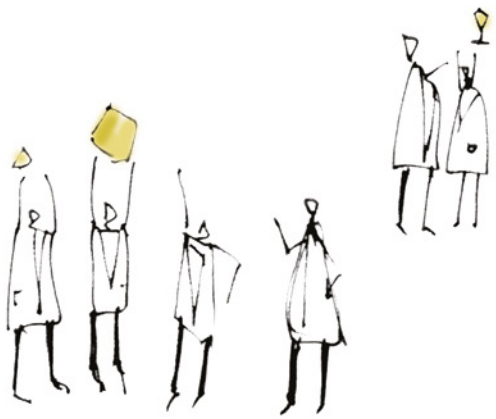
The Trump administration is considering measures to prevent Chinese citizens from being involved in sensitive research at American universities. **Alessandro Iaria**, **Carlo Schwarz** and **Fabian Waldinger** look back at history to reveal the potential damage that such policies might cause to scientific progress and technological innovation.



Threats to scientific progress, past and present

The Trump administration is considering measures to restrict Chinese citizens from performing sensitive research at American universities and research institutions. The boycott appears to be motivated by fears that Chinese researchers may be carrying out espionage activities and handing over sensitive US discoveries to the Chinese government.

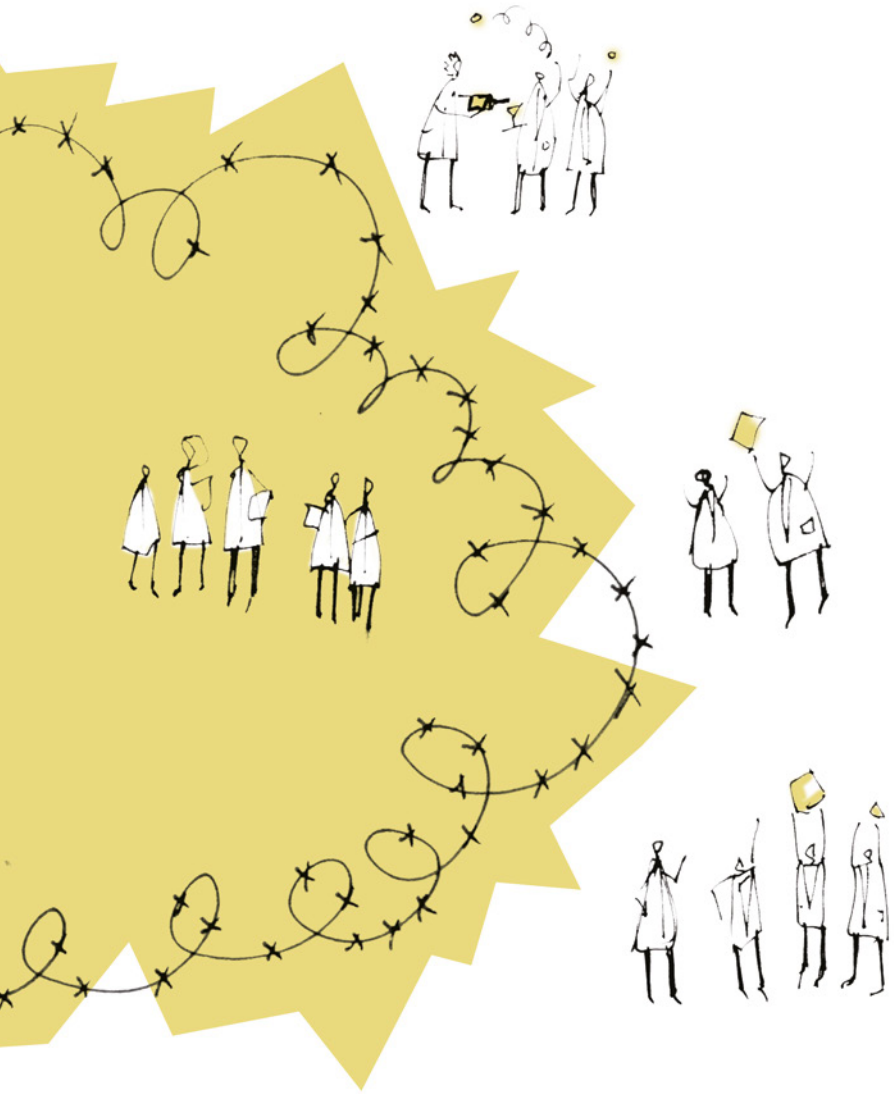
The exact details of the restrictions are still under discussion but they would probably affect graduate students, postdoctoral researchers and employees of high-tech companies in the United States on temporary visas. Roughly 300,000 researchers every year could fall victim to these measures.

While the overall effects of such a boycott are hard to foresee, there are lessons from history that can inform policy-makers about the possible detrimental long-run effects for scientific progress and technological innovation. In a recent study, we explore the repercussions of a boycott against scientists that arose as a result of the First World War.

> A US boycott of Chinese researchers could stifle scientific progress and technological innovation

As that conflict began, the world split into the Allied camp (the UK, France, later the United States and several smaller countries) and the Central camp (Germany, Austria-Hungary, the Ottoman Empire and Bulgaria). The involvement of scientists in the development of chemical weapons, and the extremely nationalistic stance taken by many in support of their homeland pitted the opposing scientific camps against each other.

Immediately after the end of the war, Allied scientists enforced a boycott against Central scientists, which separated scientists from opposing camps until the mid-1920s. Our study finds that the increased barriers to international scientific



Barriers to international scientific co-operation slow down the production of basic science and its application in new technologies

co-operation during the boycott led to a decline in the number of papers published by scientists on either side.

Those scientists who had relied on 'frontier research' from abroad – for example, US biochemists who relied on frontier research from Germany – published fewer papers than scientists who used to work with frontier research from home, such as US biologists who mostly relied on frontier research from within their own country. As a result, the productivity of US biochemists declined by 33% relative to US biologists. Importantly, the boycott did not only affect Central scientists but the entire international scientific community.

Affected scientists also produced fewer scientific breakthroughs, measured by the introduction of novel words in paper titles and by nominations for a Nobel prize, and fewer of their scientific discoveries found application in patents. These results show that barriers to international scientific co-operation not only slow down the production of basic science, but that they also harm the application of science in the development of new technologies.

The importance of frontier knowledge for the generation of ideas

The creation of ideas is crucial for scientific progress, technological innovation and economic development. One of the major inputs in the creation of new ideas is existing knowledge, something described most famously by Isaac Newton in his 1675 letter to Robert Hooke, where he wrote: 'If I have seen further, it is by standing on the shoulders of giants.'

This quotation not only emphasises that scientists build on existing knowledge to produce new ideas, but also that knowledge produced by scientific 'giants' – that is, frontier research – is particularly important. Access to existing knowledge not only fuels basic scientific progress, but it is also key for the development of new technologies.

Scientific articles that cite frontier research are more likely to become a 'hit' – that is, to end up in the top 1% of the long-run citation distribution. But while citing the research frontier is correlated with writing hit papers, it is not clear whether access to the research frontier has a causal effect on the production of high-quality ideas.

The correlation could be motivated by networks of highly productive scientists, who mostly cite each other's research, such as the physicists who advanced the quantum revolution in the 1920s and 1930s. Because of this and other endogeneity concerns, researchers have not been able to isolate empirically the causal effect of frontier knowledge on the creation of ideas.

To overcome these challenges, we study the dramatic decline in international scientific cooperation that occurred during the First World War and the early post-war years. Allied scientists were suddenly cut off from their peers in Central countries, in particular from Germany, a country whose scientists had received more than 40% of Nobel prizes in physics and chemistry in the pre-war period. Similarly, Central scientists were cut off from their peers in Allied countries; in particular from the UK

(20% of Nobel prizes), France (15% of Nobel prizes) and the United States, the rising scientific superpower.

This schism in the scientific world persisted during the post-war years because Allied scientists organised a boycott against Central scientists to punish them for their involvement in the war effort. The boycott was strongest in the first years after the war and lasted until 1926. We document that the delivery of international journals was severely delayed, and that international conferences were cancelled or only involved scientists from one of the warring camps (see Box 1).

Measuring the interruption of international knowledge flows

We show that the First World War and the ensuing boycott against Central scientists severely interrupted international scientific cooperation. After the conflict began, papers cited relatively less research from outside the camp, compared with

Between 1914 and 1926, Allied scientists were cut off from their peers in Central countries – with damaging consequences for world science

Box 1: Central scientists at the Solvay Conferences in Physics

A. 1911

B. 1913

C. 1921

D. 1924

E. 1927

F. 1930

These are historical pictures of delegates at the Solvay Conferences in Physics. Circles indicate delegates from Central countries. The first Solvay Conference was organised in 1911 and was attended by the leading physicists of the time, including Marie Curie, Ernest Rutherford, Max Planck, and Albert Einstein. In that year, nine of the 24 participants came from Central countries. In 1913, nine of the 31 participants came from Central countries.

During the war, the Solvay Conferences were discontinued. The first post-war conference took place in 1921. Scientists from Central countries were not invited. Nor were they invited to the 1924 conference.

By 1927, the boycott had ended and five of the 30 participants came from Central countries. The 1927 conference is possibly the most famous scientific conference ever organised. It took place at the height of the quantum revolution, and 17 of the 30 participants were current or future Nobel Laureates. In 1930, six of the 36 participants came from Central countries.

research from home. Similarly, papers cited less research from foreign countries inside the camp, but this decline was markedly smaller. Importantly, the decline in international citations did not only affect average quality research but also research at the scientific frontier.

We also investigate whether the collapse in international scientific cooperation affected the direction of research in the opposing scientific camps. Using the machine-learning technique known as Latent Semantic Analysis, we document that the similarity to papers from outside the camp fell sharply after the onset of the First World War and then slowly recovered during the 1920s.

Effects on scientific production and technological applications

In the second part of our study, we show that reduced international scientific cooperation led to a decline in the production of basic science and its application in new technology.

We compare productivity changes for scientists who, in the pre-war period, relied on frontier research from abroad, to changes for scientists who relied on frontier research from home. After 1914, scientists who relied on frontier research from abroad, and who were now suddenly cut off from it, published fewer papers in top scientific journals.

The interruption of international knowledge flows led to stark declines in the production of research deemed worthy of a Nobel prize nomination. Furthermore, scientists introduced fewer novel scientific concepts, as measured by the introduction of novel scientific words – for example, magnetron and electroencephalogram.

Scientific fields that were suddenly cut off from the research frontier produced fewer scientific concepts that were used in patents. Thus reductions in the output of basic science also had a negative effect on the development of new technologies.

Implications for science and innovation policy

These results show that access to frontier research is key for the production of ideas, including pathbreaking ones. Facilitating access to frontier research can therefore substantially increase the production of basic science.

The interruption of international knowledge flows led to stark declines in the production of research deemed worthy of a Nobel prize nomination

Access to the knowledge frontier needs to be interpreted in a broad sense: not only physical access to journal articles, conferences and research seminars; but also discerning the thin, ever-advancing and truly pathbreaking edge of the frontier from the millions of scientific papers published every year.

Science policy should be geared towards the facilitation of access and capitalising on the potential catalytic effects of frontier research in enhancing scientific progress. Providing open access to journals may partly achieve this goal. But discerning what constitutes frontier research requires skills that are hard to develop without guidance from leading scientists working at the forefront of scientific endeavour.

Personal contacts are particularly useful because face-to-face interactions are a superior way of transmitting ideas. High-quality doctoral programmes at universities where frontier research proliferates can therefore help to put young scientists on the most promising career paths. Even more established scientists can profit from short- and long-term visits at centres of science, and from attending high-quality conferences and research seminars.

Finally, our results show that access to frontier research not only affects the production of basic science, but that it also increases the application of science in the development of new technology. Policies that widen access to frontier research could therefore benefit society beyond the confines of science itself.

This article summarises 'Frontier Knowledge and Scientific Production: Evidence from the Collapse of International Science' by Alessandro Iaria, Carlo Schwarz and Fabian Waldinger, *Quarterly Journal of Economics* 133(2): 927-91 (earlier version available as CEP Discussion Paper No. 1506: http://cep.lse.ac.uk/pubs/download/dp1506.pdf).

Alessandro Iaria is at the University of Bristol. **Carlo Schwarz** is at the University of Warwick. **Fabian Waldinger** of LSE's department of management is a research associate in CEP's labour markets programme.

Policies that widen access to frontier research could benefit society beyond the confines of science itself