



SCIENCE ON THE MOVE

The big picture of global migration shows that scientists usually follow the research money — but culture can skew this pattern.

BY RICHARD VAN NOORDEN

Husband-and-wife neuroscientists Yuh Nung Jan and Lily Jan have run their laboratory at the University of California, San Francisco, for more than three decades: time enough to see the geography of the science world change. When the Jans started hiring employees in the 1980s, they chose home-born scientists. Nine of their first eleven employees were American.

But Yuh Nung and Lily — who themselves arrived in the United States from Taiwan in the 1960s — have increasingly drawn on talent from overseas. Today, researchers originally from China dominate the bench tops, with the lab hosting 16 Chinese scientists, 12 Americans, 2 Koreans and 1 researcher each from Canada, India, Singapore, Taiwan, Turkey and Germany.

The Jans' story is not unusual. "There is a progressively wider geographical variety of graduate students and postdocs in most leading universities," Yuh Nung says. During the 1970s, for example, non-citizens claimed around one-quarter of the doctorates awarded in the United States in physical sciences, engineering, mathematics and computer science; but by 2010, their share had risen to more than half, according to the US National Science Foundation. In life sciences, the foreign share has risen from just under 20% to 30%. The United Kingdom, Germany and Australia have seen similar trends.

By sifting through data, talking to experts and conducting our own survey of 2,300 readers around the world, *Nature* sought to identify underlying trends in scientists' movements, investigate what is driving them and explore how they may change. At stake is the shape of global science and the prospects for individual countries that hope to build up — or preserve — their research strength.

It is plausible — although hard to prove — that highly productive research systems such as those in the United States and the United Kingdom have benefited from their openness to foreign scientists. To the Jans (who together won this year's US\$500,000 Gruber prize for their discoveries in molecular neurobiology), the advantages are obvious. They believe that foreign researchers enrich the lab culturally as well as scientifically. Being able to draw on a global talent pool may also help to make up for weaknesses in the US science-education system.

But some countries worry that they are losing their top researchers. Of the world's most highly cited scientists from 1981 to 2003, one in eight were born in developing countries, but 80% of those had since moved to developed countries (mostly the United States), according to a 2010 study by Bruce Weinberg at Ohio State University in Columbus. India, for example, loses out, says Binod Khadria, an economist who studies international mobility at Jawaharlal Nehru University in New Delhi. "The best and brightest are kept in other countries."

All this underscores that science, which has always been a global

culture, is now a global marketplace, and one in which countries with well-funded and dynamic research systems come out on top. "Knowledge generation and research is really a borderless enterprise," says Rajika Bhandari, who studies the mobility of international students at the Institute for International Education in New York. "Academics go where the funding is and where the facilities are."

COMINGS AND GOINGS

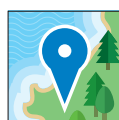
Yet the global picture of these migrations is blurry. When tracking arrivals and departures, most countries lump scientists with other 'highly skilled migrants', and record-keeping differs from country to country. "What's very frustrating is that there is no consistent tracking of people using the same methodology across countries," says Paula Stephan, who researches economics and science at Georgia State University in Atlanta. "We have lots of little studies on particular groups of scientists, but no world bank of data."

Talk of 'migration' and 'mobility' often confuses permanent long-term relocations with the short-term visits — six-month sabbaticals or fortnight-long trips — that allow scientists to build research networks without actually settling in another country. "There are so many kinds of mobilities, and people rarely specify this," says Grit Laudel, a sociologist at the University of Twente in Enschede, the Netherlands.

Stephan is part of one attempt to cut through this confusion: the 'GlobSci' survey, to be published in *Nature Biotechnology* in December. The authors asked around 17,000 researchers in four fields (biology, chemistry, Earth and environmental sciences and materials) in 16 countries about their movements; the result was what they call "the first systematic study of the mobility of scientists in a large number of countries".

The numbers show big disparities from country to country, both in the proportion of scientists with foreign origins (see 'Foreign fractions') and in the proportion of researchers who work outside their countries of origin (see 'The global diaspora'). The United States is indeed open: of the respondents working or studying there when the survey was done in early 2011, 38% were brought up overseas, and it is the number-one destination for expatriate scientists from almost every nation. Proportionally, however, Switzerland, Canada and Australia all housed more foreign researchers than the United States, with Switzerland having the highest foreign share, at 57%. India had the lowest proportion of foreign scientists, followed by Italy and Japan, but also the largest diaspora, with 40% of its home-born researchers working

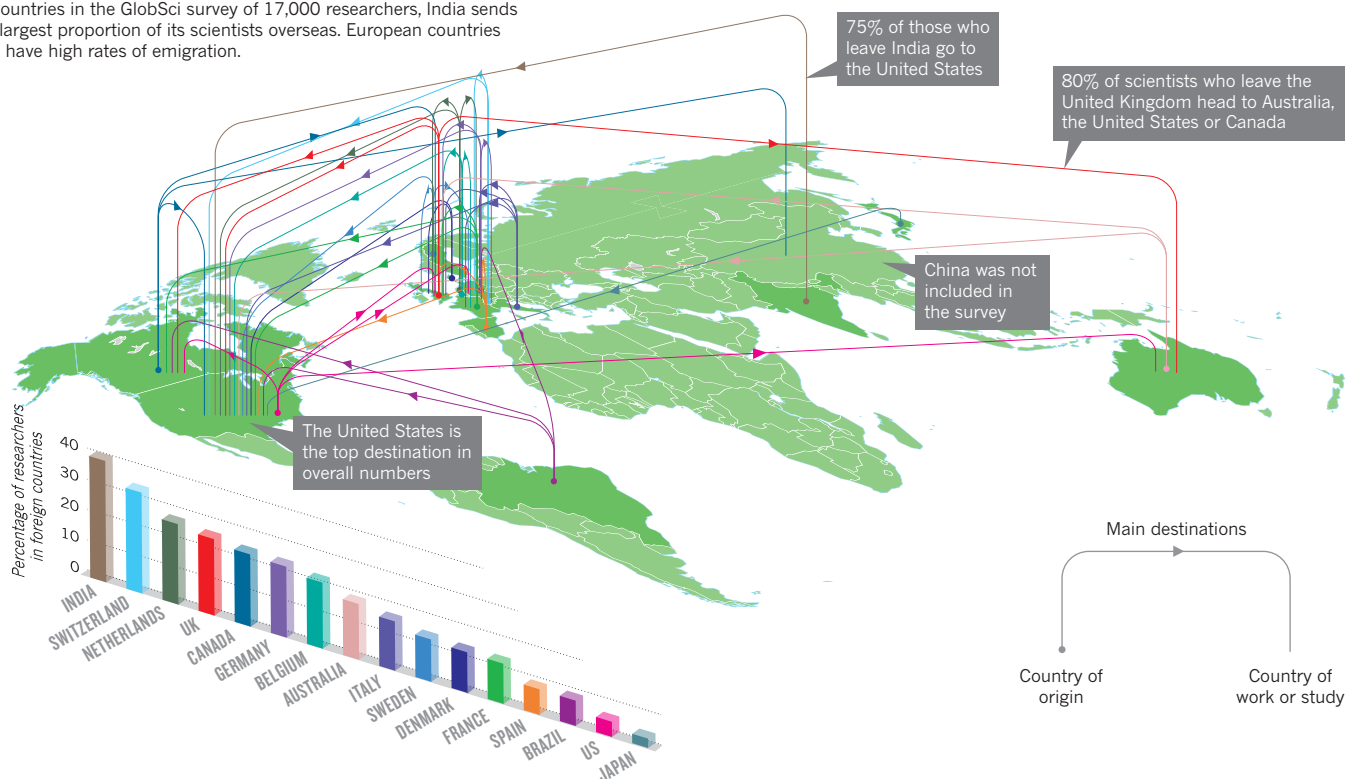
"Knowledge generation and research is really a borderless enterprise."



THE NEW MAP OF SCIENCE
The changing global landscape of research. nature.com/global

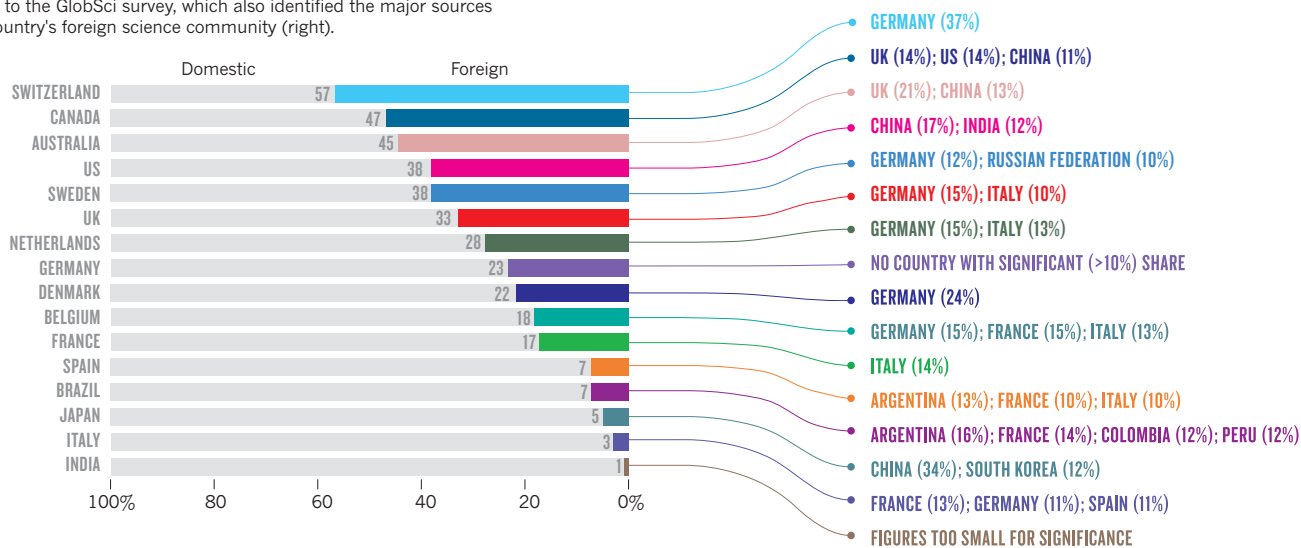
THE GLOBAL DIASPORA

Of countries in the GlobSci survey of 17,000 researchers, India sends the largest proportion of its scientists overseas. European countries also have high rates of emigration.



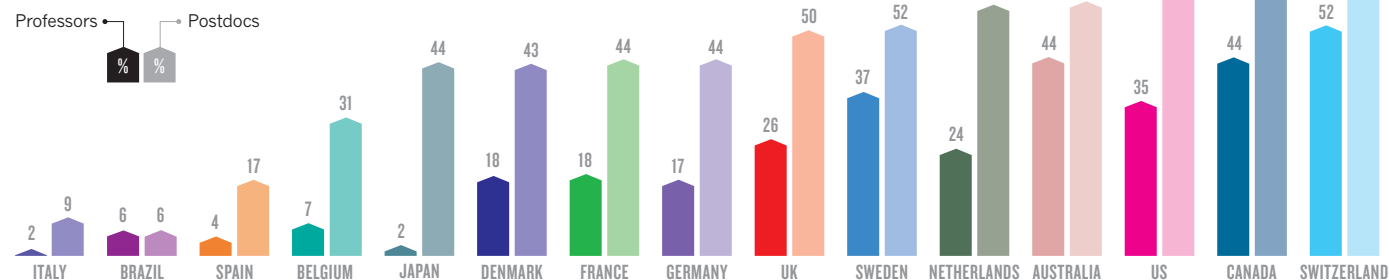
FOREIGN FRACTIONS

Developed countries have the highest proportions of foreign scientists, according to the GlobSci survey, which also identified the major sources of each country's foreign science community (right).



RESTLESS YOUTH

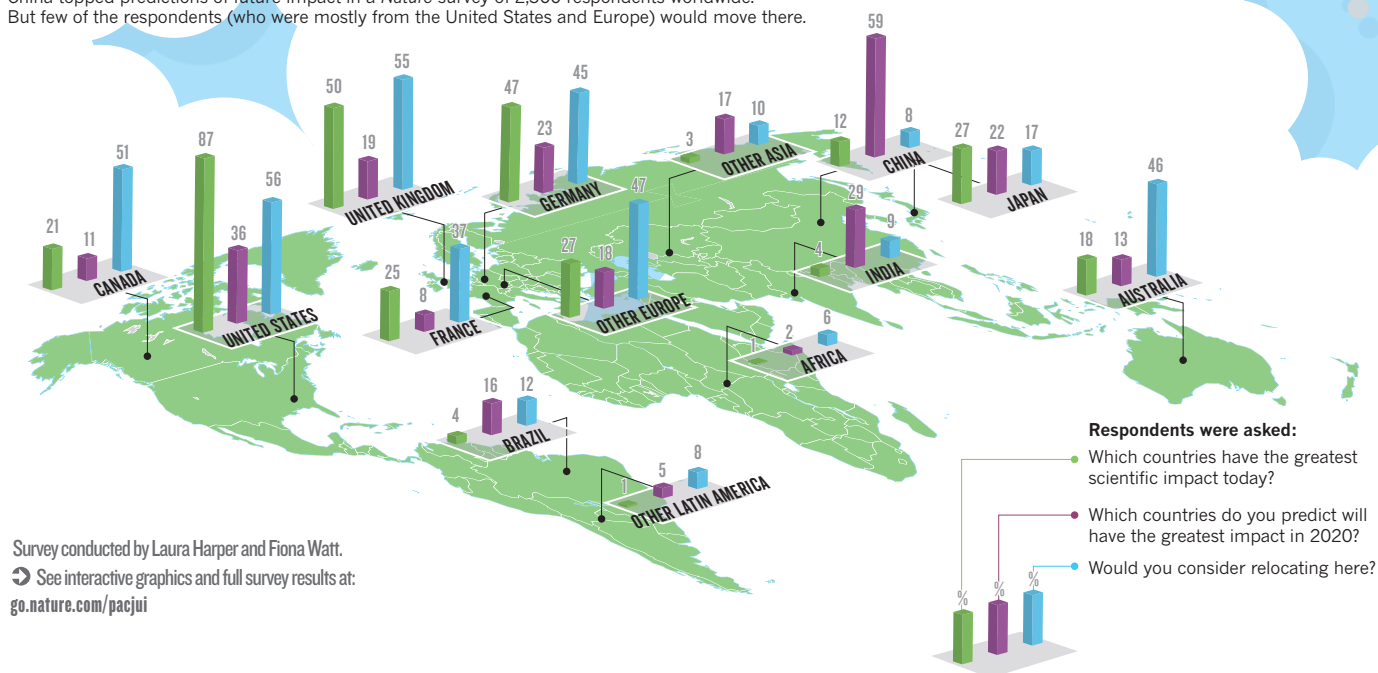
Foreign postdocs outnumber foreign professors in almost all countries included in the GlobSci survey.





LANDS OF PROMISE

China topped predictions of future impact in a *Nature* survey of 2,300 respondents worldwide. But few of the respondents (who were mostly from the United States and Europe) would move there.



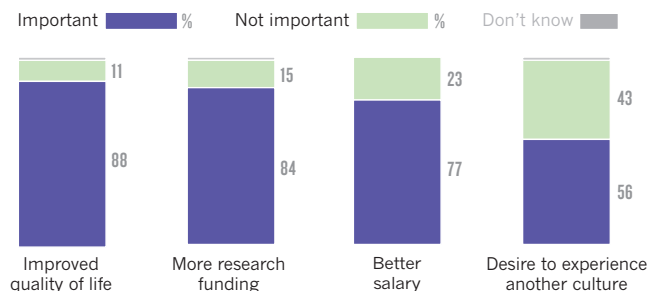
Survey conducted by Laura Harper and Fiona Watt.

See interactive graphics and full survey results at: go.nature.com/pacjui

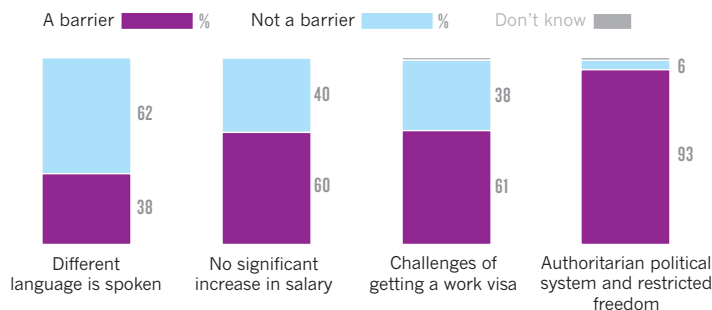
WEIGHING UP A MOVE

Nature's survey asked respondents how important various factors would be in making a decision about working abroad.

Incentives for migration



Barriers to migration



overseas. (The survey did not include China.) Japanese and US researchers were the least likely to be working abroad.

Career stage affects scientists' mobility. Chiara Franzoni, another GlobSci author, who studies science and innovation at Milan Polytechnic in Italy, has done an unpublished analysis of the GlobSci data and shown that a country's postdocs are much more likely to be foreigners than its professors (see 'Restless youth'). In the United States, for example, 61% of postdocs were brought up overseas — but only 35% of assistant, associate or full professors.

Nature found similar patterns when it surveyed readers about their attitudes toward migration, and their own histories. Those who had just obtained their PhDs were much more likely to be living outside their country of upbringing than were more senior scientists — and they were also more open to an international move, presumably because their career paths were not settled and they were less likely to be tied down by relationships and families. The proportion of respondents who said they were "not interested" in international relocation rose from a mere 10% in those who gained their doctorates within the past two years to 40% in those who had done their PhD at least 16 years ago.

"One take-away from a policy perspective is that if you are trying to

bring people back who have studied overseas, then you should target the young because they are more likely to move," says Patrick Gaule, an economist who studies science and innovation at Charles University in Prague. He has tracked the movements of almost 2,000 senior-level foreign chemists affiliated with US universities between 1993 and 2007. Only 9% will return home by the end of their professional career, he estimates, and those that do are seven times more likely to return between the ages of 35 and 45 than after 50.

ITCHY FEET

What policy-makers eager to attract foreign scientists — or stem a loss of domestic talent — most want to know is what entices scientists across borders.

In the GlobSci survey, migrants uniformly put the same two factors at the top: opportunities to improve their career prospects and outstanding research teams. The excellence of the foreign institution was also important, with quality of life and other personal reasons coming further down the list. For those who had migrated abroad and subsequently returned to their country of origin, however, personal and family reasons scored highest.

Many economists note that the richer a country becomes, the more researchers tend to flock to it. Gross domestic product and wage levels are convenient metrics, but it is unlikely that they alone are the lure: they almost certainly correlate with career opportunities and top research facilities, for example.

But wealth is not the whole picture: dynamic, flexible and competitive systems for funding and advancement are also crucial, notes Kieron Flanagan, who studies science and technology policy at the University of Manchester, UK. Japan and Italy, for example, are wealthy nations yet attract few foreign scientists because of their relatively rigid bureaucracy. "It's hard to get a job when you go there," Flanagan says, "and when you're in, it's hard to get rid of you."

A rigid system can also discourage native-born researchers from emigrating, Laudel says, noting that in Germany and the Netherlands, young scientists are encouraged to go abroad, but swiftly return. "People tell me: 'I must go back to Germany, or I will never be able to get back into the system,'" she says. "If you return too late you don't fit the career structure any more."

Atsushi Sunami, an expert in science and technology policy at Tokyo's National Graduate Institute for Policy Studies, points to another reason for Japan's insularity: culture. "Often when we ask foreign researchers about their daily research activities, they say it's fine but it's hard to adjust to our society outside of the laboratory." In some respects, researchers considering an international move are like all migrants, weighing up factors that include wages and career prospects, but extend to quality of life, schooling for any children and career prospects for spouses, says Louise Ackers, who studies the movement of European scientists at the University of Liverpool, UK.

Governments can try to tip the scales through immigration policies and travel incentives. Europe, for example, has programmes to encourage travel within the multi-country European Research Area; China has a 'One Thousand Talents Scheme' to recruit academics from abroad, as well as to persuade Chinese scientists to return. Recently, says Bhandari, "China and South Korea have done a much better job of deliberately creating well-structured incentives and opportunities for students to return back home, than, say India". And in the United States, both presidential candidates have said that they would like to expand the availability of visas for skilled immigrants.

Yet a dynamic, well-funded science system seems to trump all other incentives. Even the visa crackdown after 9/11 did not dent science students' enthusiasm for migrating to the United States. "Despite all the hand-wringing and the concern that numbers would plummet, statistically there was only a 2% drop in international student enrolment," says Bhandari. "By 2006 the numbers were rebounding."

THE CHINA QUESTION

US science-policy experts are asking how long the nation can retain its grasp on foreign talent. The country's largest contingent of foreign doctoral students in science comes from China, and research by Mike Finn, an economist at the Oak Ridge Institute for Science and Education in Tennessee, shows that for now, most stay on. Studying a cohort of Chinese scientists who had received their PhDs in 2004, Finn found that five years later, 89% were still in the United States.

Higher salaries may be the biggest attraction. Robert Zeithammer, at the Anderson School of Management at the University of California, Los Angeles, has surveyed almost 300 Chinese science students studying for their doctorates in the United States, asking them for their reactions to hypothetical job offers from the two countries. "Chinese doctoral graduates currently tend to remain in the United States because of a large salary disparity between the two countries rather than because of an inherent preference for locating in the United States," he concludes.

But as China continues its economic rise and builds its science infrastructure, that may change. Data from China's Statistical Yearbook show a slight uptick in return rates of Chinese students from abroad over the

past few years (although the data do not single out scientists), notes Cong Cao, a sociologist at the School of Contemporary Chinese Studies at the University of Nottingham, UK. But Finn says that there is no sign yet of any overall decline in stay-rates in the United States. The proportion of foreigners who say that they have "plans to stay" after graduation has gone up, not down, over the past decade, he points out.

And the lure of China remains faint for non-Chinese scientists.

Nature's survey (which drew responses mainly from the United States and Europe) asked researchers which countries would be producing the best science in their field by 2020, and more than 60% of respondents in both biological and physical sciences picked China as an option. However, only 8% said they would be prepared to relocate to China — instead preferring the United States, Europe, Canada and Australia (see 'Lands of promise'). Responses suggested that China is unappealing for foreign researchers for political and cultural reasons (see 'Weighing up a move', despite high expectations for the future quality of its research).

Such a disparity could be dangerous, says Jonathan Adams, director of research evaluation at Thomson Reuters, which is based in New York. If researchers in Europe and the United States do not spend serious time in China, he says, they will find it hard to understand how research is conducted there, even as the country's influence in science grows.

WIN-WIN?

Those who study scientists' mobility argue that the discussion need not pit nation against nation, as if China's gain is the United States's loss. In place of 'brain drain' and 'brain gain', they prefer to talk about 'brain circulation', in which international scientists dip in and out of countries at will, and everyone benefits from the collaboration. "Of course America will decline in relative terms, as the United Kingdom has, but it will do enough leading-edge research to benefit from work done elsewhere," says Flanagan. "The key thing is to have a strong-enough science base to interact with a globalized and mobile scientific world."

Researchers at the Dutch publishing firm Elsevier, who are tracking the movements of scientists by following their publishing addresses, have detected hints of that pattern. Most notable among the early results for each country is a large proportion of 'transitory' scientists, who stay in a country for less than two years at a time. The University of Liverpool's Ackers adds that some evidence, including a survey of researchers in Europe's Marie Curie Fellowship Programme, suggests that shorter, more frequent visits are increasingly supplementing long-term travel to other labs.

With the Internet making it easier to work with international collaborators at a distance, Ackers suggests, repeated week- or month-long visits can yield as much as, if not more than, a half-year stay. "The old idea of researchers moving permanently from one country to another is now quite outdated," she says, adding that it will become increasingly common for people to live in one country but work in two or three. With all this globe-hopping, the question is how long researchers will need to spend in the same place for effective collaboration — an answer that will surely differ between disciplines.

Yet this vision of a globalized, circulating world is still a long way from reality: very few scientists are global citizens, popping in and out of the best research facilities. And in developing countries such as India, "brain circulation" does not accurately reflect the situation, says Khadria. For him, the brain drain is still very real. "It is not the top-of-the-line scientists who come back; rather, they return at a time when most of their productive work is over," he says.

Science may increasingly be a globalized enterprise, but until would-be competitors boost their spending on science and facilities, it will simply give scientists even more opportunities to clump inside the countries that are already at the top of the pack. ■

Richard Van Noorden is a reporter for *Nature* in London.

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