Clarivate – WoS

be feasible and have been used in comparable analyses. The authors of the study use modern statistical simulation methods to analyze the robustness of the results to different weights. Here, the results prove to be extremely robust and the classifications of the analysis therefore reliable.

Thus, although different weighting methods lead to slight differences in the actual performance of the countries, clearly recognizable assignments to certain groups of economies emerge, largely independent of the respective weighting. It can therefore be stated with great certainty whether a country, for example, is one of the pursuers or in the leading group. Accordingly, the interpretation of the ranking positions will focus mainly on this group membership and stable long-term development trends. Minor changes to the previous years, as well as shorter gaps between countries should not be over-interpreted.

Dynamic environment

Innovation systems are highly dynamic: they change constantly and often in ways difficult to predict. These changes can have a serious impact on the functioning of the innovation system. This in turn provides measurement models such as the Innovation Indicator with major challenges, because it captures the economy's innovative capabilities based on a previously defined set of indicators. Unexpected developments and structural changes, as, for example, can be expected in the wake of the digital transformation of the economy, on the one hand, require a constant critical examination of the appropriateness of the indicators used.

On the other hand, the approach of purely quantitative indicators must always be complemented by qualitative assessments that seek to anticipate developments that may be reflected in measurable figures only in years to come. For these reasons, the Innovation Indicator follows the approach of supplementing the quantitative results with qualitative assessments in a targeted manner, which explicitly seek to account for both the current policy context as well as possible future developments.

Structure of the analysis

The following section summarizes the results and points to future challenges for innovation policy and the innovation system.

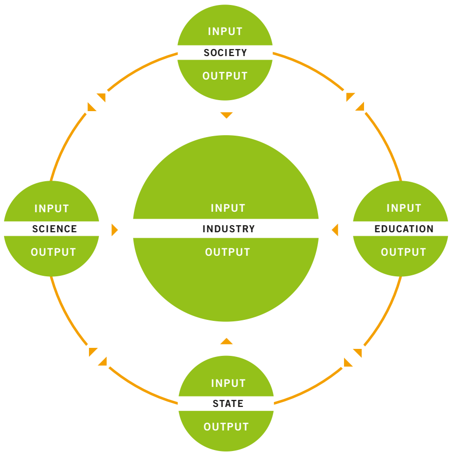
The focus topic of the Innovation Indicator 2018 deals with the openness of innovation systems. First, the concept of openness is presented and political approaches to increasing openness in Germany are discussed. The results of an openness indicator are then presented and discussed in the Innovation Indicator for the 35 countries. Finally, the development of openness over time in the four largest economies – the USA, China, Japan and Germany – is discussed and, in particular, the development in China is commented on.

Website with more information

This report summarizes the most important results of the analyses based on 2017 as reference year. One can create profiles for the individual countries, the development of individual indicators or comparisons between different countries on the website. There a detailed documentation in electronic form of the methods and indicators used is also available in the methodology report.

www.innovationsindikator.de

Main elements of the Innovation Indicator model



Source: own depiction

04

Singapore in the lead for the first time

Switzerland loses its lead after 17 years, while Belgium and Germany defend their previous year's positions.

The reference years

The 2018 edition of the Innovation Indicator presents the innovation performance of 35 countries in the reference year 2017. The previous issue of the Innovation Indicator, which appeared in spring 2017, referred to the reference year 2015. For comparisons between the current and the most recently published results, reference is made to the two reference years. In addition, the 2018 Innovation Indicator also shows the reference value for 2016.

In 2017, Singapore displaced Switzerland from first place in the Innovation Indicator for the first time. Even though both nations have almost the same number of points, 73 (Singapore) and 72 (Switzerland), Singapore is rewarded for a continuous catching-up process. Germany defended fourth place, with the gap to Belgium in the third place increasing. The USA improved significantly in terms of ranking and comes 6th in 2017. This positive development is largely attributable to the changes in innovation policy under President Barack Obama's administration. It remains to be seen whether the trend can also continue under his successor Trump.

Sweden ranks 5th between Germany and the USA and advanced three places compared to 2015. Behind the USA, the United Kingdom, Denmark, Ireland, South Korea, Austria and the Netherlands rank 7th to 12th. Finland, which was still ranked 4th in 2014 and at least managed 5th in 2015, only attains the 13th place and thus clearly falls behind. This negative development can also be attributed to the difficult economic situation that has been ongoing for years, heralded by the reorientation and restructuring of Nokia as the main economic player. China loses points after a period of continuous upward development and only obtains 14 points in 2017 (2015: 19). In terms of rankings, however, the country hardly changes.

The Innovation Indicator measures the performance of 35 economies in terms of their capacity to generate and exploit innovations. It takes into account both investments in the innovation system (input), and results of innovation-oriented activities (output). It consists of several individual indicators whose respective explanatory contribution has been put to the test in an economic model – a particular strength of the Innovation Indicator. The special approach, on the one hand, makes it possible to follow the development of individual countries over time and on the other hand, to compare countries with each other. However, the measurements are subject to statistical uncertainty, which makes it difficult to interpret differences in the relative ranks of economies lying closely together.

Leading group pulls away

Switzerland was no longer able to maintain its leading position in 2017 and falls behind Singapore in the ranking. This is the first time that a "changing of the guard" has taken place in the ranking of the most innovative countries worldwide. While Switzerland scored 75 points in 2015, five points ahead of Singapore, it only scored 72 points in 2017, one point behind Singapore. Among other things, Switzerland has fallen behind in individual education indicators and in the indicator "Employees in knowledge-intensive services". In both cases, Switzerland's performance has not really deteriorated. However, other countries have caught up, partially to a considerable extent, and Switzerland's big lead has melted away. In addition, the experts surveyed by the World Economic Forum (WEF) also rated Switzerland's performance in education, science and state less highly. Singapore has seen strong growth in the availability of venture capital, government support for research and development and labor productivity, among other areas. In addition, expert assessments at the WEF were more favorable and the indicators for societal attitudes towards innovation also pointed upwards.

Both countries have a clear lead over a broad midfield led by Belgium. Belgium has again improved by one point to 59 points and is slightly ahead of Germany, which continues to score 55 points. Germany and Belgium perform well in all five sub-systems of the Innovation Indicator – industry, science, education, state and society – even if they are not top of the league anywhere. Belgium ranks sixth in four of the five sub-indicators and fifth in science. Germany always ranks in the top third between rank 8 (state) and rank 12 (society), but not very well in any one sub-system. However, since good performance in all areas important for innovation is necessary for a functioning innovation system, countries with good system components perform better than countries with major weaknesses in individual sub-systems.

Germany's fourth place is certainly a respectable result. However, the gap between Germany and the leading group continues to widen. Improvements in, inter alia, higher education, the number of researchers and business expenditures on research and development were offset by deteriorations in secondary education and doctorates, expenditure on education, PISA results and employment in knowledge-intensive services. Policy-makers should urgently provide stimuli to spark a new dynamism of innovation.

USA face uncertain future

After many years of decline, the USA have recently performed better again. After a brief pause in 2015, they were able to continue the upward trend at least in terms of ranking in 2016 and 2017. In 2017, the USA reach 6th place in the Innovation Indicator and thus improves their performance by five places compared to 2015. Under President Barack Obama's administration, the White House updated its Strategy for American Innovation in 2015, further developing the 2009 paper. In assessing this strategy, it helps to know the context of innovation policy. Traditionally, the USA have relied on a rather linear understanding of innovation. According to this, topic-independent research (above all at universities) makes technology development possible that can be used commercially. Entrepreneurship is the central mechanism of commercialization. Policies based on these basic assumptions rely on strong institutionalized support for science. This should – apart from the defense research important in the USA – be open to new topics. In addition, it is possible to promote innovation by companies to provide financial resources for innovation. In the USA, during the last 30 years particularly when IT companies were

Overall result of the Innovation Indicator

Rank		Index value
1	Singapore	73
2	Switzerland	72
3	Belgium	59
4	Germany	55
5	Sweden	54
6	USA	52
7	United Kingdom	52
8	Denmark	51
9	Ireland	51
10	South Korea	51
11	Austria	50
12	Netherlands	50
13	Finland	49
14	France	46
15	Taiwan	46
16	Israel	44
17	Norway	44
18	Canada	43
19	Australia	43
20	Japan	39
21	Czech Republic	26
22	Portugal	20
23	Spain	19
24	Italy	17
25	China	14
26	Hungary	10
27	Poland	10
28	Russia	7
29	Greece	5
30	Indonesia	2
31	South Africa	0
32	Turkey	0
33	Mexico	0
34	India	0
35	Brazil	0

0 10 20 30 40 50 60 70 80 90 100

The index values are rounded throughout the publication.

Under Barack Obama, the USA modernized their innovation system and embarked on a more progressive course. This benefits them in the current Innovation Indicator. But the prospects are bleak.

founded, considerably more private than state funds were used for this purpose.

The administration under Barack Obama supplemented this understanding of innovation in its 2015 strategy revision. In line with the EU's "Grand Societal Challenges" program, the US innovation policy was now also supposed to focus on key issues – including advanced production technologies, medicine, smart cities and clean energy technologies. In addition, there now was an additional focus on increasing the innovative capacity of the public sector and public administration. The result was a much more progressive innovation policy, based on the traditional strengths of the USA in cutting-edge research and entrepreneurship. It also activates strategic and previously insufficiently exploited potentials in the areas of major societal challenges and innovations in the public sector.

The gains of the USA in the Innovation Indicator can be explained by this modernization of Obama's innovation strategies. It is unclear, however, to what extent these developments will continue under his successor Donald Trump. The USA are increasingly isolated nationally, the innovation system is lastingly weakened – these are rather gloomy prospects in the medium term. In addition, increasing and openly conducted political hostility towards certain scientific facts, such as climate change, is likely to weaken the USA as a science location in the medium term. Future developments are difficult to predict, but the current political orientation gives little cause for optimism.

South Korea improves noticeably

Ireland and South Korea each score 51 index points. While Ireland fell back slightly, South Korea improved noticeably compared to 2015 and advanced by three ranks. They are followed by Austria, the Netherlands and Finland with 50 and 49 points respectively. The Austrian federal government is unlikely to be satisfied with Austria's performance. After all, the country has set itself the goal in its research and technology strategy of advancing into the group of the world's most innovative countries (innovation leaders). Governments over the past 15 years have significantly stepped up their efforts to promote science, research and innovation.

Concerning innovation indicators, this was particularly reflected in the overall economic research and development share. Austria is now among the top nations here (2017: 7th place) and has left Germany (2.94 percent) behind with its spending in this area in relation to GDP of 3.09 percent. In the past 15 years, only South Korea has increased its research and development share more than Austria. However, the higher financial inputs have not (yet) led to noticeable increases in many output indicators. Austria is not one of the top nations, either for patents or for scientific publications. There are also deficits in the education sector – for example, in the number of university graduates and in education expenditure.

Moreover, experts have recently begun to assess the qualitative aspects of the Austrian innovation system less favorably. The country wants to significantly increase its spending on research and development and is aiming for a quota of 3.76 percent by 2020. The most recent increase in tax incentives for research and development to 14 percent since January 1, 2018 is intended to advance Austria in this direction. An open challenge remains how, in addition to inputs, innovation outputs can also be increased – especially in the fields of sophisticated innovations and innovations beyond traditional industrial sectors.

France (46 points), Taiwan (46 points) and Israel (44 points), as well as Norway (44 points), Canada (43 points) and Australia (43 points) are tightly clustered in the midfield. Norway is particularly interesting here. The country, which is rich in raw materials, has long been striving to modernize its economy and make it more innovation-oriented. However, this remains without measurable success to date. Norway is one of the richest countries in the world in terms of GDP per capita. However, the high dependence on a few sectors is seen as a threat to future competitiveness. In addition to fisheries and aquaculture, these sectors include above all the oil and gas producing sector as well as the primary materials industry (e.g. aluminium production) which depends on cheap energy. Due to oil and gas resources gradually depleting, this economic structure cannot permanently form the economic backbone of Norwegian society.

The Norwegian government is aware of the finite nature of fossil resources, which is why a significant part of the oil revenue goes to the Kingdom of Norway's State Pension Fund. This fund had a value of over 800 billion euros at the end of 2017 and essentially serves as a post-oil provision fund. It is a consumer-oriented pension fund and not an investment in the development of future technologies that could carry the economy in the long term. Innovation policy impulses are therefore not to be expected from this fund. In 2014, the Norwegian government presented a strategic plan for research and education, which is to be implemented between 2015 and 2024. Its goals: to counter the danger of a one-sided dependence on the oil and natural gas business and increase the innovative strength of the domestic economy. The key points of this plan relate above all to the inadequate excellence of science, the focus of innovation funding of incremental innovations than on radical innovations and addressing specific societal challenges. It is difficult to assess the success of this plan well before the end of the implementation period. However, some evidence already suggests that the plan cannot effectively address significant problems in the Norwegian innovation system. For example, some measures were supposed to reduce the fragmentation of the science system. This included above all the merging of various universities and higher education institutions. However, this primarily contributed to disrupting the previously well-functioning division of tasks between universities and university colleges. It is also to be criticized that innovation promotion continues to be based on a linear understanding of innovation and does not place sufficient emphasis on open, cooperation-based modes of innovation.

A particularly big problem of many funding mechanisms is the short-term nature of the objectives. All too often, immediate return and profitability targets come before the long-term development of new technologies that would enable a sustainable

Large investments in research and development have not yet paid off for Austria.

renewal of the Norwegian economy. To make matters worse, the profitability of energy-based sectors is still so high that a significant part of human capital is tied up here. As a result, many innovative but currently less profitable companies suffer from a considerable shortage of skilled labor.

As in previous years, Japan closes the broad middle field of innovation-oriented countries with 39 points. Japan's poor performance in the Innovation Indicator is mainly due to the low degree of openness of the Japanese innovation system and Japanese society in general (see also the focus chapter). In addition, the innovation performance of the Japanese economy is very strongly concentrated on the relatively small number of multinationals. Most small and medium-sized enterprises, on the other hand, are not very innovation-oriented.

The low degree of openness has particularly noticeable negative effects in the scientific field and in human capital. Japan is more likely to face a demographically induced shortage of skilled labor than any other highly developed industrialized country. To counter this only by mobilizing internal potentials, above all with a higher number of women with technical and scientific qualifications, seems unrealistic. At the same time, however, Japan has hardly developed any approaches to attract highly qualified people from abroad and, above all, to integrate them into the Japanese economy and society. This deficit may cost Japan dearly in the long run.

As in 2015, the lower third of the country ranking of the Innovation Indicator is led by the Czech Republic with 26 index points, ahead of Portugal (20 points), Spain (19 points) and Italy (17 points). Italy is followed by China (14 points), which still just keeps up with the stragglers, while Hungary, Poland, Russia, Greece and Indonesia are already lagging behind more clearly. South Africa, Turkey, Mexico, India and Brazil are at the bottom of the ranking of the 35 countries without any points at all, as none of the indicators are better than the worst country in the benchmark group (Germany, USA, Japan, Switzerland, the United Kingdom, France and Italy).

Overall ranking of countries 2000–2017

Rank	2000	2005	2010	2015	2017
1	Switzerland	Switzerland	Switzerland	Switzerland	Singapore
2	Sweden	Sweden	Singapore	Singapore	Switzerland
3	USA	USA	Sweden	Belgium	Belgium
4	Finland	Finland	**Germany**	**Germany**	**Germany**
5	Belgium	Singapore	Finland	Finland	Sweden
6	Singapore	Netherlands	Netherlands	United Kingdom	USA
7	Israel	Canada	Norway	Denmark	United Kingdom
8	Canada	Denmark	Austria	Sweden	Denmark
9	France	Belgium	USA	Austria	Ireland
10	**Germany**	**Germany**	Belgium	Netherlands	South Korea
11	Netherlands	Norway	Canada	USA	Austria
12	Denmark	United Kingdom	Taiwan	Ireland	Netherlands
13	United Kingdom	Austria	Denmark	South Korea	Finland
14	Norway	Israel	France	Norway	France
15	Japan	France	United Kingdom	France	Taiwan
16	Australia	Australia	Australia	Australia	Israel
17	Austria	Ireland	Ireland	Israel	Norway
18	Ireland	Japan	South Korea	Canada	Canada
19	South Korea	South Korea	Israel	Taiwan	Australia
20	Taiwan	Taiwan	Japan	Japan	Japan
21	Czechia	Czechia	Czechia	Czechia	Czechia
22	Russia	Spain	Hungary	Portugal	Portugal
23	Hungary	Hungary	Spain	Spain	Spain
24	Spain	India	Portugal	Hungary	Italy
25	India	Italy	China	China	China
26	Italy	China	Italy	Italy	Hungary
27	Poland	Russia	India	Russia	Poland
28	Indonesia	Poland	Russia	Poland	Russia
29	China	Portugal	Poland	Greece	Greece
30	Greece	Greece	Greece	South Africa	Indonesia
31	Portugal	South Africa	Indonesia	Turkey	South Africa
32	Brazil	Indonesia	South Africa	Indonesia	Turkey
33	Mexico	Brazil	Brazil	Brazil	Mexico
34	Turkey	Mexico	Mexico	India	India
35	South Africa	Turkey	Turkey	Mexico	Brazil

Excursus

Focus on China's role

Why is China already perceived as a strong competitor in some technologies and sectors, but does not perform well in the Innovation Indicator? Here are some explanations and background information:

- The Innovation Indicator looks exclusively at the 35 most innovative economies, amongst which China ranks 25th.
- The Innovation Indicator assesses China as a whole, and not just the economically strong east coast regions.
- Chinese companies are for the main part only competitive in the Chinese market.
- International competitiveness in innovative products and services is also found only in a few industries and in a few fields of technology.
- Much of China's economic success is not (yet) based on innovation, but on price leadership and infrastructure investments.
- China is currently transitioning from a low-cost to a high-tech provider, which initially involves transaction costs for the whole economy.
- China's innovation system is still very input-heavy; the output only becomes visible after a time lag.
- China's efficiency in transforming input into output has not yet reached the level of most other innovation-oriented countries.

However, it is undisputed that China…

- … has once again developed and increased significantly in recent years.
- … has developed faster than many observers had expected or even thought possible.
- … in the past two to three years has shown the political will to develop economically from the "workbench of the world" into an innovation nation in a target-oriented manner.

The sub-indicators

The Innovation Indicator is also characterized by the fact that it can draw a differentiated picture of the innovation landscape in the countries examined. It evaluates the five sub-systems industry, science, education, state and society. Industry is the most important of these. It is therefore also covered by the largest number of indicators in the Innovation Indicator. Innovations are marketable products, processes and services that are developed and commercialized by industry. It is only here that innovations are created. However, a successful industry needs good framework conditions (state), qualified personnel, a good system of knowledge transfer (education) and a strong science system in which basic and application-oriented knowledge is created. Ultimately, a societal environment that favors innovation and demands it is also necessary.

Switzerland remains at the top of the sub-indicator industry, Germany is only ninth

Industry

In contrast to the overall ranking for the sub-indicator industry, Switzerland is at the top of the list and, as in 2015, is characterized by particularly innovative companies, a high level of implementation competence and the highest innovation output – measured against the size of the country. After Switzerland's lead shrunk somewhat in 2015 and it reached 66 points, the country was able to slightly increase its lead again in 2016 and 2017, reaching 68 and 69 points respectively. This year, for the first time, Taiwan is in second place behind Switzerland, having significantly increased its score from 56 in 2015 to 64 in 2017. Singapore and the USA were also able to increase from 57 (2015) to 62 (2017) and from 56 (2015) to 60 (2017) points, respectively. South Korea, which was still in second place in 2015, falls back to fifth place because it, unlike the USA and Singapore, was unable to increase its score.

While Germany was still the leader of the pursuers group in 2015, this year it falls back significantly, at least in terms of rankings. As in 2015, Germany achieved 54 index points. However, Belgium, Israel and Ireland passed it by and improved their index to values between 55 and 57 points. As in other areas of the Innovation Indicator, Germany's development is stagnating worryingly – a trend that is not evident in other nations. Stagnation means regression in the face of intensifying international competition.

The relative decline in the innovative strength of the German economy is also documented in several other scientific studies. This shows that although innovation expenditure by the German economy as a whole has risen steadily since the 1990s, the level of participation in innovation continues to decline. In particular, many small and medium-sized enterprises are withdrawing completely. The rising innovation expenditures are thus increasingly shouldered by a few large companies. In 1995, for example, the share of expenditure borne by large companies was only 57 percent. Today, this figure is 77 percent.[2] However, increasing focus on a few large companies leads to an increasing dependence on a few key industries. The extreme case of Nokia in Finland shows how strong the adverse effects of over-dependence can be.

Germany is followed by Sweden (52 points), the Netherlands (50 points), Austria (49 points) and Japan (48 points). Austria only achieves medium or low values for many individual indicators. This applies, for example, to the share of employees in knowledge-intensive industries, venture capital used for the early stages and the balance of trade in high-tech goods. Austria only achieves top results in terms of the share of government-financed expenditure on research and development by companies in the gross domestic product.

Denmark leads the lower midfield with 45 points and the Czech Republic brings up the rear with 24 points. This group includes the United Kingdom, France, Norway and Finland. Norway, for example, has not only many poor values, such as international co-patents and the share of value added in high technology, but also distinct strengths. These include, for example – similar to Austria – the share of state-financed research and development conducted by companies, the scope of tax incentives for research and development and the high demand of domestic companies for technologically sophisticated products.

It can therefore be said that the weakness of the Norwegian economy in terms of innovation probably has little to do with insufficient state incentives to finance innovation. It is rather a systemic weakness to produce innovations. The strength of the Norwegian oil industry and its downstream industries seems both a curse and a blessing: on the one hand, it guarantees a current high level of economic prosperity, but on the other it ties up a significant portion of human capital through very high wages. This is then no longer available to new and innovative companies in other sectors.

Spain and China are almost on a par with each other with 16 points. China achieves very poor values for many indicators. This applies, for example, to the technological quality of domestic demand, US patent applications and value added per hour worked. However, China also has clear strengths. Among other things, the share of research and development financed by companies at higher education institutions is higher than in all benchmark countries.

China is followed by Hungary (15), Italy (10) and Russia (10). Italy's performance is of particular concern. In many key indicators, such as the share of employees in knowledge-intensive services or transnational patent applications, Italy has the lowest score among the benchmark countries and therefore receives zero points. The once highly industrialized country no longer has any distinct strengths either. The best indicator value is achieved by Italy with 57 in the government-financed expenditure on research and development by companies as share of the gross domestic product. In addition, the political situation does not give cause for optimism. The former "new hope" Matteo Renzi already failed back in 2016 with a constitutional referendum that was supposed to simplify political decision-making processes considerably. The defeat heralded new elections and a long process of political uncertainty that ultimately

There is no lack of ideas in Germany: Start-up Franka Emika, founded in 2016, has developed a robot system that can be operated via apps and can be taught new tasks within a few minutes even without robotics knowledge. In 2017, it was awarded the "Deutscher Zukunftspreis" (German Future Prize) led to the formation of a government comprised of the Lega Nord and the Five-Star Movement. Since then there has been no discussion of reforms that could strengthen Italy's economy again.

Science

In the field of science, Singapore has overtaken Denmark and is now the undisputed leader with 99 points. The country is particularly strong in the number of researchers per 1,000 employees as well as in quality-related bibliometric indicators such as citations per publication (citation rate) and the country's share among the 10 percent most frequently cited scientific and technical publications (excellence rate). Just a few years ago, Singaporean publications were only mediocre by international standards. This increase was achieved in such a short time through the targeted recruitment of foreign top talent – especially in the science sector – and through substantial state investment in the innovation system. The country also pursues a pronounced international orientation with intensive cooperation relations within the Asia-Pacific region, but above all with the USA. With government support, the scientific institutions in Singapore very early on focused on excellence in research and aligned their structures accordingly. The system is similarly organized to the US sci-

Indicator values of the five sub-indicators

Rank		Index value industry
1	CH	69
2	TW	64
3	SG	62
4	US	60
5	KR	60
6	BE	57
7	IL	57
8	IE	55
9	**DE**	54
10	SE	52
11	NL	50
12	AT	49
13	JP	48
14	DK	45
15	UK	44
16	FR	42
17	NO	37
18	CA	31
19	FI	31
20	AU	28
21	CZ	24
22	ES	16
23	CN	16
24	HU	15
25	IT	10
26	RU	10
27	PT	9
28	ZA	8
29	TR	7
30	PL	4
31	MX	2
32	ID	1
33	IN	0
34	GR	0
35	BR	0

Rank		Index value science
1	SG	99
2	DK	93
3	CH	90
4	FI	76
5	BE	76
6	SE	75
7	NL	73
8	NO	68
9	AT	66
10	**DE**	63
11	AU	62
12	FR	60
13	IE	58
14	IL	56
15	UK	56
16	CA	52
17	KR	51
18	US	49
19	PT	37
20	CZ	33
21	JP	29
22	TW	29
23	GR	27
24	ES	25
25	IT	21
26	ZA	10
27	HU	10
28	ID	7
29	CN	3
30	TR	0
31	RU	0
32	PL	0
33	MX	0
34	IN	0
35	BR	0

AT (Austria), AU (Australia), BE (Belgium), BR (Brazil), CA (Canada), CH (Switzerland), CN (China), CZ (Czech Republic), DE (Germany), DK (Denmark), ES (Spain), FI (Finland), FR (France), GR (Greece), HU (Hungary), ID (Indonesia), IE (Ireland), IL (Israel), IN (India), IT (Italy), JP (Japan), KR (South Korea), MX (Mexico), NL (Netherlands), NO (Norway), PL (Poland), PT (Portugal), RU (Russia), SE (Sweden), SG (Singapore), TR (Turkey), TW (Taiwan), UK (United Kingdom), US (USA), ZA (South Africa) ence system with strong research universities and intermediary institutions that support the transfer of results and cooperation between science and industry. In addition, Singapore has been able to develop a regulatory framework ideal for the country, which – it must be admitted – is easier to implement and control in a small city-state than in a large and politically pluralistic economy such as Germany or very large countries such as the USA or China.

Denmark (93 points) and Switzerland (90 points) follow behind Singapore. Both countries are characterized by a strongly internationally oriented science system, in which researchers from abroad form the majority in some disciplines and institutions. The three leading countries have a clear lead over the upper midfield consisting of Finland (76), Belgium (76), Sweden (75) and the Netherlands (73). The science systems in Norway, Australia, Austria and Germany score 62 to 68 points. France (60), Ireland (58), Israel (56) and the United Kingdom (56) follow behind them. Canada, South Korea and the USA follow with 49 to 52 points.

The USA, which is regarded as the leading science nation, therefore still lag behind expectations. On the one hand, this is because they are the largest science nation in absolute terms. In relative terms,

Rank		Index value education
1	SG	84
2	CH	69
3	FI	59
4	KR	57
5	UK	55
6	BE	54
7	CA	53
8	TW	53
9	IE	52
10	**DE**	**50**
11	AT	49
12	FR	43
13	AU	43
14	SE	40
15	JP	38
16	US	38
17	DK	37
18	NL	37
19	NO	36
20	CZ	33
21	PL	31
22	PT	23
23	RU	22
24	IL	14
25	IT	13
26	HU	10
27	ES	9
28	CN	9
29	ZA	0
30	TR	0
31	MX	0
32	IN	0
33	ID	0
34	GR	0
35	BR	0

Rank		Index value state
1	SG	100
2	FI	66
3	NO	59
4	CH	58
5	NL	57
6	BE	55
7	FR	55
8	**DE**	**54**
9	CA	54
10	US	50
11	SE	50
12	KR	49
13	AT	48
14	UK	46
15	JP	45
16	DK	41
17	IE	38
18	PT	35
19	AU	34
20	TW	34
21	CZ	29
22	CN	28
23	ES	27
24	RU	24
25	PL	21
26	IN	20
27	IL	14
28	IT	12
29	HU	8
30	ID	1
31	TR	1
32	ZA	0
33	MX	0
34	GR	0
35	BR	0

Rank		Index value society
1	AU	82
2	UK	80
3	FI	73
4	SE	71
5	CH	70
6	BE	70
7	CA	69
8	NO	58
9	IL	58
10	FR	57
11	DK	53
12	**DE**	**52**
13	US	50
14	AT	49
15	IT	46
16	IE	45
17	NL	44
18	ES	44
19	SG	37
20	JP	35
21	PT	35
22	GR	29
23	KR	27
24	CZ	14
25	PL	5
26	CN	1
27	ZA	0
28	TW	0
29	TR	0
30	RU	0
31	MX	0
32	IN	0
33	ID	0
34	HU	0
35	BR	0

however, they do not come close to the values of small open economies in terms of size. In addition, even with pure quality indicators, the USA achieve solid but not outstanding results. Their excellence rate, which is a measure for the prevalence of particularly relevant articles, reaches a value of 63, the citations per article are also only in the midfield at 54. This should not obscure the fact that the USA are home to many of the world's leading universities. However, in addition to the lighthouses, there are also many universities that achieve only extremely modest results and thus lowered the country's average.

The USA are followed by Portugal (37 points), the Czech Republic (33 points) and Japan (29 points). As in previous years, the Japanese science system performs very poorly, especially in terms of publication-based indicators. Particularly in the case of the excellence rate and the citation rate, Japan scored only zero points and thus the worst of the benchmark countries. On the other hand, Japan is really good in terms of the number of researchers per 1,000 employees. This contrast between many researchers and low output points to significant productivity problems due to continued silo effects of the science system and a low propensity to cooperate both internationally and nationally. The low dynamism of the science system is also reflected in scientific publications. Japan is the only country among the highly industrialized countries in the Innovation Indicator that has not been able to increase its scientific output in the last 10 to 15 years but has remained at a level that was already reached at the beginning of the 2000s.

Taiwan follows with the same number of points as Japan. In contrast to its strong economy, its science system's performance is only below-average. Clear weaknesses lie here – as in Japan – in all quality-related, bibliometric indicators. Greece, Spain, Italy, South Africa and Hungary reach a level of 10 to 27 points, with Greece significantly improving from 22 to 27 points compared to 2015. Greece scores particularly well for the quality indicators excellence rate (53 points) and citation

Art and science merge here: in the lotus-shaped ArtScience Museum in Singapore. Science rightly has a high status in the Asian country, because it is stronger there than ever before. The result: Singapore replaces Denmark as the leading country in science in the Innovation Indicator.

rate (86). Although Italy achieves a solid quality of scientific publications, it falls well behind most other countries in other indicators such as public expenditure on research and development or patents stemming from the public system. China with three points just barely reaches positive values. Turkey, Russia, Poland, Mexico, India and Brazil, on the other hand, score no points at all.

Education

In the education sub-indicator, Singapore (84 points) leads by a large margin, followed by Switzerland (69 points). Finland, which traditionally achieves good scores in this area, is still in 3rd place, but only reaches 59 points in 2017. This is five points less than in 2015. With South Korea (57 points) a broad midfield begins, which also includes Germany and ends with Poland (31 points). As in 2015, Germany achieved 50 index points and was thus able to improve slightly after education had been one of the greatest weaknesses in the German innovation system for a very long time. Germany scores well in the assessment of the quality of the German education system and the proportion of intermediate qualifications held by the population. This also acknowledges the importance of the so-called dual (vocational training) system for the German economy. In the PISA index, which systematically records the different thematic competences of pupils, Germany only achieves a mediocre 54. There have been improvements here for several years, but these have not continued recently. For Germany, the shortage of skilled workers remains a central challenge, especially since academic and intermediate qualifications behave like corresponding tubes in the education and labor markets.

An interesting picture emerges for Germany when one compares the development of persons with secondary education to persons with tertiary education – measured in terms of the number of employees in each case. Regarding the first indicator, Germany has fallen from 100 to 85 points since 2015. On the other hand, the indicator covering tertiary educated persons has risen from 0 to 23 points. A clear shift away from secondary education towards tertiary education can therefore be observed. This respectively was politically intended, but is also controversially discussed, under the heading "mania for academization". In practice, increasing academization holds both opportunities and risks. In a more and more technically complex world, university degrees are becoming increasingly important. However, as academization progresses, there is a shortage of skilled craftsmen and craftswomen whose activities are also of great importance in the industrial innovation process.

The broad midfield also includes Austria (49 points), France (43 points), the USA (38 points) and Norway (36 points). Behind the midfield are the stragglers, which include many southern European countries such as Portugal (23 points), Italy (13 points) and Spain (9 points). Among them, however, is also Israel, which otherwise achieves solid to good values in the Innovation Indicator. The country scores particularly poorly in the PISA index, when it comes to the proportion of foreign students and the quality of mathematics and natural sciences education. South Africa, Turkey, Mexico, India, Indonesia, Brazil and Greece remain completely without points.

State

Although the state rarely intervenes directly in the innovation process, it does set decisive framework conditions. This concerns both the funding of the education and science system as well as government demand for technologically sophisticated goods. In addition, within the framework of the tax regime, the state can provide incentives for innovation activities in companies. According to the indicators used here, government contributions to the innovation system are highest in Singapore, which scores the full score in this area. Finland, which ranks second in this sub-system, scores 66 points. Switzerland, which otherwise always competes with Singapore for the top position, reaches only 58 points and is thus only in fourth place. Compared to 2015, this is a drop of six points. Singapore's good performance compared to Switzerland can be clearly displayed by this indicator. While there is strong government intervention in Singapore, Switzerland leaves much more to the companies themselves, despite significant funding in the

Japan's scientific output remains at the level of the new millennium's beginning.

When it comes to where the happiest people on earth live, Australia is often at the forefront. But the inhabitants are also particularly open to new things. This in turn has a positive effect on the country's ability to innovate.

education sector. For example, there is hardly any state financing of private research and development, neither through subsidies nor through tax rebates.

Switzerland is followed by the Netherlands (57 points), Belgium (55 points), France (55 points), Germany (54 points) and Canada (54 points). The German weaknesses in the international comparison are revealed by the lack of tax incentives for research and development and the comparatively low level of direct support in this area within companies through subsidies or public contracts. In contrast, Germany is particularly strong in government demand for technologically sophisticated goods but could certainly expand its sphere of action within the framework of a demand-oriented innovation policy.

The USA are two places behind Germany with 50 points and thus achieves tenth place. The USA achieve good results in the share of private research and development funded by the state. This is largely due to orders for the defense industry. In contrast, the USA lag far behind when it comes to tax incentives for research and development. The support rates currently applied there are far lower than those of other benchmark countries (especially France). The lower midfield for this sub-indicator consists of the Czech Republic, China, Spain, Russia, Poland and India. Italy, with twelve points, is roughly on a par with Israel, which scores 14 points. South Africa, Mexico, Greece and Brazil reach zero points.

Society

Societal and cultural attitudes can also form important framework conditions for the emergence and dissemination of innovations. On the one hand, openness and affinity towards innovations play an important role. They determine the acceptance and rapid dissemination of innovations (see also the focus chapter). On the other hand, the basic competences and interests of a society indirectly affect the innovation capability of an economy. After all, whether people are interested in an innovation topic, actively turn their attention to it and acquire specific qualifications for it or take up scientific and technical professions – that depends, among other things, on the prestige of these topics in society.

Australia (82 points) together with the United Kingdom (80 points) again leads the ranking for this sub-indicator. This is followed by a group consisting of Finland, Sweden, Switzerland, Belgium and Canada, which scored between 73 and 69 points, clearly distinguishing themselves from the midfield led by Norway (58 points). Norway has particularly good values for female labor force participation, which is also high in other Nordic countries. Norway, on the other hand, does poorly regarding the share of inhabitants with postmaterialistic value patterns, i. e. people who aspire more to intangible values.

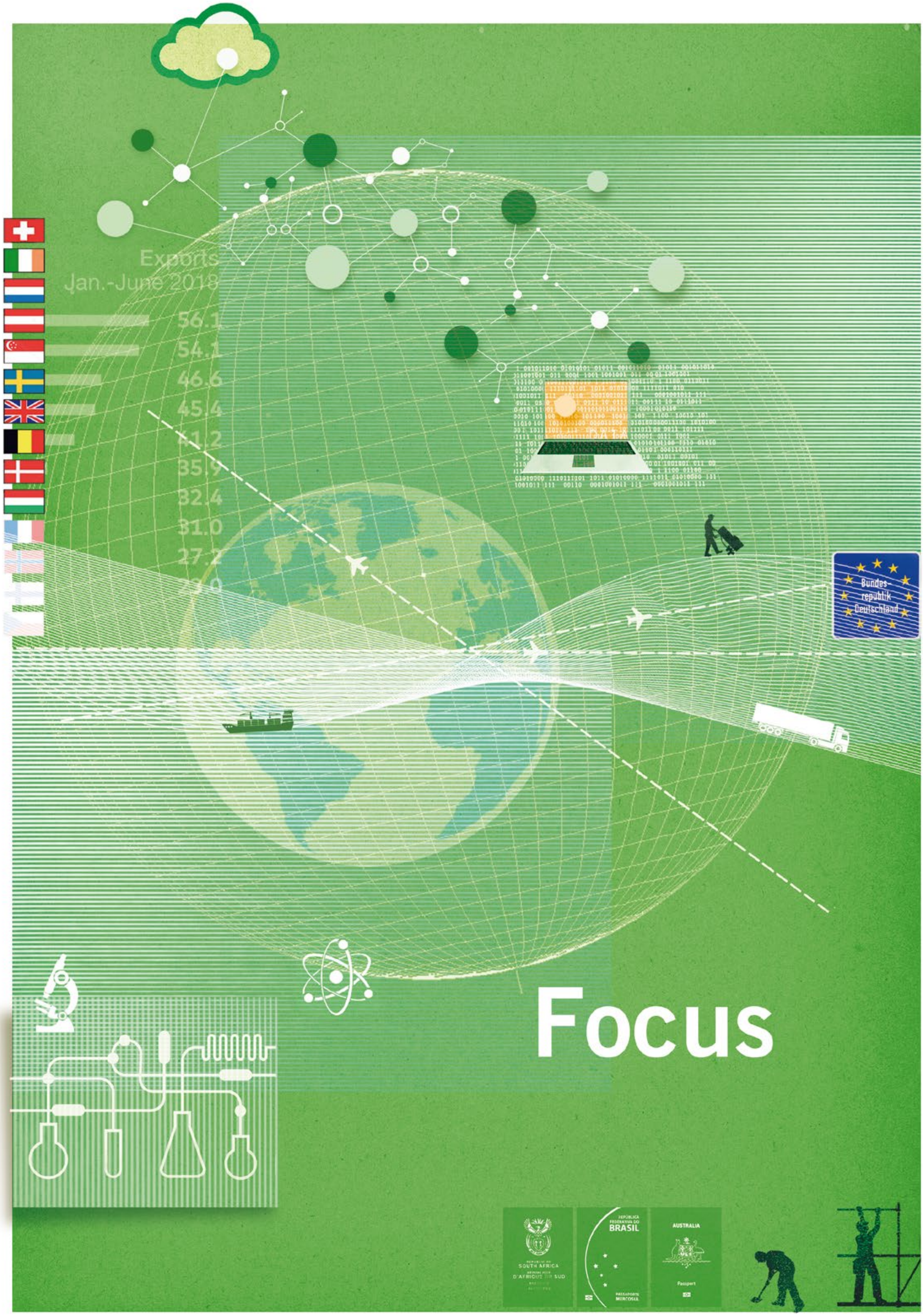
Germany lies clearly behind Norway in twelfth place with 52 points. Germany only scores well in the proportion of women in employment. For all other indicators, Germany scores below 50 points. This also applies to a central indicator that measures the frequency of news on research and development topics. Germany scores 42 points here. The poor performance in this area is particularly problematic. The low indicator value also reflects a rather mediocre interest in science and innovation-related topics among the population as a whole.

Germany is followed by the USA, Austria and Italy. As in previous years, Italy achieved its best sub-rating here with 46 points. It achieves good values above all with postmaterialists and life expectancy. However, it scores zero points in the news on research and development topics.

Singapore, which is otherwise well ahead, scores only 37 points for societal indicators. The proportion of postmaterialists is particularly poor. On the other hand, the country achieves top results in the news about research and development. Japan (35 points), Portugal (35 points), Greece (29 points) and South Korea (27 points) are also in the lower midfield. South Africa, Taiwan, Turkey, Russia, Mexico, India, Indonesia, Hungary and Brazil do not score any points. However, Taiwan's poor performance is also due to a lack of indicator values. Here, for example, only values were available for the proportion of postmaterialists – and this is traditionally low in Southeast Asian cultures.

Many Germans have only limited interest in news about science and innovation.

2 Rammer, C., Schubert, T. (2018): Concentration on the few: mechanisms behind a falling share of innovative firms in Germany. Research Policy, 47(2), 379–389.


Exports
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56.1
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SOUTH AFRICA
BRASIL
AUSTRALIA

Focus

05

Openness of innovation systems

Knowledge is the basis of all innovations – whether technical product innovations, process innovations or service innovations. The complexity of knowledge and simply the amount of knowledge necessary for innovation is increasing significantly – sometimes exponentially. In addition, new and interesting applications are emerging, especially at the intersection of specialized knowledge in individual disciplines. Interdisciplinarity is the keyword here. However, individual companies or research institutions are often unable to provide this amount of up-to-date knowledge or the necessary wide range of disciplines. Cooperation and the exchange of knowledge with other enterprises or organizations are therefore essential.

Exchange instead of secrecy

At the corporate level, Henry Chesbrough[3] presented a concept back in 2003 that has significantly influenced innovation management in numerous companies in recent years. According to the concept, companies that implement an open innovation process are particularly successful. In addition, they are open to using external knowledge within the company (outside-in or inward openness) and to transferring their own not at all or only partially utilized knowledge to the outside world (inside-out or outward openness). Henry Chesbrough thus propagates a change in corporate culture away from the secrecy of research and innovation processes towards opening and thus also towards starting points for an exchange, where previously closeness prevailed.

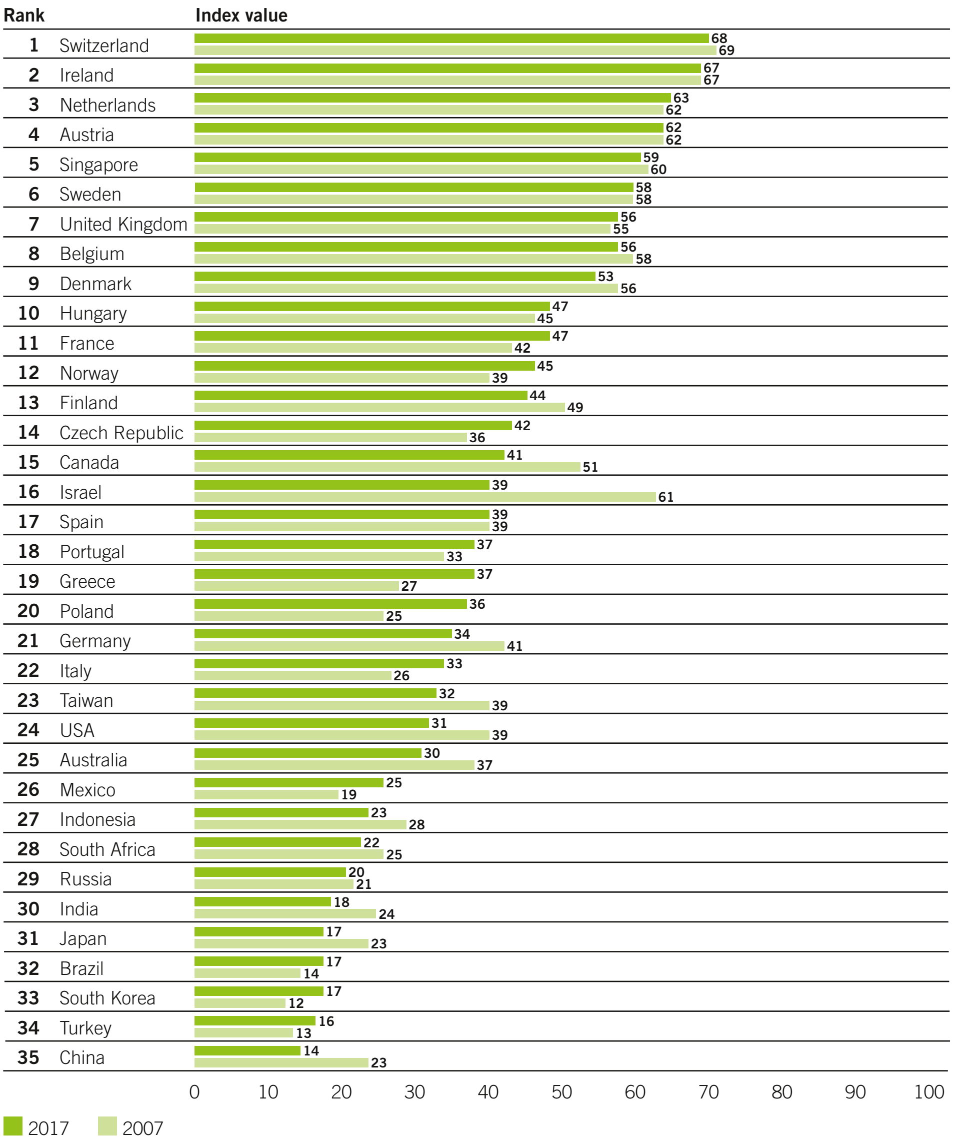
Eric von Hippel[4] identified the involvement of users and customers as well as suppliers and other partners in the innovation process as critical success factors as early as the 1990s. Building on this, he also developed a concept of open innovation with an exchange of knowledge that is as free as possible forming the central basis of progress. Open science and free access to data (open data) as well as free exchange and free use of knowledge (open source) are particularly central to this.

While von Hippel looks at the overall system and propagates the free use of knowledge, Chesbrough focuses on the individual actors and cooperations and tries to optimize them for the respective players. For Chesbrough, the protection of intellectual property is an important prerequisite for cooperation to function well and there being no need to argue about who owns what and who may exploit what. Von Hippel, on the other hand, sees intellectual property regimes as an obstacle to the exchange and free access to knowledge. Although this discussion cannot be pursued in greater depth at this point, the two approaches have significant similarities. On the one hand, an open science system geared towards exchange and transfer makes positive contributions to innovation performance in both concepts. On the other hand, both have in common that the widest possible dissemination of knowledge (and knowledge about knowledge) as well as cooperation between different knowledge carriers beyond institutional boundaries often leads to success. Cooperation (co-creation) is important here, so that the two concepts go well beyond classic approaches to knowledge and technology transfer.

Cooperation and exchange promote innovation: Switzerland, the leader, and the pursuers from Ireland and the Netherlands have understood this best so far.

Both approaches concern cultural change – on the one hand at the company level, on the other hand, at the level of society as a whole regarding attitudes towards openness and innovation. Open innovation systems depend on give and take on all sides – companies, public research, customers, suppliers and producers. In Henry Chesbrough's version there are clear boundaries and own strategies and in Eric von Hippel's version rather low barriers for the free exchange of knowledge and ideas stand out.

Comparison of the openness indicator between 2007 and 2017 for all countries examined



The Innovation Indicator compares the performance of selected innovation systems internationally. The aim of this focus chapter is to compare and discuss the openness of innovation systems. This is becoming increasingly important for the ability to innovate. Various indicators are included which reflect openness and exchange, but which on their own do not permit a stable and reliable statement. Openness has many facets. It feeds from different sources or acts in different directions. In this respect, the method of the Innovation Indicator also suggests itself here – the combination and aggregation of individual indicators to assess systems. Openness can have different dimensions and objectives. For this reason, in addition to an overall indicator of openness, an evaluation of partial aspects respectively sub-systems is also offered.

Meanwhile there are many models and operationalizations of open innovation. The dimensions used here are based on the sub-areas of the innovation system as viewed in the Innovation Indicator as a whole. They distinguish between three sub-systems: science and research, market and economy as well as government and regulation. In the following sections, the results of the analyses are presented and discussed on this basis. However, it starts with a brief overview of policy measures in Germany in the context of an "open innovation system".

Open science policy in Germany

German science policy has always relied on cooperation and exchange. It thus follows the discourse approach in science and ultimately also Wilhelm von Humboldt's ideal of a broad-based education and the combination of teaching and research. The openness of the German science system refers on the one hand to inward openness – through cooperation between science and industry, between universities and non-university research organizations or also between institutions from different organizations – and on the other hand to outward openness – through international projects and international co-publications, mobility of scientists and research cooperation with foreign companies at home and abroad.

In the past legislative period, for example, the internationalization of the Leading-Edge Clusters was promoted. The Pact for Research and Innovation, which addresses non-university research organizations and the German Research Foundation (DFG), aims to network the national science system as well as science, industry and society and to promote international cooperation. The mobility of talent to and from Germany has long been an important issue in science policy. German research institutions therefore participate in the European Research Framework Programmes, international research cooperations are funded in public projects. Germany, for example, supports companies through international collaborative projects (so-called 2+2 projects) or through bilateral calls for proposals with selected countries within the framework of the Central Innovation Programme for SMEs (Zentrales Innovationsprogramm Mittelstand or ZIM), thereby promoting research and development cooperation with foreign partners.

These policy measures are derived from the German government's strategy[5] for the internationalization of education, science and research. Published for the first time in 2008 and revised in 2017, this strategy aims to intensify international networking and transnational cooperation in science and innovation within five target fields. The internationalization strategy also supports the innovation activities of the corporate sector. Regarding science, the strategy aims to promote cooperation with the world' s best and thus promote scientific excellence in Germany. In terms of the economy, it aims to leverage innovation potential internationally and support competitiveness by further embedding it in global knowledge exchange and global value-added chains and networks. Other pillars address international exchange in vocational education and training and cooperation with emerging and developing countries. Finally, the fifth target field is aimed at the joint solution of global challenges.

Since 2016, there have also been additional approaches to further opening the science system (open science), both nationally and internationally. The results of scientific research obtained from public program funding are to be made available to all interested parties at any time and free of charge through free, digital access to scientific publications (open access). On the one hand, this is supposed to promote modern, innovative science and, on the other hand, strengthen Germany's innovative strength.[6] The German government and, for example, the DFG provide financial support to researchers to make their results available via open access. The non-university research organizations have set up their own programs to support scientists with open access publications. In this context also, there are initiatives on open data, i. e. free access to scientific data. Among other things, licensing and data protection aspects have to be considered here. The aim of open-data policy is to reduce redundancies in data collection and thus increase efficiency, but also to make results verifiable and thus achieve greater transparency in the science system.

In the recently published High-Tech Strategy 2025, the issue of openness takes up a lot of space. The German government wants to advocate "the greatest possible networking and cooperation" by, for example, strengthening the transfer from public research to industry or by supporting open forms of innovation.[7] It wants to increase cooperation between industry and science, but also between various economic actors, for example through new "campus models, demonstration projects, innovation laboratories, 'living laboratories' and communal experimental spaces".[8] Overall, cultural change is to be brought about, leading to a more open system.

The European Commission also addresses the issue of open innovation in its strategic reflections and will place greater emphasis on policy measures in this area in the forthcoming Research Framework Programme. On the one hand, the European Commission's approach focuses on users. On the other hand, there should be a so-called innovation ecosystem in the future. Based on open innovation processes, it is intended to produce new products and processes that create

With its strategy, Germany wants to strengthen its international scientific networking.

The European Commission will more strongly focus on open innovation in the next Research Framework Programme.

new markets, but it is also supposed to promote a stronger entrepreneurial culture and thus make it possible to "translate knowledge into socio-economic added value".[9]

What do the results show?

For the openness indicator, Switzerland (68 points) and Ireland (67 points) lead with some margin to a broad chasing field, led by the Netherlands, closely followed by Austria, Singapore, Sweden, the United Kingdom, Belgium and Denmark. The countries of the pursuing group attain values between 63 and 53 index points. Switzerland has slightly lost index points compared to 2007, as have some other countries from the pursuer group (Singapore, Belgium and Denmark). However, the figures for the nine top countries over a ten-year comparison are quite stable.

There is a broad midfield in which changes are more pronounced over time than in the top group. The midfield is led by Hungary (47 points) and extends to Spain at rank 17 (39 points). Israel, which also belongs to this group, has the largest change in the openness indicator over time. In 2007, the country still had close contact to the top. In 2017 it is markedly less open with an index value of 39. Israel has deteriorated primarily in terms of the import ratio, the index of investor protection and also the share of open-access publications. Other indicators, such as licensing income and expenditure from intellectual property rights, have also fallen slightly over time. All sub-indicators show the effects of a decline in Israel, but especially in science and research, the country only achieves one of the lowest places in 2017 in terms of the openness of the system. This is certainly due in part to the high proportion of defense research, which is generally less open. For a country like Israel, which wants to establish itself as a systems supplier in some of the new technologies such as artificial intelligence or autonomous driving, this is certainly not the right way to obtain the necessary knowledge, on the one hand and to gain experience in application in a broad environment on the other.

Spain in place 18 is followed by a group of countries in the lower third of the index scale. They attain values between 37 and 30 index points and the rankings 18 to 25. These include Portugal, Greece, Poland, Italy, Taiwan, the USA and Australia. Germany also ranks 21st among the countries lagging behind the midfield. Compared to 2007, this is a deterioration of seven index points and six positions.

Germany achieves high index values for the share of international co-publications, for the stock of foreign investments (net assets), for the research and development of foreign companies carried out in Germany and for the import ratio. Regarding the first two indicators and investor protection, however, Germany's values have fallen most sharply compared with 2007 and are thus largely responsible for the deterioration in Germany's placement.

The German science system is in the lower half of the distribution – despite a high proportion of international co-publications. However, for most indicators of this sub-system, Germany only attains values between 30 and 50. In contrast, the German market is comparatively open. At place 17, Germany achieved its best ranking among the sub-systems here. In addition to the high import ratio, this can be attributed particularly to the level of foreign investment, while Germany ranks at the bottom end of the league in a comparison of benchmark countries in terms of labor market participation of foreign-born people. Moreover, the German immigration regulations and the bureaucratic handling of immigrants are not very attractive for foreign talents. It is noteworthy that regarding license payments for intellectual property from abroad and to foreign countries, Germany tends to be at the lower end of the scale. Germany also does not perform very well in the sub-indicator of state and regulation.

Overall, the results suggest the conclusion that openness in Germany can still be significantly improved in all sub-areas of the innovation system. Policies in federal and state governments have long been geared towards cooperation and exchange, especially in the science system. However, other countries are even more committed. Al-

Method

This is how the openness indicator works

Like the Innovation Indicator as a whole, first a number of individual indicators were identified that could be relevant in the context of openness. A decisive factor in the selection of these indicators was, on the one hand, that they were readily comparable for a larger number of countries and, if possible, for a period of at least ten years. On the other hand, the theoretical-conceptual considerations from the scientific literature were the guiding principles for action. Indicators have been compiled that reflect aspects of knowledge acquisition, knowledge exchange, cooperation or international orientation.

To select the individual indicators ultimately used for the openness indicator, a first step was to collect nearly 40 indicators for as many of the 35 countries analyzed as possible, as is also usual for the Innovation Indicator. This includes both purely quantitative and qualitative indicators from different sources. In a second step, these indicators were evaluated empirically, firstly according to their availability and coverage, secondly according to the stability of the characteristics within the countries and thirdly according to the correlation between the individual indicators. The last step is necessary to identify indicators that reflect similar factors or dimensions.

In the interest of economical modelling, those indicators were excluded that are highly correlated with another indicator so that none of the factors or dimensions are depicted more than once or that indirect weighting takes place through them. Put differently: If two indicators measure the same thing, you can dispense with one of the two in modelling. A factor analysis was carried out for individual selected indicators, which were identified as closely related both in terms of content and empirically. For those indicators which were particularly high on one factor, an average value was then calculated for the individual indicators. In this way, 23 indicators were selected to calculate the openness of innovation systems in an international comparison. The list of indicators and their sources can be found in Table 1. The indicators were subsequently assigned to the three groups science and research, market and economy, and state and society. Thus, in addition to overall openness, the values for these groups can also be calculated and discussed. The overall openness indicator is calculated as the average of all 23 indicators.

The prerequisite for the determination of an overall index is the standardization of the individual indicators, for which the same procedure as in the Innovation Indicator was applied. All indicators are initially aligned equally, so that higher values indicate greater openness, while lower values accordingly reflect more closedness. Then, for each individual indicator, the minimum and maximum values among the seven benchmark countries (Germany, France, the United Kingdom, Italy, Japan, Switzerland and the United States) of the Innovation Indicator are determined and assigned the values zero or 100 respectively. All other countries are then classified according to their values using this scale. Values below the benchmark were set to zero, as were values above the benchmark capped at 100.

The openness of the countries is calculated from the average of 23 individual indicators.

Facts & figures

Key figures on Germany's openness

39.7 %

Import ratio (goods and services as a percentage of gross domestic product)

12.0 %

Share of foreign students of all students

40.4 %

Share of foreign investment of gross domestic product

The values shown are taken from the openness indicators. An overview of these indicators and their sources can be found on page 46.

14.8 %

Share of open access publications of all publications

55.2 %

Share of international co-publications of all scientific-technical articles

6.2 %

Share of total R & D expenditure financed from abroad

15.1 %

Percentage of persons of foreign origin in the population

Germany still has some catching up to do when it comes to opening up the innovation system. One reason for the bad results: the immigration rules are not very attractive for talents from abroad.

though institutions in smaller countries frequently find no or no adequate cooperation partners in their own countries and are thus forced to engage in international cooperation, the size of the country or the level of scientific development alone are not adequate to explain Germany's performance. Obviously, political efforts to open the German innovation system are still too limited to achieve above-average effects.

Cultural change for more openness

Consequently, the German government has explicitly included the topic of openness in the latest version of its High-Tech Strategy. It continues the policy approaches of the recent past and emphasizes an open science system – i. e. open science, essentially driven by open access and open data – as well as transparency through participation by citizens (citizen science). To further open the innovation system, the exchange between science and industry will be further intensified as an important task – for example via the Future Clusters, the Research Campuses or the continuation of the Pact for Research and Innovation. For a radical opening, however, a cultural change is necessary that cannot be achieved overnight. Exchange platforms such as co-creation labs are also considered in the High-Tech Strategy, where a division of tasks between the public sector and private actors is necessary for success.

The USA rank 24th out of 35 countries in the overall index. They too have lost index points over the years, primarily regarding open access publications, where the USA used to be the forerunner. In the meantime, however, most countries have overtaken them. The USA have also lost points in terms of licensing revenues from intellectual property rights as a share of gross domestic product (GDP). The USA have clear strengths regarding openness defined here in terms of labor market participation of people born abroad, societal attitudes towards minorities and the index of labor market policies. This reflects the role of the USA as a classic immigration country. This largely determines the openness and intercultural character of the country. Interestingly, the US index score for migration policies, on the other hand, is at the lower end of the scale. The changed policies under President Donald Trump are not yet even reflected in these figures.

Behind the USA and Australia, Mexico and Indonesia score 25 and 23 points respectively. After this, there is a group that also includes the so-called BRICS countries. South Africa (22 points) is in front, ahead of Russia (20 points), India (18 points), Brazil (17 points) and China (14 points), which occupies the last place in the ranking. With 17 and 16 index points respectively, Japan (31st place), South Korea (33rd place) and Turkey (34th place) are also in this group. Japan's poor ranking is due on the one hand to a science system that is not very open – this has been repeatedly emphasized in the Innovation Indicator in past years. On the other hand, Japan has a comparatively low openness of state and society. In contrast, the market and the economy are open to an average extent with an index value of 30 points and a ranking in the middle (16th place in 2017 Japan only sets the benchmark for net revenues from abroad in relation to total gross domestic product and scores 100 points for this individual indicator. In many other areas, however, Japan is the low benchmark and is assigned zero points. Exceptions are some indicators which are attributed to the sub-indicator market and economy. These include, for example, the stock of foreign investments (net foreign assets), the WEF experts' assessment of the attractiveness for foreign talent and the license payments for intellectual property from abroad.

The link between openness and the ability to innovate

The expectations of the openness of innovation systems, as can be found in political papers and scientific work, should also be empirically substantiated. However, only a few quantitative analyses can be found that demonstrate an influence of the openness of an innovation system on the aggregated innovation performance of the system.[10] Although there are many microeconomic studies that can show such a connection, especially for knowledge-intensive high-tech companies,[11] there is, on the other hand, as good as no empirical evidence at the level of entire national economies or even international comparisons.

For this reason, the relationship between the values of the openness indicator and the Innovation Indicator is examined here. However, no causal relationship can be shown, as the available data does not permit this. On the one hand, it is plausible to assume that the openness of the system via easier and more comprehensive knowledge flows has a positive influence on the ability to innovate. This is what most innovation policy approaches assume. At the same time, however, it can also be expected that the ability to innovate will have a positive effect on openness, because as the knowledge and innovation orientation of an economy increases, so does the need and demand for available and usable knowledge, which can lead to the opening of these processes. Thus, one can presume effects in both directions.

In 2017, for the 35 countries surveyed, there is a strong correlation ($R^2 = 0.470$) between innovation performance measured by the Innovation Indicator and the openness of an innovation system measured by the openness indicator. It is interesting to note that in the field of science and research the link between performance and openness is lower ($R^2 = 0.218$), while in the field of market and economy it is comparatively high ($R^2 = 0.392$). This means that open innovation systems tend to be more economically successful, respectively successful innovation systems result in greater openness.

In contrast, openness is barely related to scientific performance. This can be explained by the fact that most countries have implemented a more or less open science system, so that the differences in scientific openness are less striking than in the area of market and economy. Almost no scientist will dispute the importance of national and international cooperation. In addition, this area is generally pre-competitive, which is why cooperations often do not meet with any reservations. Only rarely are intellectual property rights – be-

At present, the USA are still very open – but the policies under President Donald Trump suggests a negative development for the future.

Among the world's largest economies, Germany has achieved the greatest degree of openness.

yond the copyright of publications – affected, and rarely do directly commercially exploitable results arise. Hurdles, on the other hand, are usually created by different regulatory frameworks and a lack of financial support for national and international cooperations. Cultural – including linguistic – barriers are also often an obstacle to intensive international cooperation.

The situation is different for companies and in some cases also for application-oriented research. Here confidentiality – sometimes even secretiveness – prevails. As the complexity and the amount of knowledge necessary to achieve a "marginal unit of innovation" have increased significantly, companies increasingly need knowledge from outside their organizational boundaries. The economies that best organize and support this process tend to be economically more successful than countries that fail to do so. Outstanding examples are Switzerland, Singapore, Ireland and the Netherlands.

However, some economies which are less open are also successful regarding the innovation performance of their economic systems such as Taiwan, South Korea, the USA and Germany. If, however, one believes the scientific literature and assumes a further development along the trends of the past years, then global value-added chains, necessary specialized knowledge in individual areas, interdisciplinarity or simply a further increase in the importance of knowledge in the innovation process are clear drivers of an increased need for easily realizable and more intensive knowledge flows.

Germany among the countries with a high degree of openness

A comparison of the openness of very large economies with that of small countries is a little skewed in that small economies are virtually forced to be open. This is particularly the case when small countries specialize thematically and therefore do not cover all fields of knowledge and innovation themselves. Such a strategy is completely rational in view of the limited resources of small countries and the need for critical masses to make internationally relevant contributions to an issue. However, specialization means that both knowledge and goods that are not produced domestically must be procured abroad. This requires a high degree of openness. Larger economies can and often want to cover the entire spectrum of scientific disciplines and innovation topics and therefore are under less pressure to acquire external knowledge. For this reason, larger economies tend to be in the lower half of the ranking for the openness indicator. An evaluation of these countries is therefore much more meaningful within the narrower group of large economies and, above all, based on their own development over time. For this reason, this section (see graphs on the right) compares the world's four largest economies – the USA, China, Japan and Germany – over time.

Regarding the overall indicator, it appears in a comparison of the four countries over the entire period, with the exception of 2013, that Germany achieves the greatest openness, followed by the USA. However, the USA have suffered a more pronounced decline in the years since 2014 and are thus lagging behind Germany, having reached almost constant levels since 2007. Japan currently ranks third in this index, but is operating at a similar level to China, falling behind China in the second half of the last decade. Bringing up the rear is China, which has trailed in recent years due to Japan's slight upward trend.

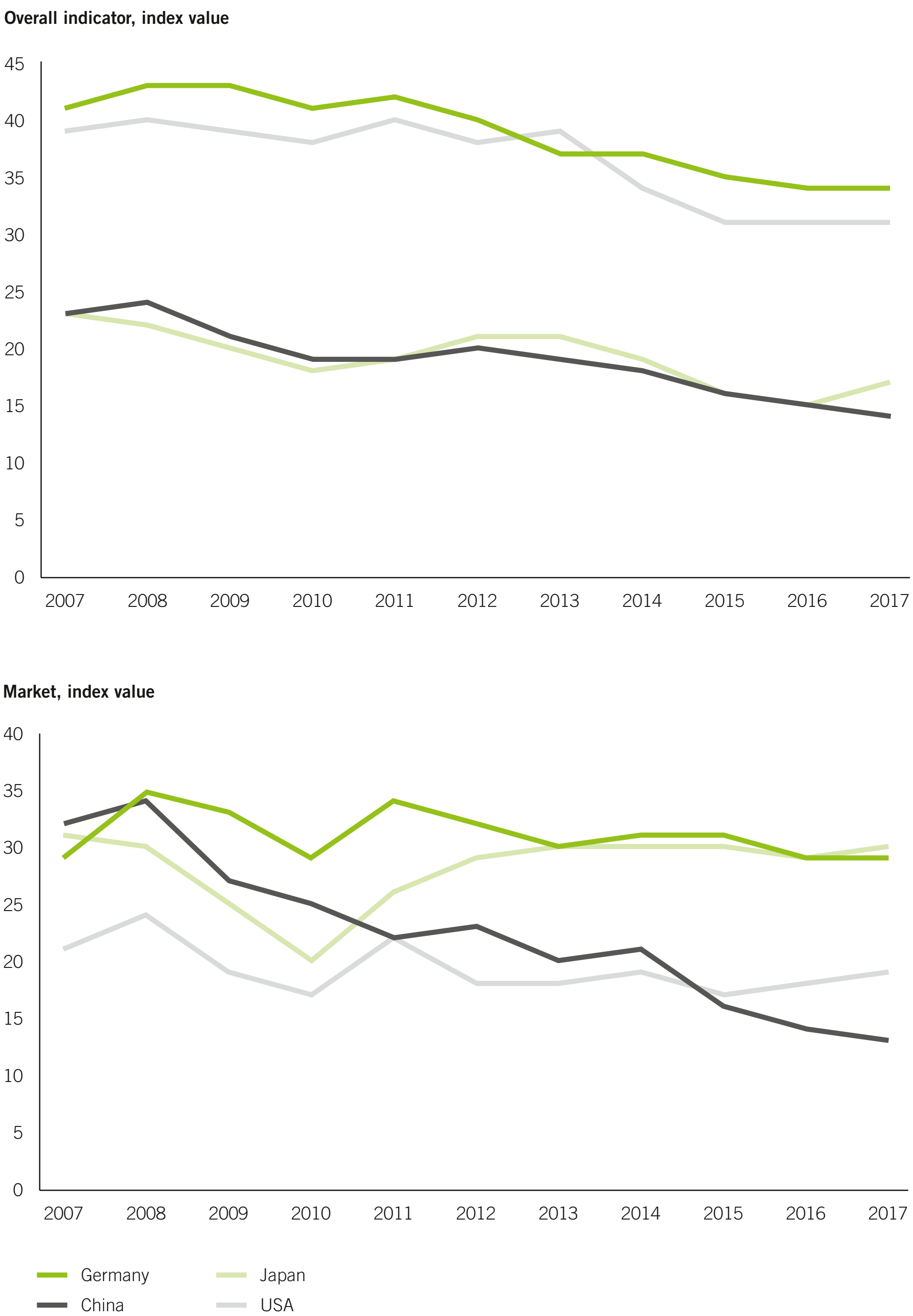
A comparison of the individual indicators shows that the four countries have very different strengths and weaknesses regarding the openness of their innovation systems. Germany and Japan, as well as partially also China, are clearly focused on international markets and the international exchange of goods and services. As an immigration country, the USA are very open to foreign knowledge and particularly to foreign labor. In addition, the USA regulate the market only to a rather limited extent, so that there is comparatively high investor protection and cross-border trade has so far been impeded only to a small extent. Migration and trade policy under President Trump will, however, have the greatest effect in the opposite direction, especially regarding the relative strengths of openness. Japan has a rather closed science and research system – it lies at the lower end of the scale over the entire analysis period. Societal attitudes and state regulation also do not promote the openness of the innovation system in Japan.

Chinese patent applications double every two years

The Chinese innovation system is a special case not only because of its size which has been reached now and the pronounced economic dynamism of the recent past. The differences in the political and economic systems are also noticeable. In addition, China's role in the region is particularly important for both scientific and economic development. For this reason, the following section deals separately with Chinese development and selected policy approaches. Since 2001, the Chinese innovation system has developed faster and more intensively than any other. An important aspect of this development was the opening respectively openness of the system. Foreign direct investment, joint ventures and intensive trade relations through the import of knowledge and goods had a decisive impact on economic development in the 2000s. They still play an important role in China's economic stability and progress today. The scientific exchange through joint publications, conferences and workshops as well as the dispatch of scientific personnel, for example to Germany, but also to other countries – above all to the USA – have quickly enabled China to catch up with the world leaders in some fields.

Since about the end of the last decade, numerous Chinese companies and research institutions have taken the lead nationally and, in some cases, internationally in a considerable number of areas – with government support, but especially in order to meet government expectations in the form of target figures. Since 2008, Chinese patent applications in China (to CNIPA, formerly SIPO) have predominantly been filed by Chinese patent applicants, and in recent years they have become the clearly dominant part. Before 2008, however, the number of filings by foreign companies prevailed. These have maintained and even slightly increased their patent application numbers at the high level of that time, while Chinese applicants

Development of the openness indicator and market openness for selected countries



doubled their applications about every two years. Correspondingly, the ratios have shifted significantly. However, patent applications from abroad continue to be a form of importing technological knowledge, which is also geared to the needs and development opportunities of the national market. Scientific co-publications or joint projects are also a form of knowledge import and in particular an important way of exchanging knowledge that offers both sides opportunities for development.

Cooperation on an equal footing

Joint scientific projects with China, for example, have been funded by the EU Commission in numerous cases under the Seventh Research Framework Programme. Independent financing on both sides is expected in the current Eighth Framework Programme (Horizon 2020). This not least accommodates the principle of equal treatment and "cooperation at eye level". Chinese actors must arrange their funding independently. The Chinese government has set up its own programs (matching funds) for this purpose. There are also joint science and research projects with Germany in various programs (such as "2+2") and projects with mutual funding. This not only ensures the "eye level", but also the active interest of the partners involved. This leads to research outputs of mutual benefit.

The development of the openness index shows declining values for China. The opening of the country in scientific, economic and also societal terms is decreasing over time – measured against the development in the benchmark countries. This is not a favorable development for a country like China that is geared to international markets and international exchange. It harbors the risk of reduced participation in knowledge sharing and in knowledge and competence networks, which could ultimately have an impact on value chains. In the case of China, the negative development of the overall index of openness is largely determined by those individual indicators that are normal-

China's economic development benefits from foreign direct investment, joint ventures and intensive trade relations.

ized to gross domestic product. These all point downwards – that is, GDP has grown faster than the opening to the outside world has widened. This applies, for example, to foreign investment or research and development financed from abroad. Here China had already reached quite high levels, which have recently fallen.

On the other hand, for many other indicators, China shows low values compared to the benchmark countries over the entire analysis period. This applies to migration as well as to the technological balance of payments or the share of open access publications. The proportion of international co-publications in China was already rather low, measured by the country's size and level of development. They are usually well below those of the other East Asian countries and have risen slightly in recent years over the longer term, but are currently stagnating. The USA, which in absolute terms have a comparable size of the science system in terms of publication output, are also well ahead of China in this regard. The index value measured here does not reflect the slight increase in the share of international co-publications, as China is well below the lower benchmark value. However, the slightly increasing shares cannot hide the fact that even in the science system openness is declining. For example, the travel regulations of the Communist Party[12] together with measures to combat corruption have led to a significant reduction in exchanges with foreign partners. Scientists have to reckon with sanctions and are now acting very cautiously. The regulations may be justified and may also reduce the negative excesses of the system. However, the positive effects are also reduced.

The indications of a further closing or isolation of the country can thus be seen across the entire range of indicators used here. At any rate, an increased opening cannot currently be reflected in the figures. What this means for the Chinese science and innovation system in the medium to longer term cannot be estimated at present. However, the comparison with Germany, for example, shows that the issue of openness must be actively addressed by governments and companies. Even then, changes are slow and modest.

"Made in China" à la Industrie 4.0

China should urgently initiate programs and measures to intensify international cooperation and exchange. Some of them already exist, such as participation in large-scale research infrastructures (ITER, CERN and others). However, these measures also include, for example, opening public procurement to foreign companies, as laid down in the WTO treaty, or further opening individual industries to foreign investment, as already announced.

The Chinese government under President Xi Jinping repeatedly stressed the openness and opening of the country. "The door is wide open and will continue to open" is a frequently used metaphor of the Chinese leadership. Xi's famous speech at the World Economic Forum in Davos in January 2017, in which he emphasized free world trade, underlines this, as does the repeal of the joint venture constraint in the automotive sector. Among the most important innovation policy strategies are "Made in China 2025" (MIC2025), which is based on the German Industrie 4.0 approach, or the Internet Plus strategy for far-reaching digitalization of numerous industries and the establishment of new business models. Cooperation between science and industry, but also with foreign countries, is always highlighted. These topics, especially Industrie 4.0, will not only bring cooperation and exchange to the fore, but also competition between innovation systems.

With its MIC2025 strategy, China plans to build up its own competencies in the core competence fields of German industry. Even more than with other issues, cooperation must take place to the advantage of both sides, otherwise one of the two cooperation partners will have no genuine and long-term interest in the cooperation. In this context, openness also means responding to the concerns and needs of the partner. The current reforms of the science system, such as the Chinese Academy of Sciences (CAS) with its "Innovation 2020" strategy or the announced reforms to increase the efficiency and quality of the output of the science system and state enterprises, can actually only succeed if there is an opening both inwards and outwards. Especially regarding effec-

Science and innovation in China are opening only on paper.

China sees the state as a strong player in the market also in the future.

tiveness and efficiency, open systems promise an advantage over closed systems, as has already been emphasized several times here.

The main policy objective in the field of industry, science and innovation is to transform China into an innovation-driven economy, as the country's leadership reiterated in May 2016.[13] Its implementation can only be successful through active cooperation with other economies. Accordingly, starting points in these strategies are also explicitly mentioned. However, the concrete measures have not yet been formulated and implemented in all areas. The opening of the market and the strengthening of market forces is repeatedly emphasized in many places, including within the main strategies MIC2025 or Internet Plus. Also, at the Party Congress in October 2017 or at the People's Congress in March 2018, those responsible emphasized this again and again. However, one thing should be clear to Western government and business representatives: with its reference to a stronger role for the market, the Chinese government does not mean market liberalization in the capitalist market economy sense, but also in future sees the state as a strong player in the markets.

The paradigm of a closed innovation system based on research and development, which was still the fundamental basis in the vast majority of countries in the 1980s and 1990s, has changed significantly, at the latest since the beginning of the new millennium. In China's rapid catching-up process over the past decade, centering on technology has accelerated, if not even made possible, gaining on highly industrialized economies. However, to be able to live up to its claim of an innovation-driven economy, China must now join the ranks of other innovation nations and cannot ignore the global trends of knowledge and value creation networks.

Sources for openness indicators and attribution to the three sub-indicators

Description	Source	Science and Research	Market and Economy	State and Society
Share of international co-patents in all applications for transnational patents	EPO-PATSTAT	x		
Share of international co-publications in all scientific and technical articles	Clarivate – WoS	x		
Share of foreign students in all students	OECD – EAC	x		
Total R&D expenditure (GERD) financed from abroad (% of GDP)	OECD/MSTI	x		
R&D carried out by branches abroad (% of GDP)	OECD/MSTI	x		
Technological balance of payments (% of total R&D expenditure)	OECD/MSTI	x		
Proportion of open access publications in all publications of a country	Elsevier – Scopus	x		
Labor market participation of foreign-born persons	OECD		x	
Import ratio (goods and services)	World Bank		x	
Attractiveness for foreign talent, 2012–2016	WEF		x	
Payments to foreign countries for intellectual property (% of GDP)	World Bank		x	
Income from abroad for intellectual property (% of GDP)	World Bank		x	
Net revenue from abroad (% of GDP)	World Bank		x	
Share of international PCT patent applications in all national patent applications of a country	EPO-PATSTAT		x	
Stock of foreign investments (% of GDP)	World Bank		x	
Index: "Do not want to have as a neighbor..." (people of other races, immigrants/ guest workers, homosexuals, people of other religions)	World Value Survey			x
Cross-border trade	World Bank			x
Strength of investor protection	World Bank			x
Index on migration policy	IMPIC			x
Labor migration policy index	IMPIC			x
Index of the strength of intellectual property protection (Ginarte Park)	Park[14]			x
Population of migrants (% of population)	World Bank			x
Taxes on international trade (% of profit)	World Bank			x

Deeds must follow words

On the occasion of the German-Chinese government consultations in the summer of 2018, in which both the mutual opening as well as the cooperation between science and industry at the highest political level were the topics discussed, Stefan Mair, member of the Executive Board of the Federation of German Industries (BDI), stressed: "China has moved, but must not freeze again. Words must be followed by deeds. Only through major reforms and a genuine opening will Beijing set up its own economy to be compatible with market- and rule-based systems."[15] If China wants to be accepted permanently as a market economy and as an equal partner, adaptations to global changes, including in the exchange of knowledge and ideas are essential. It is very unlikely that economies that are closed off will be able to meet the requirements of an innovation-driven economy in future – not even China, even if it were to find a "Chinese way". An opening and open processes, however, do not arise automatically. They must be actively pursued. The Chinese government would be well advised to use its policies to increase networking and enable as unhindered a flow of knowledge as possible – just like the governments in all other innovation-based economies, above all Japan, but also Germany or the USA. As with companies on a small scale, open innovations – both outside-in and inside-out – are essential for success in economies as a whole. Both the absorption of new ideas and new knowledge and the transfer to third parties – and thus often a better, faster and more comprehensive exploitation – are key factors for the realization of an open innovation system. According to the analyses presented here, open markets are even more important for the performance of innovation systems than open science systems.

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Project partners

Federation of German Industries
The BDI is the umbrella organization in the field of industrial enterprises and industry-related service providers. As representative of the interests of industry, the BDI contributes to the opinion-forming and decision-making of its members. It provides information on all areas of economic policy. The BDI thus supports enterprises in the fierce competition that comes with globalization.

www.bdi.eu

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Notes

Notes

On the German-language website of the Innovation Indicator you will find a detailed methodological report as well as further background material. You can also compare individual economies using "My indicator". The website can be used with all end devices from desktop PCs to smartphones.

www.innovationsindikator.de

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