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A G2 FOR SCIENCE?

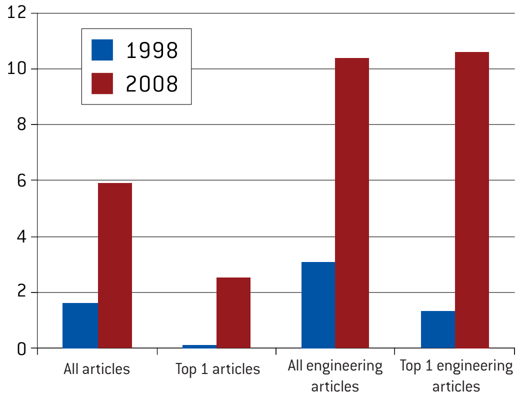
by **Reinhilde Veugelers**
Senior Fellow at Bruegel
Professor at the University of Leuven
reinhilde.veugelers@bruegel.org

THE ISSUE Science is becoming increasingly globalised. The emerging economic powerhouses, particularly China, are building up their own scientific capabilities rapidly and in a targeted way. This is provoking concern within advanced economies that they might be losing their advantage in the scientific domains that can be part of the foundation for new areas of growth. Strategies for knowledge-based growth, such as the European Union's 2020 strategy, must take these global trends into account if they are to deliver long-term international competitiveness.

POLICY CHALLENGE

Both the European Union and the United States must adapt to the scientific surge from China and other emerging nations. In the US, decision makers fear that their open model for building scientific power, based to a great extent on recruiting talent from abroad, has passed its peak. But for the moment the US-China connection is still strong, growing, virtuous and mutually beneficial. In fact, the emerging multipolar science world looks set to be dominated by a US-China G2. With its more inward-looking perspective, the EU needs to do more than focus on internal integration. The European Research Area programme provides the framework for a European policy agenda, but this should place much greater and more urgent emphasis on building excellence and openness to researchers and their institutions from outside the EU.

Trends in China's share of world scientific publications (%)



Source: Bruegel based on NSF, Science and Engineering Indicators 2010.

SCIENTIFIC RESEARCH used to be predominantly a developed-world activity, with the United States at the forefront and the European Union close behind. But a more multipolar scientific world is in the making, in which several emerging nations will participate prominently. The most striking case is China, which is going through a uniquely rapid rise. In fact, the future multipolar scientific world looks set to be dominated by a G2 – China and the US – which will build on self-reinforcing links.

The EU needs to adapt if it is to keep pace. At present, it is mostly focused on creating an integrated internal market. Its international collaborations are marked by pronounced EU-supported, intra-EU collaboration, diverting attention from the US and emerging Asia as scientific collaboration partners. The EU is also less active than the US as a source and destination on the world market for scientific talent.

By contrast, the US science model has traditionally been very open. Because the US science and engineering workforce is highly dependent on foreigners, especially from Asia, the rise of Asia provokes deep concern about the sustainability of the American capacity for innovation and international competitiveness. However, there are no signs so far that the open US model has become less attractive to foreign talent. On the contrary, the US continues to attract and retain increasing numbers of talented Chinese scientists.

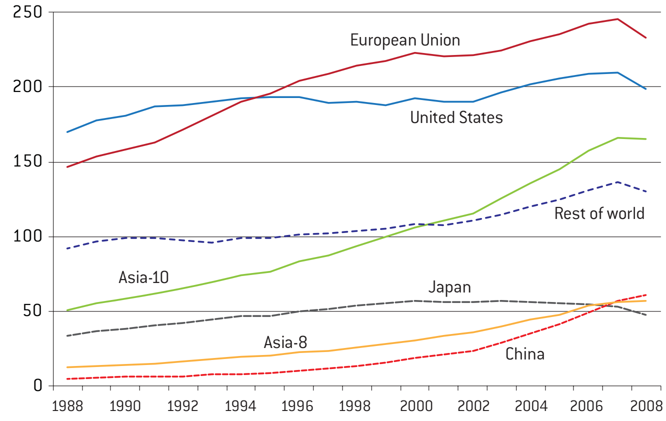
The changing face of the scientific world shows how many emerging country governments have come to view science and technology as integral to economic growth, and have consequently taken steps to develop their science and technology infrastructures. In its twelfth five-year plan (2011-15)[1] China lists the promotion of scientific and technological progress and innovation as a major tool for supporting strategic economic restructuring, and aims to be the world's scientific leader by 2050. Consistent with the build up of its high-tech industrial competitiveness, China is becoming particularly strong in engineering, chemistry and physics.

In this Policy Brief we first look at the shifts in global science, asking if new scientific powerhouses have emerged. The answer is clearly that they have, with China the most impressive case. We then study the impact of these shifts on the international mobility of scientific talent and the patterns of international scientific collaboration. Most of this analysis focuses on the relationship between the US and China. That the EU is not prominent in the analysis reflects its position on the sidelines. With its more inward-looking model, will the EU be able to respond to the globalisation of science? We conclude with a discussion on the policy implications for the EU if it wants a seat at the new global science table.

THE CHANGING GEOGRAPHY OF SCIENCE

The US and the EU have for decades led the world in production of scientific knowledge in both quantity and quality terms[2]. However, in quantity terms, both the US and the EU, and other developed nations have started to lose ground to Asia, particularly

Figure 1: Science and engineering journal articles (000s)



Source: Bruegel based on NSF, Science and Engineering Indicators 2010. Note: Asia-8: India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan and Thailand. Asia-10: Asia-8 plus China and Japan. Counts for 2008 are incomplete.

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[1] http://www.gov.cn/english/.

[2] Publications and citations as recorded by Thomson's ISI-Web of Science journals, which includes only journals that satisfy a number of quality criteria (internationally peer-reviewed). These journals carry an English-language bias as well as a disciplinary bias in favour of biomedicine and life sciences. For a similar analysis of world scientific publications, using the Scopus database, see Royal Society (2011).

China. China has doubled its output since 2004 and now publishes more than any other country apart from the US (Figure 1). Publication frequency has also risen in other emerging nations such as Brazil, South Korea and Turkey. By contrast, the quantitative performances of India and Russia have stagnated or declined.

China's research priorities are shown by a big jump in its share of world publications in engineering (from three percent in 1995 to 13 percent in 2007), chemistry (three to 15 percent), and physics (four to 13 percent). India and South Korea are also notable for increasing volumes of engineering articles. However, in life sciences China is still weak. For the moment, the EU and the US are holding on to their predominant role in this area (Table 1).

Quality of research is another matter of course. In terms of research impact, measured by the number of times scientific publications are cited, the US's dominant position is less contested (Table 2). At the top of the quality distribution, more than half of cited articles continue to originate from the US. This position is only slightly eroding, with the EU catching up in the top segment (whereas in quantity terms it has outperformed the US since 1994).

Table 1: Share of region in world publications, by field (%, 2007)

	US	EU	China	Japan	Asia-8
All fields	**28**	**32**	**8**	**7**	**7**
Engineering	20	28	13	8	15
Chemistry	16	31	15	9	11
Physics	18	31	13	10	10
Life sciences	34	34	4	7	5

Table 2: Trends in publications shares across the quality distribution (%)

All fields	Share of all articles		Share of Top1 articles		Share of Bottom50 articles	
	1998	**2008**	**1998**	**2008**	**1998**	**2008**
US	34	29	62	52	30	25
EU	35	33	25	30	34	33
Japan	8.5	7.8	4.3	4.5	9	8.5
China	1.6	5.9	0.1	2.5	2	6.7
Asia-8	3.6	6.8	0.3	2.2	4.5	7.9
Engineering	Share of all articles		Share of Top1 articles		Share of Bottom50 articles	
	1998	**2008**	**1998**	**2008**	**1998**	**2008**
US	30	21	49	38	28	19
EU	30	29	29	25	29	27
Japan	12	10	9	6	12	11.5
China	3.1	10.4	1.3	10.6	3.4	10.6
Asia-8	7.9	14.1	2.2	10.6	8.5	14.9

Source for both tables: Bruegel based on NSF, Science and Engineering Indicators 2010. Note: Top1: 99th percentile of citations received; Bottom50: publications with 0 or 1 citations; 1998 are all 1994-96 articles cited by 1998 articles; 2008 are all 2004-06 articles cited by 2008 articles.

China and other Asian countries are for now only very modestly making inroads into the top segment. However, in specific fields, engineering being the prime example, the top segment is also contested. China and other Asian countries are already having a significant impact on this discipline, and the gap between China/Asia and the EU/US is closing fast.

THE CHANGING GEOGRAPHY OF R&D EXPENDITURES AND WORKFORCES

The rise in the scientific output of Asia, particularly China, correlates with substantial investment by these countries in building up their scientific and technological capacities (Figure 2, panel A, on the next page). South Korean R&D spending has increased steeply, and China's R&D/GDP ratio has more than doubled, from 0.6 percent in 1996 to 1.5 percent in 2007, a period during which China's GDP grew at 12 percent annually – an enormous, sustained increase. China plans a 2.2 percent R&D/GDP ratio for 2011-15. By comparison, although it has a three percent research spending target, the EU continues to hover below two percent.

Estimates of the number of scientific researchers provide broad support for the trends and shifts suggested by the R&D data (Figure 2, panel B, on the next page). China has more than doubled its research workforce, boosting its world share from 13 percent to 25 percent between 1995-2007. It now has as many researchers in its workforce as the EU and US: about 1.4 million.

And there are many more Chinese researchers to come, as indicated by bachelor, master and PhD degree award trends. This holds particularly for natural sciences and engineering. While western governments are concerned about lagging student interest in these areas, which are considered vital for knowledge-intensive economies, the number of first university degrees awarded in these fields in China has risen spectacularly from about 239,000 in 1998 to 807,000 in 2006. The trend is also seen in the award of PhD degrees in China, where natural sciences and engineering doctorates increased more than tenfold up to 2006, close to the number awarded in the US (about 21,000). In the EU there has been little increase in the number of doctorates. It is also worth noting that, in the US, 31 percent of doctorates are awarded to students from China, 14 percent to students from India, and seven percent to students from South Korea.

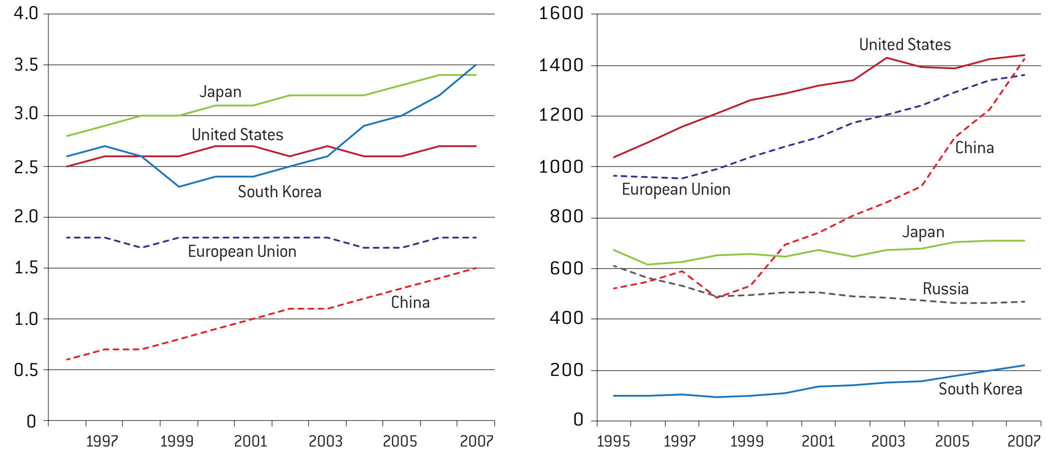
The Chinese programme of building indigenous scientific capacity concentrates on the top end. Of the 1700 Chinese chartered institutes of higher education, six percent are so-called 'Project 211' national key universities and colleges. These receive 70 percent of scientific research funding, and award degrees to about a third of all Chinese undergraduate students, two-thirds of graduate students and four-fifths of doctoral students. Within the Project 211 group, Tsinghua and Beijing Universities are on the way to being among the world's elite universities. Both are already listed among the top 200 in the Shanghai Ranking of Research Universities[3].

SHIFTING PATTERNS IN INTERNATIONAL MOBILITY OF STUDENTS AND SCHOLARS

What will the impact of the rise of the Asian scientific powerhouses be on science in advanced economies? In particular, does a shift of scientific power to Asia mean that the flows of scientific talent from east to west will dry up, crippling the advanced economies' scientific machines?

US universities import much of their scientific talent from abroad, particularly from Asia, and are therefore particularly worried about continuing to be able to fill their laboratories with imported brains. This concern, however, is not so far justified by the data. On the contrary, the evidence shows

Figure 2: A (left panel) R&D expenditures as % of GDP;
B (right panel) Number of researchers by geographic area (000s, full-time equivalent)



Source: Bruegel based on NSF, Science and Engineering Indicators 2010. Note: US data for 2007 estimated based on 2004–06 growth rate.

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[3] See http://www.arwu.org/.

that the international mobility of scientific talent is increasing.

While in 2000, 1.9 million foreign students were enrolled in tertiary education outside their country of origin, the figure was more than three million in 2007 (OECD, 2009). The most significant country of origin of these students was, not surprisingly, China (15 percent of all foreign enrolled tertiary students), followed by India (5.4 percent). The favoured destinations for these students were the US (20 percent), followed by the UK (20 percent), Germany (8.5 percent) and France (8.2 percent). The China-US flow is thus the most important international educational connection, closely followed by the India-US flow. The China-US flow has not reduced, notwithstanding China's increasing indigenous scientific capacity. On the contrary, the number of Chinese students heading to the US increased at an average annual rate of 8.5 percent between 1997-2008 (NSF, 2010).

'Foreigners in US academic institutes contribute disproportionately to top science.'

When focusing on PhD students among tertiary students, the China-US link is even more pronounced. China's share of PhD degrees awarded by US institutions to foreigners continues to grow, being almost one third of all 'foreign' PhDs in the US in 2007 (Table 3). Tsinghua and Beijing Universities provide more students to US graduate schools than any other institutions, with native Berkeley only coming in third place (Stephan, 2011).

Table 3: Non-US recipients of US PhDs by home country (%, all fields)

	Share of total		Plan to stay	
	96-99	04-07	96-99	04-07
China	26	31	93	91
India	12	12	90	89
S. Korea	9	10	50	69
Europe	14	14	71	75

Source: NSF, Science and Engineering Indicators 2010.

The presence of foreign PhD students in the EU is less well systematically recorded. The imperfect evidence shows that the PhD student populations of EU countries have fewer foreigners compared to the US, and the origins of foreign PhD students are different, with a less strong Asian presence and geographic, cultural and political links being more important[4].

One could interpret the evidence as showing that Asian countries are building their capacities in natural sciences and engineering by sending their students to the best training ground in the world – the US – in order to bring them back home with state-of-the-art scientific knowledge. The data, however, do not show high return rates for foreign students who have obtained a PhD in the US, at least in the period immediately after PhD graduation. Stay rates for Asian PhDs in the US in particular are significantly higher than the rates for other foreigners (see Black and Stephan, 2007). And as Table 3 shows these high Chinese and Indian PhD stay rates have not diminished during the time period.

Many foreign PhD students move after their PhD studies to take up post-doctoral positions in other US research institutes, which recruit post-docs both from US and non-US graduate schools. Post-doc positions are thus another entry point to the US for foreign talent. The share of temporary residents among post-docs at US universities stood at 57 percent in 2006 (NSF, 2010) up from 51 percent in 1993. Asians are also taking more academic positions in US institutes. In 2006, about 17 percent of academic positions were held by Asians (with US citizenship or foreign born), up from eight percent in 1981 (NSF, 2010).

There is evidence that foreigners in US academic institutes, having gone through a tougher selection process, contribute disproportionally to top science. Foreigners in the US are twice as likely than natives to be the first author on frequently cited 'hot papers', or to be among the most-cited authors (Stephan and Levin, 2007). A virtuous circle thus seems to emerge: the US's top position in science is based on its openness to the best foreign talents, who stay long enough to make a contribution to quality science, and this top position continues to

[4] The pattern of foreign PhDs in the EU is completely different to the US. First, there are fewer foreign PhDs in the EU: Other-EU nationals represent five percent of doctoral candidates, Extra-EU nationals represent 17 percent, spread between Asia, Africa and Latin America. Major destination countries are the UK (for Asia), France (for Africa) and Spain (for Latin America). Source: Mougeroux (2006).

[5] See eg China's Thousand Talents Programme, offering positions, housing, equipment, research teams, funding and preferential tax treatment for researchers working overseas who come back to work in China.

attract the best foreign talent. The EU has not managed to establish such a virtuous open model.

What if the rise of indigenous scientific and technological capacity in Asia/China should eventually persuade their foreign-educated scientists to return home? As Table 3 shows, this does not yet seem to be happening, at least not immediately after graduation. But Asian scientists could be returning home at later stages in their careers. There is no doubt that China is aggressively seeking to bring home talented individuals[5]. But hard data supporting the importance of these return flows is still lacking. In any case, return flows at later career stages still leaves plenty of scope for the host country to benefit from imported foreign talent.

INTERNATIONAL COLLABORATION IN SCIENCE

Is China also becoming a new partner for scientific cooperation with the west? The data does not show major shifts in collaboration patterns (Table 4). The emerging scientific powerhouses, particularly China, are still relatively under-represented as partners for the west. China's collaboration is mostly with other Asian economies. Its collaboration with the US has increased over time on par with the growth of its own scientific power. The intense flow of PhDs between the US and China undoubtedly contributes to smoother US-China collaboration. European countries, missing out on this flow of talent, benefit less. The EU's collaboration with China remains at a far lower level that it could be, considering the growth of China's scientific power.

By contrast, intra-EU collaboration has substantially increased over time, suggesting progress has been made in building the integrated European Research Area (ERA), but diverting from extra-EU collaboration.

IMPACT BEYOND SCIENCE

Beyond academia, foreign-born PhDs are also widespread in the US private sector research workforce. Foreigners made up 25 percent of tertiary-educated workers in science and engineering occupations in the US in 2003. For holders of doctorates, the figure was 40 percent (NSF, 2010). About half of the foreign-born scientists and engineers in the US are from Asia (16 percent from India, 11 percent from China, 4-6 percent each from the Philippines, South Korea, and Taiwan). The Chinese share increases to 22 percent for those with a PhD.

Foreign talent is thus vital for US science and engineering[6]. This explains why the US fears that its science machine will start to splutter if the pool of mobile foreign talent entering the US dries up. There is no clear evidence so far to justify this fear. For the moment, the increase in Asia's own capacity to produce science

Table 4: Collaboration trends; International Collaboration Index for selected country pairs (1998-2008)

With US	1998	2008	With China	1998	2008
US-UK	0.67	0.74	CN-UK	0.58	0.52
US-GER	0.68	0.68	CN-GER	0.6	0.44
US-FRA	0.56	0.6	CN-FRA	0.39	0.38
US-JAP	1.03	0.89	CN-JAP	1.53	1.38
US-CN	0.82	0.97	CN-US	0.82	0.97
US-SKOR	1.38	1.23	CN-SKOR	1.72	1.17
US-INDIA	0.92	0.79	CN-INDIA	0.98	0.64
Intra-EU	**1998**	**2008**	**Intra-EU**	**1998**	**2008**
UK-GER	0.68	0.86	NL-BEL	2.5	2.68
UK-FRA	0.73	0.87	NL-GER	0.95	1.29
UK-IT	0.86	1.04	GER-PL	1.15	1.34
UK-NL	1.05	1.27	GER-CZ	1.27	1.46
FRA-GER	0.74	0.91	PL-CZ	2.15	3.48
FRA-IT	1.12	1.34	SE-FIN	3.39	3.98
ES-IT	1.38	1.63	SE-DK	2.88	3.38
ES-PT	2.55	2.9	FIN-DK	2.36	3.15

Source: Bruegel based on NSF, Science and Engineering Indicators 2010. Note: an index of international collaboration corrects for the effects of the unequal size of countries' research establishments. Values above '1' indicate greater-than-expected rates of collaboration.

6. There is also evidence that foreigners are increasingly responsible for US patents. Freeman (2005) reports that one quarter of US patent applications filed at the World Intellectual Property Organisation in 2006 were authored by a non-US national, up from seven percent in 1998. Of US technology and engineering start-ups, about one quarter have an immigrant as a key founder. For Silicon Valley start-ups, this may be even more than half (Demos, 2008).

and engineering degrees does not seem to have disconnected the US from the pool of potential Asian scientists. In fact, the contrary seems to be the case.

On the back of an increase in its indigenous scientific and technological capacity, Asia has become an increasingly attractive location for multinational companies' research activities. In an UNCTAD survey of the world's biggest corporate R&D spenders, China (third) and India (sixth) were already among the top-ranked countries for corporate R&D. As future target locations, China was ranked first and India third (UNCTAD, 2005).

When asked why they are moving their R&D labs east, western firms report not only lower labour costs and the importance of the growth potential of Asian markets, but also, and equally important, the quality of R&D resources and the proximity to universities and institutes (Thursby and Thursby, 2006). The increase in Asia's indigenous scientific capacity is therefore increasingly becoming a factor in the attractiveness of Asia for western corporate R&D labs.

'The EU, to a great extent, remains on the sidelines of the globalisation of science process.'

EU POLICY IMPLICATIONS

Emerging economies have grasped that scientific power is based on ambition and massive investment in R&D and higher education. Their governments have firmly built investment in higher education and science into their development policies as they vie to build competitiveness in technology-intensive sectors. The result has been a continued increase in the scientific power of these countries.

The benefits from a more global science world will accrue to many, but some will benefit more than others. The open US scientific system has traditionally benefited from foreign brains. The US's dominant position in science is based on its openness to the brightest talents of all nationalities. Its top position continues to attract the best talents of all nationalities, who disproportionally contribute to US scientific, technological and economic success. With continued high attrition rates and high stay rates for Asian scientists, this open model, at least for the moment, continues to bear fruit for the US, even if its most important source country, China, is rapidly developing its own scientific capability and wants to bring its foreign-based scholars home.

China's scientific growth model, aspiring to be indigenous, involves sending out its increasingly better locally-trained scholars to the best institutes in the world, and reaping the benefits when they return, typically at later stages in their careers when they have fully developed their capabilities, leaving enough of a window of opportunity for the host country to likewise benefit from them. This favours the continued robustness of the mutually-beneficial unique China-US connection. While this continues, the global science landscape will look more like a G2 than a truly multipolar global system.

'The globalisation of science is mainly about the relationship between China and the US.'

The evidence in this Policy Brief shows that the globalisation of science is primarily a story about the relationship between China and the US. The EU, to a great extent, remains on the sideline. In this context, the EU has some serious thinking to do about its place in the future global science landscape. For now it is largely holding its own, based on the intensifying process of intra-EU integration, the making of a European Research Area (ERA). However, it does not have the same deep openness to foreign scientific talent as the US, implying that steps must be taken if the EU is to ride the waves of scientific globalisation.

As a starter, the EU must show more commitment to joining the science globalisation train, and to subsequently ensuring that European economies will benefit. European science and technology policymakers should therefore promote scientific collaboration outside the EU, should do more to attract and retain the best foreign talent, and should stimulate the EU's talents to go to the best universities and institutes, wherever they are in the world. Connections with these outflows must be maintained, and incentives must be provided to encourage scholars to return home, at optimal stages in their careers.

A large scientific area characterised by scientific excellence is a necessary condition for this policy agenda. Excellence will ensure that talented people in European research institutes and firms will be better able to absorb the new knowledge generated abroad, and that European research institutes and firms will be more attractive hubs for the best talent from abroad, and will be better able to connect with new scientific hotspots.

ERA, the European Commission's long-running programme to establish an integrated market for research in the EU[7], provides the framework for this European policy agenda, but it should be given a much greater sense of urgency with a much stronger focus on building excellence and openness to researchers and their institutions from outside the EU. The intra-EU mobility agenda should not be about navel gazing, but should be a lever for global integration.

The globalisation of science will undoubtedly bring unprecedented scientific and economic benefits to the world. But it will also provoke concerns about increased competition. Only the best will be able to master this game of competition and cooperation.

When Freeman (2005) asked a top Harvard physicist, who had published important work in cooperation with Asian scientists, "so, you are helping them catch up with us?" the scientist replied, "no, they are helping us keep ahead of them".

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[7] See http://ec.europa.eu/research/era/index_en.htm.

Bruegel, Rue de la Charité 33, B-1210 Brussels, (+32) 2 227 4210 **info@bruegel.org** **www.bruegel.org**