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The driving forces of scientific research in higher education

The four competing narratives – which is right?

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[Opening slide]

Prior to the emergence of the Internet in 1990 science was organised and produced solely in national science systems. Though knowledge flowed freely across borders there were lags and international collaboration was modest: of papers published in 1970 and indexed in Web of Science only 2 per cent have authors from more than one country.

After 1990 the Internet made possible 'thinking through the world' (*tianxia)* and the global science system

Electronically-mediated communication made possible the rapid expansion of a networked global science system. By 2018, 23 per cent of all papers in Scopus had co-authors from more than one country. The global science system consists of four elements. First, accessible knowledge in the common global language of English, defined by what is included in the bibliometric collections. Second, scientists and their collaborative relations with each other. Third, the networked structures within which they work, including publishing. Fourth, the collegial rules and protocols governing their autonomous interactions.

This global science system is radically incomplete, and also exceptionally dynamic. Let's look at both factors.

Not all knowledge is English-language or Western global science

First, radically incomplete. Global science is defined by what is included in the two primary bibliometric collections, Web of Science and Scopus. These do not include all science and still less all knowledge. WoS and Scopus lag behind the explosion of scientific 'grey matter' online. Other items are consciously excluded. First, nearly all papers in languages other than English are excluded. Second, books and many social science journals and nearly all humanities scholarship, even in English, are outside WoS and Scopus. Recognised global science grossly exaggerates the extent to which intellectual work is concentrated in Anglophone countries and to a lesser degree, Western Europe.

Other nations, languages, scholars, and scientists are positioned as in deficit, regardless of what they do. Endogenous (indigenous) knowledge everywhere is excluded. Global science is Anglo-European centric, especially Anglo-American centric, structured by an inclusion/exclusion binary at two levels: first, the selection of global knowledge, and second, the ordering of value inside it. Scientists from the leading countries, especially the US, set agendas, determine standards and produce most highly cited papers, defined by citation counts in the same skewed system.

Rapid growth of science: Since the start of the internet in 1990 the global science system has spread in dynamic fashion

Second, however, exceptional dynamism. Despite its incompleteness, what *is* global science is growing and spreading very rapidly by historical standards. The dynamism is apparent in the rate of growth, the diffusion of science systems to many more countries, the growth of cross-border papers, the pluralisation of power in science, and growing global integration.

GROWTH: Number of science papers in Scopus, by type of collaboration, world: 1996-2018

Between 2000 and 2018, while world GDP grew by 3.5 per cent per annum (World Bank 2020), papers in Scopus grew by 4.9 per cent per annum. As the graph shows, the number of internationally collaborative papers in light blue grew much more rapidly than papers from one institution in dark blue. The Leiden University ranking shows that in the ten years prior to its 2016-19 count, the number of universities with 5000 papers in Web in Science rose from 131 to 248, and in China from 10 to 61.

DIVERSIFICATION: The spread of research to more countries 1987-2017

At the same time national capacity in research and doctoral education has spread from the traditional science nations North America, Europe, Japan and Russia to many middle-income and poorer countries. Whereas in the year 2000 scientists from 30 nations, eight outside Anglo-Europe, authored over 5000 Scopus papers a year, by 2018 there were 52 such nations, 24 outside Anglo-Europe, many below the world average per capita income.

PLURALISATION OF POWER: Number of science papers in Scopus by large world region: 1996-2018

There are also any signs that science power is pluralising. Look at the growth in this graph in the categories 'China' and 'Rest of the World'. In 2018 China produced more papers than the US and India has passed UK and Germany to move to third in the world.

RISING GLOBAL COLLABORATION: Growth in internationally co-authored science papers, all countries: 1996-2018

Science is also becoming more international, as you know. Between 1996 and 2018 the internationally collaborative share of papers rose from 12.4 to 22.5 per cent of all Scopus papers. This proportion was relatively high in Europe (for example Germany 53.2 per cent), where collaboration is fostered by funding schemes, higher still in small countries like Singapore and lower in large emerging systems that emphasise the growth of endogenous national networks (e.g. China 21.7 per cent, India 17.8 per cent). In the US, 39.2 per cent of papers in 2018 involved international co-authors, high for a very large country where like China there are many potential domestic collaborators, indicating that US scientists are intensively networked at world level.

The nation-state factor in science

Of course, not just global cooperation but nation-states underpin the growth of science. Global science consists of published knowledge; scientists; networked structures and collegial rules and protocols. But this global science is underpinned by national and locally embedded funding, laws, policies, institutions, training and resources; and some knowledge generated in the local and national scales does not enter global circuits of knowledge. These national and local elements do not derive from the global system, but are necessary to it.

Global science and national science: two distinct and overlapping science systems

This is the key to contemporary science. It is partly globalised, but only partly. It consists of two distinct and overlapping systems – the global science system and national science systems. There is a productive division of labour between global and national science - and potential for tensions. The point I want to emphasise is that to understand global science, as with global ecology, it is necessary to step outside the national container and see the global system clearly. Global science is not an outgrowth of national science, in Italia or anywhere else. It has its own existence, autonomy and dynamism. Unlike the different national science systems, the global system is not normatively integrated from a single centre, the nation-state. It is grounded in the autonomous self-managed association of scientists themselves, regulated by autonomous professional conventions and standards and by global publishing.

Differences between global and national science

How then does this more recently emerged global science system relate to national science systems, and multilateral agencies in Europe, where science is resourced, housed and employed? Governments expect science to fulfil policy objectives, and national investment is growing. Nations, and universities, want to strategically direct science and in broad terms some of them do so. For national governments the ‘internationalisation’ of science promises access to the technological edge. Global links are also advanced by universities, for whom global science is a limitless source of status, talent and resources. Science is produced in a complex eco-system in which scientists connect to a range of funders and networks in different scales. Science is not either global or national/local. It is both. The national/global relation is not zero sum. Globally active scientists often lead national and university centres. However, the global network offers scientists a robust collective identity and a shelter from direct interference. Many scientists manage two sets of loyalties, to cross-border discipline-based networks and to national and institutional authorities. Yet collegial links in science are more bottom up than top down, science is more collegial than nation or institution driven.

What sustains international scientific collaboration? [1]

What then holds the global disciplinary networks together? A large literature investigates or reflects on scientists' motivations in cross-border association. These include cognitive accumulation or knowledge formation, not just curiosity, or a common interest in global problems, but the desire to make a distinctive contribution and achieve breakthroughs.

What sustains international scientific collaboration? [2]

Also intellectual affinities with others; diverse perspectives, complementarity, in research teams; the quality or 'excellence' of partners; not to mention shared resources and data.

What sustains international scientific collaboration? [3]

Another explanation focuses on the sociological idea of 'preferential attachment'. Here junior scientists attach themselves to more highly cited colleagues for status and career benefits. Global science is seen as a positional competition driven by self-advancement. International co-authorship is also associated with greater citation rates, though the direction of causality is open to debate. Self-interest helps to explain some collaboration decisions, but cognitive factors are the only ones present in all scientific collaboration.

The global science system?

What then drives global science? To say that it is primarily bottom up, autonomous agency is modified by structural influences, and scientists have mixed motives for working together, does not provide a larger explanation or narrative. There are four such narratives already in existence: global science as a *collaborative network*, global science as an *arms race between national governments*, global science as a *market of 'World-Class Universities'*, and global science as a *world systems hierarchy* controlled from a Euro-American global centre. Often more than one narrative is used, but they are only partly consistent with each other. The remainder of this paper critically reviews each of the four narratives. The underlying question is: 'How explanatory of global science is this narrative?' I will argue that none of these familiar narratives is consistent with the empirical evidence on global science, nor sufficient to furnish a cogent explanation of it. The conclusion suggests a different approach.

Narrative 1: An open and flat network that expands continually

The material foundations of the network narrative are the logic of the open network form of information system, as explained by Castells in *The Network Society*.

Network connectivity

As the network grows each new agent, each node, is added at negligible cost. It adds value to existing nodes by growing the potential connections and cheapening the average unit cost of each. Any node connects to any other node. Networks continually call new nodes and links into being, expanding naturally towards complete inclusion of every possible node, while intensifying existing connections. The costs of exclusion grow faster than the benefits of inclusion. Network diagrams can be too static, missing the exceptional rate of change.

Network dynamism

Networks are prima facie disposed to expansion, openness, inclusion, horizontality, bottom-up agency and a binary inclusion/exclusion dynamic. Science is an information system, and once synchronous electronic communication was established, global science expanded in the manner of a Castellian network. National governments assisted the trajectory: few blocked the Internet, while many built the capacity of national science to source the global science pool. There was no brake to global growth.

Global science is flat?

The network idea lends itself to imaginings of science as more informal, open and flat than the other narratives suggest. Caroline Wagner and colleagues emphasise the dynamism of growth, the facilitation of new entrants to global science, and the fact that strong science countries do not gatekeep the network. There's no doubt that global science grows as a network. However, where the science network imaginary falters is in identifying vertical as distinct from horizontal relations – gaps and exclusions, and inequalities, hierarchy, inside the network. Castells notes that the network form 'allows metropolitan concentration and global networking to proceed simultaneously'. Network-based studies do not fully explore the concentration part. National and institutional power concentrates at the nodes.

Reasserting the vertical

In networks, the links are not necessarily equivalent, but arguably, network analysis does not distinguish sufficiently between links embodying expressive and innovative power, links based in reciprocal relations, and links signifying mimetics and dependence. As Sebastien Conrad (2016) remarks: 'If hierarchy is neglected, preoccupation with connections may blur an accurate understanding … the network is embedded in structural inequalities, but the impression arises that it operates in a vacuum'.

Narrative 2: National arms race in innovation

In the nation-centred narrative, science is a weapon in the endless competition of states. Nations do not delegate their strategies to the voluntary actions of global scientists. They shape priorities, incentivise innovation and tap global science to their advantage. Their objective is not science for its own sake but national security, military strength, geo-political power, lucrative IP, industry innovation, prosperity and employment. The nation-state problem is that creativity cannot be managed from a distance. To render the nation more competitive they depend, after all, on the voluntary actions of global scientists. But nations that expect linear causality from global science to innovation to profit are disappointed

Methodological nationalism leaves us trapped in the national container

The material foundation of this narrative is the real role of nations in global science. National funding is correlated to output and citation recognition. The nation is especially potent in regulating the mobility of talent. Policy on visits, immigration, security blocks and eligibility rules for funding all affect science output. Because nations fund science they also shape and limit the study of performance in science. In most scientometric papers, the nation is the primary category and the main focus is cross-national *comparisons* of performance, either pure scientific performance as measured by output, citation and collaboration indicators, or performance relative to resources. In many such comparisons, scholars arbitrarily assign collaborative papers between countries, as if global science has no independent existence; it is an outgrowth of the nation-state.

Is it valid to arbitrarily ascribe global science data to individual nations?

Some scholars are uneasy about this. In collaborative science it is perhaps impossible to validly identify separate national components. This was pointed out by Robert May, in a seminal 1997 article which, arguably, launched contemporary global comparisons in science. In subsequent studies May's methodological concerns have often been repeated, though never really addressed. The essential question is how 'national' is the combined knowledge, especially from a *tianxia* perspective? Are scientists agents of the nation state pursuing national interests, or nationally-based persons with bottom up disciplinary relations in autonomous global science? A key question is the extent to which the nation-state controls ‘its’ part of global science as an instrument of will. Though the answer varies by country, it likely boils down to ‘not much’. Open knowledge flows and protocols allow many scientists to step outside the framing of science as a national enterprise. A further problem for the arms race narrative is that studies of the link between investment in science, scientific performance and innovation performance are inconclusive. Science enters a global pool. Innovations by national industry can be sourced in foreign science. National science can be used by foreign not local capital.

Science to innovation to business profit? The myth of linear causality

There is also the challenging point made by Klavans and Boyack. Most basic science is ‘altruistic’ not economic in purpose, for example medical research, and social science. Though it dominates the orthodox picture of science, the arms race narrative makes little sense. National *factors* like language, culture and resources matter in global science but the effects are refracted through the global system. Framing science as a zero-sum competition, as a mosaic of separated national systems, perpetuates the fiction that nations wholly order their own destinies, and all else, and the dynamic global science system does not exist.

Narrative 3: Global market of ‘World-Class Universities’

The material foundations of the narrative of science as a global market of ‘World-Class Universities’ are the facts of science-oriented institutions; their competition for prestige, talent, and in some countries, international students; their corporate freedoms outside the national borders; and the major role of research in university visibility and status.

The key role of science in global university rankings

But what has elevated this narrative to a central place in understandings of global science is the key role of research, of a particular kind, in the three most prominent and influential global university rankings. The Academic Ranking of World Universities, QS and Times Higher rankings are primarily driven by the measured characteristics of Anglo-American science universities: paper volume, high citations, Nobel Prizes, research income, university reputation in surveys, mobile faculty and students. Rankings standardise the performance of each individual university, using these primarily science-based indicators, into a single number, calibrating a highly visible global order with the familiar names on top.

Composite multi-indicator approach to competitive science?

This narrative imagines a world of stand-alone, context free universities, responsible for their own fate, contesting a level playing field. Apparently, university performance can be separated from governments, resources and also the collegial links sustaining global science. In reality, universities are highly contextualised, nested in states, with varying autonomy, and their performance rests on resources, the stability of government support, language of use, and faculty who mostly operate independently of institutional strategy. There are also numerous problems with the rankings as social science. The multi-indicator approach, combining heterogenous measures in a single number, rests on arbitrary weightings which have no intrinsic standing, but determine the outcome.

University rankings explain nothing useful about science, yet they order it

Yet rankings are compelling - widely used in decisions by students, faculty, governments when allocating scholarships and selecting skilled immigrants, by private investors and donors; and a primary performance indicator of university leaders and governing bodies. The narrative of science as a global competition of WCUs was popularised not to explain science but to order universities as a neoliberal global student market, in the QS and the Times Higher rankings, or to benchmark their global position, as in ARWU. But rankings have become an explanation. Science is used to compile the university rankings, and the rankings have returned the favour, shaping orthodox ideas of global science, while reproducing its cultural biases and epistemic exclusions. However, as with the national arms race narrative, the global market narrative misses what is distinctive in global science. Like the national arms race narrative, the global market narrative cannot explain the exceptional dynamism of network growth and diversification. It conceals the role of collegial networks and drivers. Both nations and universities provide favourable conditions for growth, but knowledge-based networks are more motivating in science than institutional competition. For example, scientists are much more likely to retain their field and change university, than vice versa.

Narrative 4: Centre-periphery world systems hierarchy

Science is a site of relations of power. It is moulded by the geo-political and economic distribution of activity, resources and status between countries, cities and universities; and by hierarchies of disciplines; and in turn it constitutes inequality of knowledge, agents, sites and national science systems. While for Wagner and colleagues global science is a vast open quasi-market of scientists pursuing self-interested partnerships, on one hand there is also knowledge building for its own sake, with anyone from anywhere; on the other hand there is hierarchy and oligopoly, enclosure as well as openness, language requirements, journal hierarchies, citation counts and rankings that entrench inequalities. The fourth narrative, from world-systems theory, attempts to explain hierarchy and inequality in terms of world-systems theory's centre-periphery logic. This framework has influenced writing on science.

Wallerstein's world-systems theory and the centre-periphery model

In Immanuel Wallerstein's world systems theory applied to science, the countries of the centre in the US, UK and parts of Western Europe reproduce their dominance by maintaining the permanent subordination of science on the periphery. Between the centre and the periphery is an intermediate zone of countries in the 'semi-periphery'. The position of individual countries can be understood only in terms of the 'totality' of world capitalism. As Wallerstein puts it: 'There is no such thing as "national development"'. There is limited 'surplus' at world level and for one country to rise another must decline. Wallerstein emphasises that countries rarely move out of the periphery or semi-periphery. He is critical of Eurocentrism in science, but he sees it as inevitable.

But many countries in the 'periphery' are successfully developing science systems

At first sight the centre-periphery model looks consistent with the binary effects of inclusion/exclusion and Anglo-American hegemony in science. But world systems theory underplays the potential of individual states on the 'periphery' and 'semi-periphery' to lift national development. It made more sense in the 1970s, before the dynamic growth of science, international collaboration and diversification, including 'periphery to periphery' networking. The last two decades of global science are inexplicable in world systems terms. The graph lists the 26 countries where scientists authored more than 5000 papers in 2018 *and* the annual growth in science between 2000 and 2018 exceeded the world average of 4.94 per cent. In ten of those countries per capita incomes were below the world average. Science is spreading from middle income countries to upper low income countries.

Chinese science has destroyed beliefs that the 'West' is more intrinsically creative

The collapse of the centre-periphery model is confirmed by China's breakthrough to a leading global role, and the rise of autonomous systems in India, Iran, South Korea and Brazil which like China emphasise both global networking and national capacity. China now outperforms the US in high citation mathematics, and is closing the gap in computing, engineering and chemistry, though it remains well behind in biomedicine and life science.

Top universities in STEM research

Last week's 2021 Leiden University ranking finds that for high citation papers published in 2016-19, Tsinghua University has passed MIT, Stanford, Harvard and Berkeley in both physical sciences and engineering, and mathematics and computing. In top 5 per cent papers by citation in mathematics and computer science, Chinese universities hold the first six places. However, rising systems like China, Korea and India have not modified the Anglo-American domination of professional language, conventions, standards and, often, topics.

The centre-periphery model in science studies: ignoring reality

In sum, the economic theory of centre-periphery has been rendered obsolete by global science. World-systems theory is unable to explain the dynamism of growth and network extension, and the relative openness of scientific collaboration and capacity building, the fact of a global system that extends beyond the nation-state, and the rise of science in countries branded 'periphery' and 'semi-periphery', which draw part of their capacity building from the networked global system. The centre-periphery model misses the point about global hegemony in science. That hegemony was created by Anglo-American imperial power, but it is now primarily cultural and epistemic, not military or economic. China, Korea, India, Iran and others have arrived as scientific powers, but are yet to modify the Anglo-American domination of professional language, conventions, standards and, often, topics.

The four narratives of global science: the test of explanation

Few human activities are more globally integrated than science. Here the challenge is, as Castells puts it, 'to conceptualise a new form of society … made up of specific configurations of global, national and local networks in a multidimensional space of social interaction'. Global science is a partly autonomous system with distinctive relational characteristics. It connects to national and institutional agents but is not subsumed in those scales.

In most areas the four narratives of global science fail the test of explanation. Policy is especially poorly served by the two narratives in popular use: arms race of nations and global market of World-Class Universities. Neither adequately explains the dynamic growth and spread of science. Assumptions about intrinsic zero-sum competition are undermined by the growth of collegial collaboration. The centre-periphery model has been exploded by the evolution of the global system. The network narrative is the only one that acknowledges that collegial communities are central to global science, and captures the developmental dynamics of the system. However, it has no explanation for inequality and hierarchy. Each narrative on its own constitutes a stereotype that conceals as much as it reveals.

Conclusions

The way forward is to acknowledge the partial autonomy of the global system, and both its horizontal and vertical dimensions – to combine network theory with theorisation of the unequal nodes, and the hegemonic power that stratifies and excludes, while remaining open to multipolarity. 'Partial' autonomy, because science is impacted by arbitrary state intervention, and market forces. States affect global science by actions that impact nodes, and actions affecting the network. Neither politics nor economics permanently suborn the collegial conversations sustained by networked epistemic sociability. If global science is gripped by a firm Anglo-American hegemony, the fact must be faced that it is science communities themselves, together with the commercial bibliometric companies, that exercise the homogenising role, locking out more diverse knowledge, agendas and agents.

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If linguistic plurality and reciprocal translation were normalised, and bibliometrics opened up to a fuller range of disciplines and forms of output, much would change in global science.

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