SEAN GALLUP/GETTY

GERMANY'S SECRET TO SCIENTIFIC EXCELLENCE

With a national election this month, Germany proves that foresight and stability can power research.

BY ALISON ABBOTT

Ask any German researcher why the country's science base is blooming, and they are bound to mention Chancellor Angela Merkel. The world's most powerful woman, they say, has not forgotten her roots as an East German physicist.

During a decade of global financial turbulence, her government has increased annual science budgets in a stable, predictable, quintessentially German way. It has spurred competition among universities and improved collaboration with the country's unique publicly funded research institutions. Under Merkel's watch, Germany has maintained its position as a world leader in areas such as renewable energy and climate; and with the guarantee of strong support for basic research, its impact in other sectors has grown.

Foreign researchers are increasingly choosing to make their careers in Germany rather than opting for traditional brain magnets such as the United States or the United Kingdom. With its safe-but-dull reputation, Germany is starting to look like the tortoise to their hare. And as the country prepares for a national election on 24 September, most onlookers expect the trends to continue.

Under the watch of Angela Merkel, Germany has invested heavily in energy innovation.

The reasons behind Germany's success go beyond science budgets or some sort of 'Merkel effect', says Wolfgang Schön, a director of the Max Planck Institute for Tax Law and Public Finance in Munich and vice-president of the DFG, Germany's main university-research funding

agency. Like Merkel, the country has deep science roots, he says.

Germany was a world leader in science and technology before the turbulence of the twentieth century; it established traditions that many countries still follow. Although it struggles with the remnants of male-dominated hierarchies and pervasive, inflexible regulations, German research is looking as strong as ever, particularly on a global stage that seems increasingly indifferent to science. "I'd love it if our science-policy and budget decision-makers in the US were willing to take lessons from Germany again today," says Kenneth Prewitt, a political scientist at Columbia University in New York City.

The structure of modern German science rests on concepts developed two centuries ago by Wilhelm von Humboldt, a Prussian educator who pioneered ideas that continue to hold sway around the world. It was he, for example, who suggested that university professors should do front-line research as well as teaching.

His philosophy that education should be both broad and deep, and that academic life should be free from politics and religion, remains engraved in the German psyche. "The Humboldtian system is in our DNA," says Thorsten Wilhelmy, general secretary of the Berlin Institute for Advanced Study. "That's why politicians are not so tempted to cut basic research when times get tough." (See 'Build, link and trust'.)

These ideals have weathered dramatic political upheaval. Adolf Hitler's Third Reich perverted science and led to the country's devastation in the Second World War. In 1949, Germany was refounded as two countries, which rebuilt their scientific strengths under opposing political systems.

West Germany's democratic constitution, which remains in force, declared: "Arts and sciences, research and teaching shall be free." To ensure that centralization and abuse of power could never happen again, it created a highly federalized country in which responsibility for culture, science and education lies with the *Länder*, or states — a feature that was to have negative as well as positive effects on university development.

By contrast, the communist German Democratic Republic (DDR) centralized research and kept it under tight control. Scientists were isolated from their colleagues in the West and their system became impoverished as the DDR's economy gradually failed.

Merkel grew up in this system, graduating from the Karl Marx University in Leipzig in 1978 with a degree in physics and then moving to the Central Institute for Physical Chemistry in Berlin, one of the most prestigious research centres in the DDR. There, she met her second husband, quantum chemist Joachim Sauer, and earned her PhD with honours. Her zeal for physics did not extend to the required political education. In the DDR, no one got their PhD without an accompanying certificate in the study of Marxism–Leninism; Merkel's dissertation for that subject, 'What is the socialist lifestyle?', was accepted with the lowest passing grade.

When the two Germanys were unified in 1990, special committees from the West evaluated the DDR scientists for competence. Many lost their jobs, but Sauer was accepted for transfer to Berlin's Humboldt University. Merkel, who had not been overtly political before, jumped into democratic politics and soon joined the centre-right Christian Democratic Union (CDU). Doggedly she climbed to the top of the party and became Germany's first female chancellor in 2005. She won federal elections in 2009 and 2013 and looks set to maintain her position. (In Germany, there is no time limit on serving as head of government.) In March, she opined: "I came from basic research myself and have always said, you can't predict things there — you just have to leave space."

STABLE SUPPORT

German publicly funded science is organized into five pillars: the universities and its four unique research organizations, each named after a scientific giant in German history.

The Max Planck Society, founded in 1948, now runs 81 basic-research institutes whose directors are given extraordinary budgets and free rein to tread their own paths. A director in life sciences typically gets a basic package of €2 million (US$2.4 million) a year to run their research programme, not including major equipment purchases. The Fraunhofer Society was founded a year later and is dedicated to applied research. It is named ▶

COMMENT

Build, link and trust

Staying strong will require huge investment and more international cooperation, says **Wilhelm Krull**.

COURTESY OF VOLKSWAGEN STIFTUNG

The German higher-education and research system seems to be in good shape. The country is near the top of global league tables in terms of output, publication quality, and numbers of students and faculty members from abroad (see 'Germany by the numbers'). So why worry about the future? My reasons for concern relate to the political conditions under which universities and research organizations will have to operate in the 2020s. And, from my experience as director of Germany's largest private funder of basic research, I feel that it is essential to establish more sustainable, long-term alliances with leading research institutions in other countries — in particular with universities from the Southern Hemisphere.

In 2020, a policy called *Schuldenbremse* or 'debt brake' is set to roll out in most German states. Agreed by the federal government and the 16 state governments in 2009, this will put a strict upper limit on budget deficits and prevent them from making new debts, especially at the state level. If implemented as planned, universities will struggle to maintain or refurbish their infrastructure, let alone acquire new buildings or facilities. Current estimates are that some €35 billion (US$41.2 billion) is needed until 2025 just to keep existing lecture halls and laboratories fit for purpose. Meeting these challenges will require the next federal government to make a strong financial commitment to the university sector.

Policymakers at every level must widen their objectives considerably in terms of what a resilient higher-education and research system should achieve. This was discussed earlier this year by the Hightech Forum, a government advisory body on which I sit. Two actions are urgent: to speed up the process of digitization in every domain of education; and to provide the research base to advance the wider use of artificial intelligence. The next government must also build on the considerable progress made in internationalizing the student and research communities. Germany will need to expand its foreign policies to integrate transnational innovation policies, including conceptual inputs to the European Union's next Framework programme.

Ultimately, the goal of all higher-education and research management must be to open up time and space for critical as well as creative thinking, to stimulate bold ideas and to aid movement beyond incremental achievements towards radical innovations. Policymakers, politicians, presidents, rectors and researchers must work together towards the high-trust culture of creativity that Germany and others are trying to achieve. ■

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COMMENT

Get behind electric cars

Cheap and easy charging, and ready access to low-carbon power, are the way forward, says **Irene Feige**.

For Germany to retain its lead in climate policy and automotive technology, it must drive the switch to electric cars with coherent policies and investments in clean energy and infrastructure.

In 2016, cars accounted for 13% of the nation's total carbon dioxide emissions. Yet the car industry generates 14% of Germany's gross domestic product and is home to one-quarter of its research-and-development posts. The new government must align two major goals. The first is to cut CO_2 emissions by at least 80% of 1990 levels by 2050. The second is to maintain dominance as a producer of premium cars. Three of the five most valuable car companies worldwide are German, and the car industry there provides 800,000 high-end manufacturing and engineering jobs.

Cars account for almost three-quarters of the kilometres that people travel in Germany. But although registrations for electric cars this July were up by 131.8% on last year's, only 0.06% of the nation's cars run solely on electricity. So now what?

First, electric vehicles need access to low-carbon power (see page 26). Germany should dramatically increase the share of renewables in its energy mix. Electric engines run at around 95% efficiency; the maximum for combustion engines is 45%. Their CO_2 emissions are 20–50% lower than those of diesel cars, even if the energy mix is relatively carbon-intensive, as in Germany. Low or even carbon-neutral energy could reduce emissions by 80–100%. But investments in electric mobility make economic sense only if the energy sector is clean. Why? Because cutting one tonne of CO_2 by switching to electric cars costs 100 times more than doing so by changing agriculture practices and 10 times more than by installing wind power.

Second, electric vehicles must become cheaper and easier to charge. Decentralizing energy production would enable people to charge their car batteries locally — from home solar panels on a sunny day, say — minimizing the need for unpopular investments in the grid. Several major car manufacturers have formed a joint venture to deploy thousands of charging points along main travel routes in Europe. But cities need these charging stations too: in car parks, for example. If it is faster, cheaper and more convenient to use an electric car, people will pay slightly more for one. Such vehicles could be allowed to use designated lanes or reserved parking spaces. Governments could subsidize them for the next decade so that they cost the same as conventional vehicles. ■

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after the Bavarian physicist Joseph von Fraunhofer (1787–1826), a pioneer of precision optics. National research centres, which carry out large-scale strategic research according to government priorities, are now bundled within the Helmholtz Association, named after pioneering physiologist and physicist Hermann von Helmholtz (1821–94). A collection of other scientific institutes and facilities has been bundled into an association named after polymath Gottfried Wilhelm Leibniz (1646–1716).

In a deal that goes back to 1949, the federal government shares the costs of the research organizations with the *Länder*. But in general, the *Länder* have to finance the universities on their own. There are around 110 of these, and 230 *Fachhochschulen*, universities of applied sciences that can't offer PhDs but train the work force for industry.

"The clarity and transparency of this structure appeals to the German order-loving mentality," says Ferdi Schüth, a director at the Max Planck Institute for Coal Research in Mülheim. "It makes the system easier for outsiders, including politicians, to understand."

Support for research quickly built up during the years of West Germany's *Wirtschaftswunder*, or post-war economic miracle. Although the reunification of Germany exacted a heavy cost on the country, politicians have in most years maintained steady and strong support for science. Until 2015, the government increased support for all research organizations and the DFG by 5% per year; that annual increase has dropped in the current 'Pact for Research and Innovation' between the federal government and *Länder*, which runs until 2020, but remains enviable at 3%.

"This security about future funding allows us to really plan our research strategies in the long term," says chemist Martin Stratmann, president of the Max Planck Society. "It's a big advantage that few other countries share."

THOMAS STRAUB

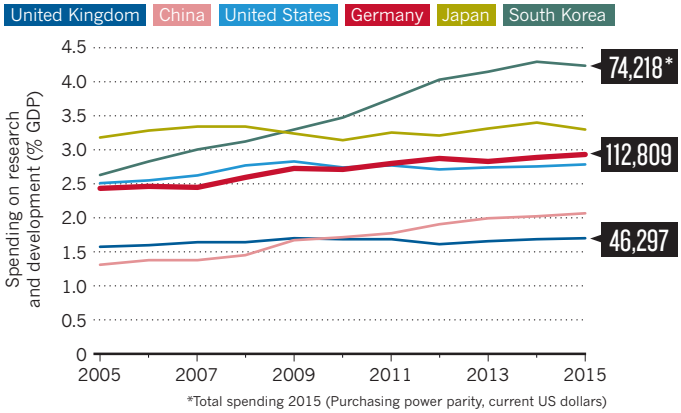
FUNDING FLOW

It was confidence in long-term funding that kept immunologist Dolores Schendel from returning to her native United States after what was meant to be a two-year postdoc placement at the Ludwig Maximilian University (LMU) in Munich in the late 1970s. She had intended only to help establish a mouse lab for the LMU's bone-marrow-transplant programme. But the facilities were seductive, and as her research became increasingly translational — and no longer lent itself to a regular flow of high-profile papers — she knew she could rely on secure local funding. She later moved to the Helmholtz Centre Munich to scale up her work. Then, when a start-up she had founded was bought out, she became chief executive and chief scientific officer of Medigene, an immunotherapy company in Munich. Now she is running clinical trials of candidate cancer vaccines. "I'm not sure I could have achieved this in the United States,

GERMANY BY THE NUMBERS

SPENDING German investments in research and development have risen steadily, relative to gross domestic product (GDP). The country spends less in absolute terms than the United States, Japan and China, but more than other powerhouses.

SOURCE: OECD



*Total spending 2015 (Purchasing power parity, current US dollars)

where funding tends to be more erratic," she says.

But Schendel is a rare case. Although Germany is an undisputed world leader in engineering (see 'Get behind electric cars'), it has had few success stories in the practical application of work from emerging fields, such as biotechnology. Decisions and changes happen slowly, thanks to the layers of bureaucracy between the federal and *Länder* governments. What's more, the abuse of science under the Third Reich, including eugenics and human experimentation, left Germans suspicious of genetics in any form and prone to moral outrage. All this has led to sluggish development on some fronts.

The disruption of reunification in 1990 forced the country to fix some systemic problems, such as a lack of collaboration across institutions. Politicians set about chipping away at the numerous obstacles to cooperation.

"I'M NOT SURE I COULD HAVE ACHIEVED THIS IN THE UNITED STATES."

In 1999, the federal government that preceded Merkel's — a coalition between the Social Democratic Party and the Greens — amended a law that required *Länder* ministries to make all university decisions, from allocating budgets to making academic appointments. One by one, the *Länder* began allowing universities to run their own affairs.

The same government proposed a major shake up for universities, which had traditionally been considered all of equal status. As one of its last acts, it launched the 'Excellence Initiative' in 2005. Now well established, this encourages universities to compete for federal money to promote top-level research, graduate schools and, most importantly, 'clusters of excellence' — major collaborations with scientists in other research organizations. Universities that win in all categories also earn the title of 'elite', which comes with extra cash.

When Merkel became chancellor later that year, she appointed as education and research minister her like-minded colleague and friend Annette Schavan, who drove the Excellence Initiative through a series of rounds that fundamentally changed German universities. So far, the federal government has poured €4.6 billion into the scheme and a total of 14 universities have won elite status in various rounds. Those that have not yet earned that title have upped their game by trying for it, and by collaborating within clusters, which have opened up other streams of funding. The once-isolated pillars of German science are now working together.

Merkel and Schavan have championed laws that allow the federal government to fund university research directly and allow universities to offer high salaries to attract or keep the best scientists (as civil servants, German academics generally earn less than scientists in other countries or those in industry).

As a result of all these changes, German universities have climbed up the world rankings. In 2005, only 9 German universities appeared in the Times Higher Education top 200. Now, there are 22. The LMU, which tops the German list in most years and has won in each round of the Excellence Initiative, rose from 61st place in 2011 to 30th in 2017.

Physicist Axel Freimuth has been rector of the University of Cologne since 2005 and says the university has changed beyond recognition. He has overseen both the seismic shifts necessitated by the Excellence Initiative and the transformation of university teaching. Around the time he became rector, Germany began converting from its own idiosyncratic, drawn-out diploma system to the European standard of bachelor's and master's degrees, which process students more efficiently, in three to five years. With the arrival of university autonomy, Freimuth coordinated a new governance system for his institution. "We have learnt how to act strategically as a university," he says. "There is a whole new spirit here."

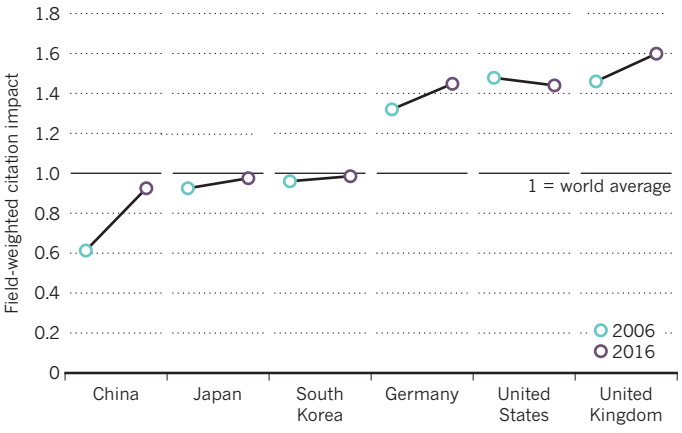
CLUSTER BUGS

In the meantime, research-cluster fever has taken over Germany. Schavan launched several initiatives to get scientists from different pillars to work together and with industry. Most strikingly, she created a network of national institutes of health under the umbrella of the Helmholtz Association, which bundles nationwide competencies across institutions in health areas such as neurodegeneration or metabolic disease.

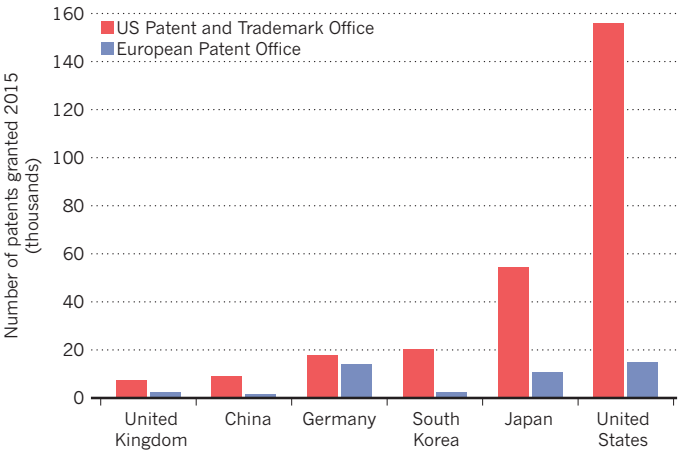
Berlin is experimenting with gathering together parts of its health-related research at the Charité teaching hospital and the Max Delbrück Centre for Molecular Medicine, a Helmholtz centre, into a translational-research structure called the Berlin Institute of Health. And the state of Baden-Württemberg has poured hundreds of millions of euros into the Cyber Valley initiative. Launched in December last year, this clusters all regional research in artificial intelligence and is heavily supported by big companies such as BMW, Daimler, Porsche, Bosch and Facebook.

"This clustering really does have a lot of advantages," says neuroscientist Hannah Monyer, who has joint positions at the University of Heidelberg and the German Centre for Cancer Research, a Helmholtz centre in the same city. Although it requires researchers to spend more time talking and organizing, she says, "it's the best thing we can do these days". A cluster ▶

PUBLISHING Enhanced competition among German universities and deeper collaborations across all research institutions have begun to show global effects in the impact of German research. Papers from the country receive 45% more citations than would be expected on average according to one standard metric.



PATENTS Germany especially shines in industrial research. It received 20% of all patents issued by the European Patent Office in 2015, and the US Patent and Trademark Office gave it the fourth most of any country.



SOURCE: PUBLISHING, SCIVAL/SCOPUS; PATENTS, USPTO/EPO

COMMENT

Adapt to stay ahead

German science should invest in professorships and cut bureaucracy, says **Oliver G. Schmidt**.

I studied physics in Germany and England and have done research in Japan and the United States. I worked for ten years at a Max Planck institute and have spent another ten at a Leibniz institute. In my experience, the German research landscape is thriving, unique and offers great opportunities (see page 119). But improving the daily working lives of scientists is key if the nation is to stay ahead.

Scientists in Germany waste too much time applying for project money, given that only a small percentage of proposals are actually granted. Then there's the time spent on peer reviewing the exploding number of proposals and initiatives for excellence. All in all, scientists — hired to use their creative minds to come up with innovative ideas — lose thousands of hours in this way. Worse, big funding programmes and evaluation panels are in thrall to major research trends and shy away from radical approaches.

Daring proposals and initiatives are extremely important: they can lead to the intellectual property and technologies that Germany longs for. High-tech start-up firms have not made it into the list of Germany's top 100 companies for decades. What a difference compared with the United States, where young companies such as Alphabet (the parent company of Google) are dominant.

Every funder and institution wants to support promising young scientists, so time-limited programmes abound. But there are too few opportunities available to researchers after these. The best support for the best minds would be to create more professorships, with more resources — perhaps even by rebalancing some funds away from early-career research.

Administrative departments must serve academics, not the other way around. Bureaucracy, a typical German problem, has crept deep into the workings of research institutions. A time-recording scheme might make sense for someone in clerical work, but it doesn't help a scientist. And how can the country attract the best talent from around the world if proposals must be written in German, as several funding agencies demand?

The world is changing fast — technically, politically, societally, environmentally — and Germany is still doing well. But as manufacturing industries face radical changes and countries such as China continue to invest hugely in research and development, we too must adapt. ■

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set up under one of the rounds of the Excellence Initiative saved her enormous work when her research led her briefly into the unfamiliar area of pain mechanisms, she says. Rather than having to learn everything from scratch, she enjoyed a seamless collaboration with a local behavioural lab, which provided advice, equipment and technical support.

The mega-collaborations are still in a test phase. Vascular biologist Holger Gerhardt left a permanent post at the Crick Institute in London to join the Berlin Institute of Health initiative in 2014. "I know it is all one big experiment," he says. "But I feel I really might be able to build up something new here."

The improvements that researchers now enjoy are sometimes challenged by the German cultural desire for administrative and moral order. Gerhardt says he often finds himself reminding cluster partners not to create unnecessary organizational structures. Primate research, although permitted, is very difficult to do. And use of human embryonic stem cells, aside from a few older cell lines, is forbidden — Merkel remains unshakeable on this point.

Germans' moral outrage can also be brutally swift. Merkel made a rare blunder in 2011, when she supported defence minister Karl-Theodor zu Guttenberg after he was proved to have plagiarized his PhD thesis. Merkel immediately argued that such accusations shouldn't matter to his current job; he was not acting as a scientific assistant. But within two weeks, he was forced to resign. Many prominent politicians in Germany have PhDs, and the affair unleashed a crusade to check each of them. Schavan herself faced accusations over her 1980 thesis. Although many scientists did not consider what she did to be plagiarism, she nevertheless had to resign in 2013.

COURTESY OF OLIVER G. SCHMIDT

Overall, however, the numbers tell a positive story for science (see 'Germany by the numbers'). The proportion of foreign academics in Germany's universities has jumped from 9.3% in 2005 to 12.9% in 2015. Germany now ranks above the United States for the percentage of papers it publishes among the top 10% most highly cited.

But German science still has some catching up to do, particularly in university infrastructure (see 'Adapt to stay ahead'). Compared with the pristine modernity of non-university research institutes, university facilities look positively shabby. The *Länder* have to bear the costs of increasing numbers of students — who attend for free — and cannot keep up with building repairs. The crumbling concrete of science labs and lecture theatres that shot up when the universities expanded in the 1960s and 1970s is embarrassing, says Wilhelm Krull, general secretary of the Volkswagen Foundation in Hanover, Germany's largest private research funder: "There is a contrast of *Glanz und Elend* — splendour and misery."

Few scientists in Germany see the country leaping back to the very top of the scientific world. For one thing, the German language can be off-putting — even though English is generally spoken in the country's labs these days. The regulations and need for form-filling frustrate many. And, says Krull, "Germany is still somewhat risk-averse. Radical, disruptive innovation is less common here."

What's more, the country has much to do to improve the representation of women in research. At research institutions, the proportion of women in top scientific positions has risen from a dismal 4.8% in 2005 to a still-meagre 13.7% in 2016. At universities, the share of women holding top-level academic positions has gone from 10% in 2005 to 17.9% in 2014. That still falls well below the average for the European Union. And things hardly look better in industry; Schendel is one of only 3 female board members out of 160 at the country's top 30 technology companies.

But scientists are generally confident that things will continue to improve steadily. Merkel's election platform pledges to continue supporting research and innovation, and to raise annual budget increases to 4%. Each day when not travelling, the chancellor goes home to her flat near the Humboldt University to spend what is left of the evening with her chemist husband. Schüth says that it simply comes down to her roots. "She knows what it is to be a scientist, the value of research," he says. "That tone trickles down from the top." ■ SEE EDITORIAL P.5

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