Paper to be presented at the **Globelics conference**

INLCUSIVE GROWTH, INNOVATION AND TECHNOLOGICAL CHANGE: EDUCATION, SOCIAL CAPITAL, SUSTAINABLE DEVELOPMENT

Dakar, Senegal, October 6-8 2009

Theme 8 International cooperation and national innovation policies facing global challenges

Linking innovation personnel: international networks among scientists

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Abstract: Innovation ultimately depends on people with innovation skills. The mobility of scientific and technological personnel is becoming a major mechanism for technology transfer via research networks and international collaborations, often between more and less developed regions and countries. These networks and collaborations develop their full potential through the mobility of scientific personnel and the links they create as they pursue their careers. This paper reports data from a recent study concerning more than 10,000 scientists currently working in Asian countries and Australia but who are also developing links with Africa, the Middle East, Latin America and Pacific countries. The paper focuses on joint publications as a way of indicating developing linkages. The focus is Asia but the study has relevance to other areas of the world and could be taken as a model for investigating and highlighting developing knowledge hubs in Africa and indicates areas for further public policy attention.

Keywords: Mobility of scientists and knowledge personnel; knowledge flows, knowledge networks, human resource development; regional technology development; human resource collaboration; research collaboration and learning.

Introduction

The apparent loss of scarce skilled personnel, the ‘brain drain’, from developing countries to the richer nations has been a pervasive concern for many years (Kapur and McHale 2005; Zweig 2007) This loss has frequently been seen as ‘stealing’ human capital from those who can least afford it. Patterns of mobility of skilled personnel have altered over the years, perhaps first affecting on a large scale scientists from China and India who went to the USA and the UK, while in recent years some more developed nations, such as Australia and even the UK, have seen public disquiet about the loss of science and technology personnel. In Australia, there has been brain gain as public policy failures have meant that around 40% of doctors working in Australia have been trained overseas, often in countries that cannot afford to lose them.

National policies for science, technology and innovation are now widely recognised as having an important impact on all countries, including the developing world. Higher education was rather neglected for many years in Africa following reports that suggested that the best investment was in primary education, but that is now changing. Recent discussions, for example, on the Science and Development Network website describe how countries, some donor agencies and several leading universities are developing partnerships for science and technology development in developing countries and a multitude of new models are emerging.

In Latin America, for example, Chile has recently (2009) launched a program for attracting centres of international excellence to encourage the development of leading edge technologies that address Chilean issues, especially related to maximising the value of the country’s natural resources (see Science and Development website). More than US$100 million is to be used to create five centres which will attract international top scientists to undertake leading edge work for a period of ten years. Each centre will receive US$19.5 million, 50% of its funding needs, with the international partners or the centres themselves to provide the rest. The announcement further shows the international interest in this approach by saying that the Fraunhofer Institute in Germany, the VTT (technology research organisation) of Finland and Australia’s CSIRO (national research organisation) have all expressed interest in being involved.

Uruguay has also instituted a program designed to capture the expertise of Uruguyan scientists working abroad. Under this program, beginning in 2009, US$107 million will be devoted to funding such scientists to return to Uruguay for periods ranging from 10 days to three months to work with local scientists and improve the standard of research in the country via postgraduate supervision, courses and projects. This program is intended to create a more dynamic vision of the brain drain by transforming it into brain circulation and ensuring Uruguayan scientists and technologists have access to the best in the world via the country’s expatriates. The problems underlying the need for this kind of program were shown in Arocena and Sutz in 2006 and may have been exacerbated since.

Two important issues arise from the discussion above and our work underlines the critical nature of these. The first is aid donors’ preference for choosing the areas of cooperation they invest in and their tendency to invest in single projects in these areas, notably in agricultural cooperation. An article by Olsson (11.3.09) recognises this, saying that:

> Sustainable research is best built on a broad foundation of core disciplines and facilities. And a vibrant research community not only produces research but also communicates “the world of scientific findings” to decision-makers, students and others who might use them. [However], most research funding in developing

> countries goes to commissioned studies in specific areas, prioritised for their potential to promote development – governments and external funding agencies are anxious to get immediately useful results.

In contrast, Olsson says, this approach is not the best use of resources: capacity-building is also an important objective and in most low-income countries any given project will have negligible effect on capacity-building and may even hinder it. The Swedish International Development Cooperation Agency (SIDA), for which Olsson formerly worked, takes a different approach. SIDA recognises the need to invest in at least one research-based university in each partner country and funds core facilities needed to improve the conditions for research, including laboratories, libraries and ICT infrastructure and training for academic staff; SIDA is, for example, helping rebuild Makerere University in Uganda through a long term (20-30 years) program. Importantly, it has also integrated support for research into its bilateral country cooperation strategies and has research advisors in country teams with research funding linked to strategic directions selected by universities and/or national science and technology policies as in Mozambique where the government initiated a national network to integrate locally-based S&T development discussions with national level policy debates. Disappointingly, Olsson goes on, other funding agencies have yet to support such broad strategies for research development.

Our paper also suggests that capacity-building is a critical focus for donor countries and partner universities to invest in. The data we present show the importance of strategically linking country development strategies and individual science and technology career choices so that capacity at home can develop systematically over time and home country investments are not ‘lost’. The present paper builds on a study of the mobility, career choices, research networks and active collaborations of nearly 10,000 Asian scientists and their co-publishing colleagues. The results of this study have been reported in Turpin et al. (2008), Woolley et al. (2008) and Marceau et al. (2008) and we provide only selected findings here to indicate how less developed countries can take national advantage from the career decisions taken by individual scientists and technology experts. The geographic mobility of scientists is both a driver and a consequence of international competition for personnel and the increasingly globalised organisation of scientific work (Mahroum 2000) as well as of policies developed ‘at home’ in countries of origin. Research into the production, retention and circulation of STHC and the structure of their careers has become increasingly important to policy-makers trying to fill scientific and technological roles (Fontes 2007; Laudel 2005) but has seldom been undertaken on a large scale.

The present paper focuses on some of the results of a further study, this time of co-publications and focuses on the less-developed countries of Asia. Our approach takes publications by scientists in these countries to show trends in collaboration in research and suggest the use of such collaborations that can be made by strategic policies to raise the level of science at ‘home’. At the same time, such policies can improve both the willingness of local scientists who have gone abroad from advanced training to return home and their capacity to create and maintain links with key international centres in their fields so as to provide continuing channels for the communication and use of leading edge knowledge producers worldwide.

Thus, to the plea by Olsson for funding for research infrastructure and capacity we add a recommendation that governments plan strategically for international cooperation and permanent links. Capacity-building investments by international donor agencies will provide the basis for high level work in low-income countries which, in turn, will encourage the return and brain circulation of top national scientists and publications diffusing new results to policymakers and trainee scientists alike as well as the international science and technology peer community.

As a background to this recommendation, this paper suggests that the overall development of science and technology in countries that were once ‘debtor’ nations in the science and technology personnel field is coming to mean greater scientific networking and collaboration across national boundaries and, further, that this trend is one that can provide strategic advantages for developing nations if public policies are tailored to maximise the benefits that can be gained. In Asia, for example, the ground has shifted in recent years and the Asian region has begun to emerge as both a significant locus for the production of knowledge and for investment in research and development (R&D). This emergence of a strong new scientific region is beginning to change the international dynamic of scientific and technological development. We suggest that this can happen elsewhere and benefit developing countries by providing a broader range of scientific and technological powerhouses for them to access as they need as they continue to develop their own capacity.

These developments are creating new networks, centred in older developed countries but growing links with newer ones, which have the potential to contribute to easing ‘brain drain’ concerns (Meyer and Wattiaux 2006; Mahroum and De Gutchneire 2006) as the emergence of new distributed knowledge networks (DKNs) has ‘…subverted the traditional ‘brain drain’ migration outflow into a ‘brain gain’ skills circulation by converting the loss of human resources into a remote although accessible asset of expanded networks (Meyer and Wattiaux 2006: 5). Our primary study of Asian Pacific scientists showed that both training and scientific careers in that region have created continuing links between countries both in the region and beyond but, also, and more importantly in the context of developing science, have created new networks of creation, distribution and maintenance of knowledge. Following Amin and Cohendet (2004), we see the networks thus formed as ‘connected capabilities’ located in specific places and enhancing local intellectual, material and practical capacities through network links with others in different places. The creation of trans-national innovation networks via international research training and the take up of early career post-doctoral research position helps create networks made up of local and expatriate scientists centred in developed countries but can also be the basis of links to newer ones, potentially transforming ‘brain drain’ into ‘brain circulation’.

These network relationships grow at differing rates in different countries, even in the Asian region. Some winners are already emerging and developing new scientific and technological hubs, with the countries concerned both growing their own STHC personnel and attracting such personnel from around the region and beyond. For these nations, notably Singapore, public investment has paid off handsomely and their scientific and technology systems, linked to other aspects of their national goals and innovation systems, are able to return value to the society through their contribution to economic growth. For them *brain gain* is significant. Other Asian countries still have much lower levels of scientific capability and rates of capacity-building (UNCTAD 2005); for them in particular, *circulation* of STHC and the associated ability to access centres of excellence regularly are important for science and innovation capacity-building.

The potential for developing countries to benefit from the new nodes of knowledge production is clearly there but encouraging brain circulation rather than gain and drain may need further intervention at an international level as well as more targeted and strategic national policies based on better environment scanning and targeted financing of research and research training.

The basis for the present paper is an analysis of co-authored publications by selected countries in journals listed by the ISC (for a detailed description of the study methodology see Turpin et al. 2008 and Woolley at al. 2008). The data are focused on the developing countries of South East Asia - Indonesia, Thailand, Malaysia, the Philippines and Vietnam and the locations of their publishing (and hence presumably researching) partners. Data have also been gathered for Singapore but this country is anomalous in this context as it has a highly developed science base, a higher standard of living and a more strategic investment in science-based industries and the attraction of overseas-trained scientists to work in Singapore. For this reason the data on Singapore are not presented in detail but only as they sharpen the picture. We complement this analysis with a brief look at Australian collaborations with the less developed Asian countries and with Africa. The approach and analysis presented in the paper are intended to provide a model that can be applied by policymakers in Africa and elsewhere who desire to develop local capability but have limited means and who need to make strategic choices about investment, preferably in partnership with international funding agencies and knowledge-generating organisations, whether in public or private sectors.

The analysis undertaken and presented here shows a complex picture of collaborations that have resulted in co-publications, whether with one other country (bilateral) or two or more (multilateral). The picture shows the importance of the degree of development of local science bases, the effects of historical association and geographical propinquity as well as strategic choices made by scientists as they develop their careers and governments as they invest in the development of their local science bases.

Discussion of the publications data suggest the importance of mobility by scientists so as to achieve desired collaborations and access to sophisticated science equipment and colleagues and that policymakers need to take strategic account of the collaboration phenomenon. Data we gathered from our earlier study of training and career paths of Asian and Australian scientists and published elsewhere (Turpin et al 2008; Woolley et al. 2008) show the critical importance of choices of locations for doctoral training and, especially, post-doctoral education. We present the most important findings as they affect our policy recommendations.

Part 1 Careers, collaborations and future policies

Building research careers in science: training, networks and collaborations

The data gathered in our main study show that five countries dominate choices of research training location and network creation for many Asian scientists: the USA, the UK, Australia, Germany and Japan. The data suggest a close relationship between selection of country of research degree and country of current work and between country of post-doctoral training and participation in current research networks since, as research engagement intensifies, new networks are developed and existing ones consolidated. While the ‘pulling capacity’ of major knowledge-centre countries will continue to attract scientific talent from other parts of the world, there are many people who return ‘home’ as scientific and technological careers progress and these provide conduits for sustained scientific interaction across national and organisational boundaries.

A fifth of all respondents with a research degree in our study did their research degree abroad. This is a considerable proportion for a developing region. Three main results are evident: first, marked diversity in the rates of international research degrees undertaken by respondents from the different locations shown; second, the considerable concentration in locations of international research training undertaken by respondents - the USA was the most common location for all respondent groups except Australia and China – and third, that most of the international training undertaken by respondents (except the Chinese) was located outside the region, notably the USA, the UK (7.3%), Germany (6.0%) and France (4.0%).

Individual training choices are in part a function of history, as seen in the choices of many Indian scientists to train in the UK, or relate more specifically to opportunities, as in choices by many nationals to go to the USA, as well as geographical propinquity. Young scientists were considerably more likely to go abroad for the post-doctoral training essential now for a research career in science than for doctoral studies: almost a third of respondents with a research degree from the six major countries studied had undertaken post-doctoral research training abroad, indicating a very high level of international mobility at post-doctoral stage. Given the high level of competition for many post-doctoral positions, these respondents represent an elite group of STHC and are thus especially valuable players both in their new countries and potentially 'at home'. Responses from the ASEAN bloc, comprising 10 less-developed Asian countries, show a strong outward movement for research degree preparation, directed toward the UK, the USA, Australia and Japan. An even greater proportion went overseas for post-doctoral study, with 80 per cent completing their studies in a country outside the ASEAN region. This trend probably represents the currently relatively poorer alternatives for studying at high level at home but is the basis for long term links.

Returning home

Countries where policymakers are considering the risks and advantages of sending their bright young scientists abroad for training may be interested to hear that return rates were very high in most countries, though not necessarily immediately on completing training, reaching 75-90% for nationals of the richer countries in the region. While **Chinese** return rates were lower, they nevertheless reached almost two thirds (62%). Comparatively good or improving opportunities overseas are important but growing R&D investments in India and China, particularly in the increasingly sophisticated special economic zones, are likely to provide growing opportunities for careers 'at home'. In contrast perhaps, as scientific engagement increases through post-doctoral studies and research sabbaticals, scientific mobility and on-site collaboration in these areas may also increase. As inter-country activities expand, they will also offer new opportunities for both doctoral research and post-doctoral training. Sophisticated research infrastructure and the opportunities to collaborate with world class researchers are important factors pulling scientists to particular areas, including home countries in the region. These are factors that can be used by policymakers to advantage when considering how to support people from developing countries requiring sophisticated training in science. Given that the facilities available and the expressed desire to continue collaborations were important factors in decisions about whether and when to return 'home', policymakers will need to ensure their scientific and technical personnel have periodic but guaranteed access to the locations that nurture their skills in science and hence their capacity to lift capability in their home countries. This again is a factor for aid agencies to consider when funding investments in poorer countries.

Relationships between research training, post-doctoral and the trans-national sharing and production of knowledge

The data gathered in our study suggest strong relationships between destinations for training and early career research positions and the location of both later networks and collaborative partners, patterns which, begun in the early stages of a career, persist into longer term work despite differing cultural attributes, such as language, political conditions in particular locations and socio-economic factors affecting access to research infrastructure or other resources.

International research networks are vital conduits for sharing techniques and other knowledge while collaborative research projects are a particularly close form of working in the same field as others. Technology transfers can occur through both these avenues, building and extending DKNs in the process but may have different roles and come into play at different times. Research projects are more often formalised institutionally (and supported financially) than are the more informal activities of research networks and posts within those projects may be a funded way for scientists from less developed countries to gain specific knowledge and skills. Both national and international policymakers should consider this option but also place it in the context of funding the infrastructure needed.

Mobility and field of research

Four observations stand out from our data. First, all research fields showed a correlation between the location of scientists' research degree and location of their main international network. With the important exception of engineering, for all fields of research the relationship between location of post-doctoral position and country of most important collaboration was considerably stronger even than the correlation between location of research degree and most important collaboration. Second, the USA is the country of choice. Third the concentration of networks and collaboration is considerably stronger (more narrowly focused) for some fields of research. For example, nearly 50% of all post-doctoral appointments in medical and health science were undertaken in the USA, compared to only 19% in maths and computing sciences. These differential concentrations are reflected in the location of networks and most important collaborations. Fourth, while the USA dominates in all fields, the influence of post- doctoral training among the other main developed countries varies according to field. Germany, for example, is among the top five network and collaboration locations in life sciences and chemical sciences but is far less important for medical/health and maths and computing sciences. China is important for the latter field and for chemical science but less so for medical/health and life sciences. These factors again underline the importance for policymakers in developing countries of considering carefully how much value any proposed overseas training and collaborations may have for the country of origin.

Reasons for moving

Desire to collaborate is a critical reason for scientists moving country. The largest group (32%) of respondents who identified another country in which they would like to work indicated a strong desire to consolidate both existing collaborations and networks. Then came desire 'to gain access to better research infrastructure' (21%) and 'to be part of a scientific community or intellectual climate' (21% each). These three factors combined suggest strong 'pull' factors from areas where there is a well-established 'knowledge centre' in a given field. The US continues to be highly attractive to overseas scientists who see it as containing most of the world's leading edge scientific and technological work. This places a special responsibility on US organisations recruiting and training scientists from low-income countries.

Scientists from the poorer nations in our study, the ASEAN group, were more concerned with seeking higher salaries and moving to an organisation with more prestige or simply seeking to move as an alternative to working in their current location. This again is an issue which needs to be addressed by national research policies and can perhaps be mitigated by more sophisticated targeting and provision of career options which involve spending periods overseas in return for transferring the knowledge and technology thus acquired on return to the home nation.

In summary, a desire to consolidate work with colleagues in the context of a high level of technical research infrastructure and support are the main reasons for mobility for scientists throughout the Asian area. The process is inherently self-reinforcing; as overseas research experience intensifies through post-doctoral research so too does the formation of scientific networks. As these links develop further over time the desire to ensure their continuation and deepening become increasingly powerful attractors. Later in careers, it seems that choices are in good part a function of investment by governments in particular areas of science and the industry development strategies that often go with them. The decisions taken by Singapore, for example, to invest very heavily in IT and then in biotechnology and in the attraction and retention of major leading edge firms in IT and the attraction and creation of biotech firms seem to have paid off in the high level capacity of a very small country to attract excellent science and technology personnel (Kesavo, 2007a and 2007b). There may be some policy lessons for others here.

In the following sections we explore the practical consequences of such choices and opportunities for different countries in the region. The data reveal two trends, one towards concentrating scientific expertise in the economically dominant countries and the other towards the emergence of a small number of new knowledge hubs where there are growing expenditures on science and technology.

Part 2. Collaborative publishing patterns

This section of the paper presents data from an analysis of scientific publications in the ISC lists to show patterns of co-publication, whether bilateral or multilateral, that can develop from patterns of international scientific research training undertaken by scientists in the lower-income countries of Asia, with Singapore presented as the contrast and potential for future development elsewhere. We show this to demonstrate the role of international work in developing high quality science and how scientists in developing countries can develop reputations for excellent work in particular fields and expertise they can potentially take back to their home bases. We present the work country by country to show patterns over time and by research field.

Indonesia: The total number of journal articles with a least one Indonesia-based author was 6,691 for the period 1986-2008. Annual numbers were very small until around 1992 but have grown quite rapidly since then so that total publications in 2008 were around six times the early 1990s level. The growth in publications has been heavily concentrated in international co-publications, with articles featuring only Indonesia-based authors not growing in real terms over the past two decades.

Malaysia: The Malaysian pattern differs considerably from the Indonesian one in that the growth in publications (150% between 2002 and 2008) was due equally both to locally co-authored and internationally co-authored work. In 2008, the number of publications produced by solely Malaysian-based authors jumped strikingly.

The Philippines: Publication numbers for The Philippines have grown steadily since the mid-1990s, mainly via the number of publications including foreign-based co-authors.

The sharp rises in publication numbers in 2007 and 2008 were driven largely by an increase in the numbers of wholly domestically authored papers, however.

Thailand: Since around 2000, total numbers of papers with authors based in Thailand have grown rapidly from a small base. Total publications in 2008 were around 350 per cent of 2000 numbers, with particularly rapid growth in publishing activity after 2005. International co-publications make up a greater share of all publications than domestically authored papers. International co-publications were becoming increasingly important up until 2005 but from this point domestic papers grew more rapidly than international co-authorships. Overall, growth in both locally and internationally co-authored publications has followed a similar trajectory.

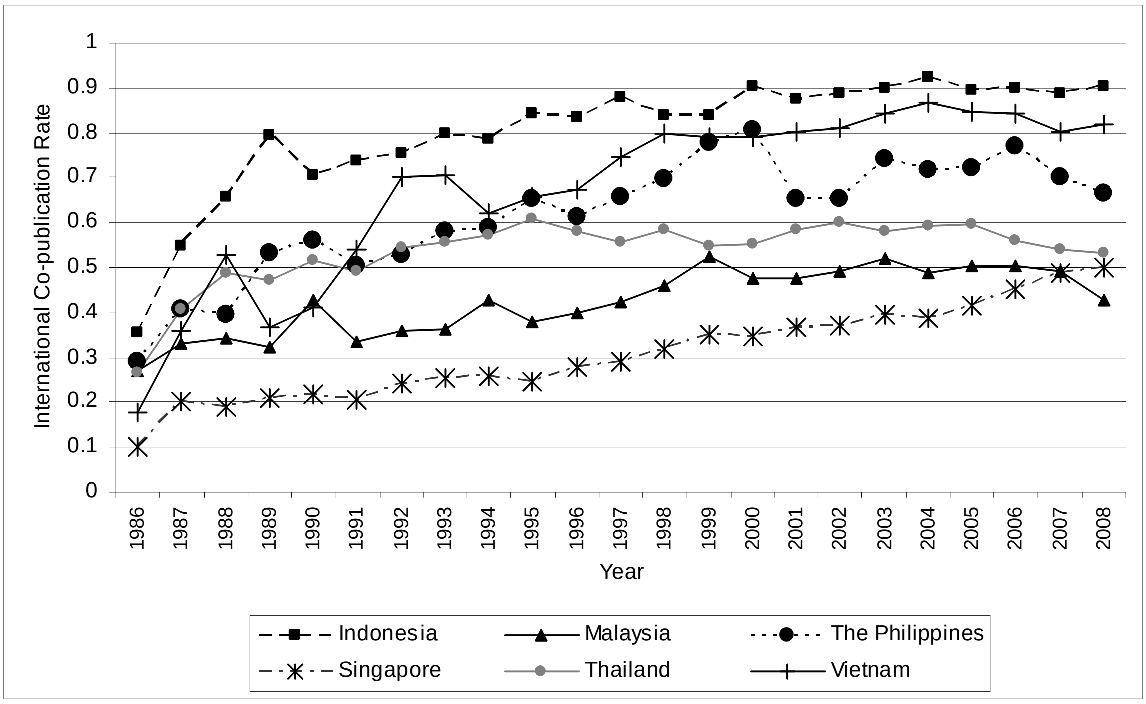
Vietnam: Total numbers of publications by Vietnam-based authors have grown strongly since around 2002. The vast majority of these papers include an international co-author. Growth in internationally co-authored papers has been rapid, whilst papers involving Vietnam-based authors only have also increased in number very recently (starting from a very small base). The degree of reliance on co-publication with authors based overseas parallels that for Indonesia. Similarity in the level of scientific capacity established in these countries probably lies behind the very similar co-publication patterns.

Singapore: Singapore presents an entirely different picture to the other countries in South-East Asia under discussion. From the start of the available data series, Singapore-based publication has been driven by domestic authors only, with international co-publication providing less than half of all papers until the late 1990s. Rapid acceleration in journal article publication from Singapore institutions has continued from around 1998, doubling in total numbers since 2000, starting from a much higher base than other countries in this comparison. International co-publication has been an important contributor to this growth, becoming proportionally the more significant contributor to this growth rate from around 2004. The total number of international co-publications reached parity with wholly domestically produced papers in 2007, as domestic-only production flattened out and international collaboration continued to surge.

In summary, there appear to be clear differences in the composition of publications viewed from the perspective of international co-authorships. Three countries analysed on this basis, Indonesia, The Philippines and Vietnam, had very similar high proportions of international co-publications. Recent sustained growth in publication numbers from relatively small bases are driven mainly by international co-publications. Some growth in publishing by domestic authors only was also evident in Vietnam. These results reflect the importance of international linkages in building scientific capacity, developing knowledge producing science institutions and engaging in dispersed scientific communities.

Data for Thailand and Malaysia showed similar trends in growth in both paper numbers and in the proportions of international co-publications. Figure 1 below shows each country's publication data for the period 1986-2008 converted into an international co-publication rate.

Figure 1. International co-publication rates, selected SE Asian countries (%)



The three countries with the highest comparative level of publication output have the three relatively lowest levels of international co-publication. This no doubt reflects the relatively high levels of scientific capacity Malaysia and Thailand, making these countries less dependent on international input to scientific knowledge production and giving them more capability to go it alone in the scientific publication stakes.

In contrast, however, it seems that countries with very high science capability at home move again towards international collaboration as a means of rapid knowledge generation and diffusion. Thus, the rate of international co-publication has grown most rapidly in recent years in Singapore, the country with the most highly developed science system of countries in the selected group. This rapid doubling of international co-publication probably reflects the rise of Singapore as a regional knowledge hub, associated with the location there of increasing numbers of foreign science and engineering professionals and which enables the building of co-publication networks back to their previous research and training locations, whether in the country of their nationality or elsewhere.

At the other end of the scale, publications from the countries with the less developed science systems in our sub-sample, Indonesia and Vietnam, are far more likely to involve internationally-based co-authors. While international co-publication rates seem more volatile in Indonesia, Vietnam and The Philippines because of the smaller numbers of publications, these rates appear to have largely stabilised at high levels - 90 per cent in Indonesia, 80 per cent in Vietnam and 70 per cent in the Philippines - in recent years.

Patterns of trans-national co-publication

Journal articles written by co-authors from different countries may involve either *bi-lateral* or *multi-lateral* collaborations. Analyses of co-publishing activity frequently focus on bi-lateral involvements but this approach can overlook the extent to which co-authorships are multi-lateral undertakings. In this section we highlight the major co-author locations, by country of institution, including the proportions of bi- and multi-lateral co-publications. For space reasons we limit ourselves to further examination of the location of only the major co-author but do highlight the locations of other co-authors involved in multi-lateral publishing activity. We also show the main subject areas of these collaborations. In order to show quite detailed data, in this section data Tables are broken in two. Data for Indonesia, The Philippines and Vietnam are displayed together with data for Malaysia, Singapore and Thailand in the second table.

Table1. SCI publications 1986-2008 co-author locations – Indonesia, Philippines & Vietnam

Indonesia		Philippines		Vietnam	
Co-author location	% of total country papers (n = 6,794)	Co-author location	% of total country papers (n = 6,525)	Co-author location	% of total country papers (n = 6,133)
Japan	22.3%	USA	22.1%	Japan	13.4%
USA	20.1%	Japan	15.4%	USA	11.2%
Australia	14.1%	Australia	6.7%	France	11.2%
Netherlands	10.2%	Peoples R China	6.1%	Germany	8.0%
Germany	6.4%	Germany	4.7%	England	6.6%
England	5.9%	India	4.5%	Australia	5.7%
France	5.6%	England	4.0%	South Korea	5.3%
Malaysia	3.5%	Thailand	3.6%	Netherlands	5.1%
Thailand	3.4%	France	3.3%	Sweden	4.2%
Canada	3.0%	Netherlands	3.0%	Thailand	4.1%
Peoples R China	2.6%	Canada	2.7%	Belgium	4.1%
Philippines	1.9%	South Korea	2.2%	Peoples R China	3.2%
India	1.9%	Singapore	2.1%	Italy	2.7%
South Korea	1.9%	Indonesia	2.0%	Russia	2.3%
Italy	1.8%	Malaysia	1.9%	Switzerland	1.9%
Scotland	1.7%	Taiwan	1.8%	India	1.9%
Singapore	1.6%	Vietnam	1.5%	Philippines	1.6%
Vietnam	1.4%	Switzerland	1.5%	Indonesia	1.6%
Switzerland	1.4%	Belgium	1.0%	Canada	1.4%
Belgium	1.3%	Spain	1.0%	Taiwan	1.4%

Source: ISI Web of Science database

Table 2. SCI publications 1986-2008 co-author locations – Malaysia, Thailand & Singapore

Malaysia		Thailand		Singapore	
Co-author location	% of total country papers (n = 8,080)	Co-author location	% of total country papers (n = 26,738)	Co-author location	% of total country papers (n = 58,760)
Peoples R China	7.1%	USA	19.2%	USA	11.5%
England	6.5%	Japan	12.4%	Peoples R China	10.3%
USA	5.9%	England	6.9%	Australia	4.3%
Japan	5.8%	Australia	5.3%	England	4.1%
India	5.1%	Peoples R China	2.8%	Canada	2.2%
Australia	4.0%	Germany	2.7%	Japan	2.2%
Thailand	2.9%	France	2.5%	Germany	1.6%
Singapore	2.7%	Canada	2.3%	India	1.4%
Germany	1.6%	Malaysia	2.0%	Taiwan	1.2%
Canada	1.5%	Netherlands	1.8%	France	1.0%
Scotland	1.5%	India	1.3%	Malaysia	0.9%
Indonesia	1.3%	Switzerland	1.2%	Switzerland	0.7%
France	1.2%	Sweden	1.2%	South Korea	0.7%
South Korea	1.1%	South Korea	1.1%	Sweden	0.7%
Iran	1.0%	Austria	1.0%	New Zealand	0.6%
Netherlands	0.8%	Singapore	1.0%	Scotland	0.6%
Philippines	0.7%	Vietnam	0.9%	Netherlands	0.6%
New Zealand	0.7%	Philippines	0.9%	Italy	0.5%
Belgium	0.6%	Taiwan	0.8%	Thailand	0.5%
Taiwan	0.6%	Indonesia	0.8%	Hong Kong	0.3%

Source: ISI Web of Science database

As Table 1 shows, Indonesia and the Philippines-based authors have relatively high levels of co-publishing with colleagues in the USA, with one in every five papers featuring a US-based co-author. Indonesia-based authors have an equally strong co-publishing rate with Japan-based authors, with Australia- and Netherlands-based authors co-publishing one in every ten papers with Indonesia. This pattern may result from historical links with the Netherlands and geographical proximity with Australia. Japan and the USA are also the major locations of co-authors for Vietnam-based authors, with France and Germany-based co-authors also prominent.

Malaysia-based co-authors are less strongly focussed in particular locations. First comes China, but only at a rate of around one in every fifteen published papers. Thailand-based authors have a particularly dominant co-publishing relationship - this is with USA-based authors, at one in every five papers – while Japan provides co-authors for one paper in every ten. Quite strong levels of international co-publication are evident between the six countries in this SE Asian group.

Table 3. Co-author locations, selected countries SE Asia, 1986-2008

Co-author location	**Papers (n.)**	**% of all papers (123,030)**
USA	16,482	13.40%
Japan	8,957	7.28%
PR China	8,814	7.16%
England	6,512	5.29%
Australia	6,417	5.22%
Germany	3,185	2.59%
France	2,750	2.24%
Canada	2,625	2.13%
India	2,619	2.13%
Netherlands	2,143	1.74%
South Korea	1,476	1.20%
Taiwan	1,309	1.06%

Bi-lateral relationships or multi-lateral networks?

In this paper we distinguish between bi-lateral and multi-lateral co-publication activity. Data for the two most prominent co-publishing clusters for each of the six SE Asian countries were analysed to determine the extent of bi- and multi-lateral publications. Japan and the USA were the two most common locations of co-authors for Indonesia, the Philippines and Vietnam. Table 4 summarises data for these co-publishing clusters.

Table 4. Bi-lateral and multi-lateral co-publishing, Indonesia, Philippines & Vietnam

Author Country	**Co-publisher Country**	**Total Papers**	**Bi-lateral Papers**		**Multi-lateral Papers**		
		N.	*N.*	*%*	*N.*	*%*	*Additional co-publishers (% of multi-lateral)*
Indonesia	Japan	1500	1194	79.6%	306	20.4%	USA 6.0%; Thailand 3.2; S Korea 3.0; Australia 2.4; PRC 2.1
	USA	1357	700	51.6	657	48.4	Australia 7.9; Japan 6.7; Thailand 5.7; Netherlands 5.5; England 5.1
Philippines	USA	1425	816	57.3	609	42.7	PRC 9.9; Japan 8.5; India 6.0; Thailand 5.8; Australia 5.5
	Japan	993	715	72.0	278	28.0	USA 12.2; PRC 7.9; S Korea 5.0; India 4.6; Thailand 4.1
Vietnam	Japan	800	558	69.7	242	30.3	USA 6.0; PRC 5.2; S Korea 4.6; Thailand 3.9; Germany 3.2
	USA	671	302	45.0	369	55.0	England 9.0; Thailand 9.0; France 8.1; PRC 8.0; Australia 7.7

Source: ISI Web of Science database

The relative importance of bi-lateral and multi-lateral publishing is also likely to be a function of how scientific work is conducted, the nature of collaboration and types of contributions made by participants (Laudel 2002). What is evident is that the level of multi-lateral co-publication is significant in each case. There is more multi-lateral than bi-lateral co-publication between Vietnam-based and USA-based authors. Additional co-authors are most commonly drawn from the same locations as bi-lateral co-publications.

The apparent difference in amount of multi-lateral publishing when co-authors are based in Japan or the USA is striking. The amount of multi-lateral co-publication for the six groupings shown in Table for the period 2001-2008 has been consistent for all years and base countries, suggesting that the focus on either bi-lateral relationships or more diffuse networks may be related to differences in the organisation of international collaboration with Japan and the USA. Multi-lateral collaborations have been growing over recent years and may also be a function of the level of development and volume of knowledge production of our three relatively small producers of scientific paper. It is useful then to compare these results with those for the three larger producers of scientific papers in our SE Asian group.

Table 5. Bi-lateral and multi-lateral co-publishing, Malaysia, Singapore & Thailand

Author Country	Co-publisher Country	Total Co-authored Papers	Bi-lateral Co-authored Papers		Multi-lateral Papers		
		N.	*N.*	*%*	*N.*	*%*	*Additional co-publishers (% of multi-lateral)*
Malaysia	PR China	1262	972	77.6%	283	22.4%	Thailand 10.7%; Singapore 5.8; USA 4.9; Australia 4.3; Japan 3.9
	Japan	1025	697	68.0	328	32.0	USA 8.8; England 6.3; S Korea 5.6; Thailand 5.3; PRC 4.8
Thailand	USA	5055	3496	69.2	1559	30.8	England 5.8; Japan 5.0; Australia 4.4; PRC 3.4; Canada 2.7
	Japan	3245	2552	78.6	693	21.4	Japan 7.7; USA 2.7; Australia 2.2; England 2.0; S Korea 1.7
Singapore	USA	6612	4383	66.3	2229	33.7	PRC 9.6; Australia 5.3; England 4.6; Canada 4.0; Germany 3.2
	PRC	5863	4454	76.0	1409	24.0	USA 10.8; Australia 4.2; England 2.9; Japan 2.3; Taiwan 2.3

Source: ISI Web of Science database

Table 5 shows the extent of bi- and multi- lateral co-publication for Malaysia, Thailand and Singapore. Again, multi-lateral co-publication rates are significant, with at least one in every five internationally co-authored papers being multi-lateral. In the cases of Malaysia-Japan, Thailand-USA and Singapore-USA co-publications, the rates are around one in three papers being multi-lateral. Overall, multi-lateral co-publication rates are lower than for Indonesia, the Philippines and Vietnam. Over the period 2001-2008 there seems to be an overall upward trend in multi-lateral co-publication. In particular, multi-lateral co-publication is growing in significance for Singapore-USA, Malaysia-Japan and Thailand-USA.

In summary, multi-lateral publication is an important part of scientific knowledge generation in these emerging SE Asian countries, especially for the smaller knowledge producers and especially in relation to the USA where collaborations are multilateral. It seems that as time goes on and the scientific base of a country develops greater capacity, international co-authorship is likely to grow. Malaysia, Thailand and Singapore produce far greater numbers of internationally co-authored papers and there are clear signs of increasing levels of multi-lateral collaboration in this activity. Singapore’s strong collaborative relationship with PR China appears to be taking on a more multi-lateral networked form over time. Thailand also appears to be broadly involved in multi-lateral co-publishing activities with many of the countries. Judging by co-publications data then, it seems that distributed networks of scientific workers are an increasingly common form of organization of scientific work contributing to the development of science systems and knowledge production in the SE Asian region.

Scientific subject areas

The extent and range of international co-publication, both bi- and multilateral, very by the research fields in which researchers based in different countries are working. Data for each of the main publication clusters in the countries in focus here are provided for the period 2001-2008 so as to show more clearly which current areas of scientific endeavour.

Table 6. Co-publications cluster subject areas, Indonesia, 2001-2008.

Japan as Co-author		USA as Co-author	
Subject Area	*% of total (n = 770)*	*Subject Area*	*% of total (n = 740)*
Pharmacology & Pharmacy	6.1%	Public, Environmental & Occup. Health	11.1%
Plant Sciences	5.7%	Tropical Medicine	7.7%
Chemistry, Medicinal	5.6%	Infectious Diseases	7.4%
Agronomy	5.1%	Ecology	7.2%
Biochemistry & Molecular Biology	4.9%	Environmental Sciences	6.5%
Biotechnology & Applied Microbiology	4.7%	Plant Sciences	5.9%
Chemistry, Multidisciplinary	4.3%	Zoology	5.9%
Chemistry, Organic	4.2%	Immunology	5.7%
Soil Science	4.2%	Microbiology	4.7%
Physics, Applied	4.0%	Multidisciplinary Sciences	4.7%
Forestry	3.9%	Geosciences, Multidisciplinary	4.3%
Geosciences, Multidisciplinary	3.9%	Genetics & Heredity	4.2%
Materials Science, Multidisciplinary	3.6%	Pharmacology & Pharmacy	3.9%
Microbiology	3.6%	Nutrition & Dietetics	3.6%

Source: ISI Web of Science database

Some differences appear in the focus as between clusters in the countries concerned in the analysis. The co-publishing cluster Indonesia-Japan is focused on agriculture, chemical sciences and pharma whereas the Indonesia-USA cluster appears to be oriented toward population health and disease research. Overall, the category Public, Environmental and Occupational Health is the largest subject area for Indonesia-USA co-publications. The most common locations for co-authors on multi-lateral publications in this area are Thailand (11 papers), India (7) and Vietnam (7), with only one including a Japan-based co-author. Both co-publication clusters include 44 papers in the Plant Sciences area but only six of these overlap (ie feature both Japan- and USA-based authors.

It therefore seems that co-publications with Japan and USA-based scholars represent quite separate organizing of collective knowledge production and different strategic choices made by the scientists concerned. These choices may represent involvement in areas of perceived strength in the overall science capability of Japan and the USA.

Similarly, while data on areas of collaboration among Philippines-based scientists and their overseas colleagues suggest some overlap in publication clusters or collective knowledge-production organization involving both USA- and Japan-based researchers, the overall picture when considered in, for example, Plant Sciences, Agronomy and Multidisciplinary Agriculture suggests two quite distinct clusters working on similar scientific areas. This suggests both that scientists are quite selective as to whom they collaborate with, for what purposes and where, rather than it simply being a matter of convenience and that as knowledge-hubs emerge and deepen they attract additional scholars from elsewhere. In Vietnam, the picture is similar, with plant-related science collaborations more common with Japan and health-related with the USA.

In contrast, the two international co-publication clusters of Malaysia-based scientists are very different in subject area. The smaller Malaysia-Japan cluster appears most active in areas of capability evident in Japan-based co-publications with Indonesia, the Philippines and Vietnam and has consistently included a relatively high rate of multi-lateral co-publications as compared with most other Malaysia-, Singapore- or Thailand-based clusters. Work with China, on the other hand, is very heavily concentrated in crystallography and other chemistry-based areas involved in the broader field of materials science. A second large crystallography co-publications cluster involved India-based authors (321 papers), with Thailand-based authors the most common additional co-publishers of papers in the field (54 papers). While the clusters in this field seem separate, it may be that Thai scientists are creating indirect links between them.

Overall, the international co-publication clusters of Malaysia, Singapore and Thailand appeared more differentiated from each other, probably reflecting greater levels of capacity and the development of strengths in particular specializations as well as strategic choices by scientists. It seems as though scientists (and perhaps their governments) within the countries concerned have selected what they see as priority areas for collaboration following the perceived strengths of the partner countries. They are able to pursue these choices more systematically and over a greater range of fields and partnerships the higher the capacity of the countries seeking the partnerships. Thus, the collaborations of Thailand and Malaysia, and especially Singapore, are both broader (more multilateral) and deeper, reflecting specialisation in particular sub-areas as well as overall fields.

The Australian –African axis

Our data do not provide much specific comparative information on links between different countries and African nations. We do, however, have some information on one developed country's publication collaborations with Africa, a set of less -developed Asian countries, Japan, the key international partner for all our scientists, the USA, and an emerging science powerhouse, China.

Table 6 Australian co-authored publications with authors at institutions in selected country/regions: 2001-2008

Year (number of publications)	*Africa*		*ASEAN*		*USA*		*Japan*		*PRC*	
	n co-authored publications	% all Australian papers	n co-authored publications	% all Australian papers	n co-authored publications	% all Australian papers	n co-authored publications	% all Australian papers	n co-authored publications	% all Australian papers
2001 (n=16829)	187	1.1	316	1.9	2423	14.3	467	2.8	412	2.5
2002 (n=17004)	149	0.9	413	2.4	2415	14.2	475	2.8	535	3.2
2003 (n=18,837)	213	1.1	481	2.6	2571	13.7	520	2.8	669	3.6
2004 (n =18,230	221	1.2	457	2.5	2725	15	489	2.7	762	4.2
2005 (n =20944)	267	1.3	582	2.8	3039	14.4	588	2.8	859	4.1
2006 (n =21867)	289	1.3	572	2.6	3186	14.6	990	2.7	990	4.5
2007 (n=22320)	294	1.3	688	3.1	3295	14.8	615	2.9	1215	5.4
2008 (n =27506)	371	1.3	854	3.1	4030	14.7	692	2.5	1683	6.1

The overall number of publications by scientists based in the countries studied between 2001 and 2008 has risen considerably. Papers co-published by Australians with colleagues in the USA and Japan have remained fairly constant in proportional terms. The proportion of co-authored papers with ASEAN countries (largely driven by Singapore and Thailand) have increased and those with China have increased significantly. Co-publications with African institutions have grown in number of papers but because of the considerable overall increase in the numbers of papers co-authored internationally by Australians the proportion with Africa has only just kept up with the overall proportional increase. The considerable growth in Australian collaboration with China and ASEAN countries compared to the African situation suggests that there is an urgent need for governments, institutions and scientists themselves to examine their co-authorship patterns with other leading science countries. This would enable policymakers to assess whether African science is being left further behind growing knowledge hubs in other parts of the world and to examine patterns of co-publication by Africa-based researchers both in terms of countries of linkage and field of research so that they can make informed decisions about choices of strategic collaborations.

DISCUSSION AND CONCLUSIONS

This aim of this paper has been to use our study of the growth of Asian science and engineering as seen through the training and career trajectories and the mobility undertaken by STHC personnel that is emerging fast throughout the region. This provides a functioning example which could be used by African and other developing countries science policymakers as the basis for making more targeted and strategic decisions about how to fund and shape the training and career paths of their valuable science and technology research personnel. We have indicated the importance of international training at doctoral levels and, especially, at post-doctoral levels for the potential upgrading of science and technology and, to the extent that innovation depends on S&T, to innovation levels in different countries. We have shown the different trajectories followed by younger and older scientists and engineers from the different nations in the Asian region since better understanding of researchers' motivations and outcomes can underpin better policies in the field since our results may indicate what is possible elsewhere. We have shown the motivations that keep many wanting to stay away from 'home' or to move countries, indicating the importance in these of maintaining and expanding the research networks and collaborations built over the course of training and careers. Managing the development of science research careers through the 'passage points' of international research training and/or international post-doctoral positions is critically important for many countries seeking to acquire globally competitive innovative capabilities and participate fully in the effective emerging spatial distribution of scientific and technological skills and knowledge.

The potential for effective technology transfer through the moves made by these personnel is considerable and could be built on further in the development strategies of a much broader group of nations. Comparatively good opportunities at home in major countries of the Asian region (Japan, China, Korea) and some of the smaller ones (Singapore and Thailand) for scientists' career choices are factors at play but growing R&D investments in India and China are also likely to provide growing opportunities for creative jobs for scientists from overseas and provide growing foci for collaboration through distributed knowledge networks. Many newly developing countries can follow this pattern, selecting carefully the countries with whom they can most usefully collaborate with a view both to further knowledge generation in a field and for technology transfer in already developed fields. As scientific engagement increases through post-doctoral studies and research sabbaticals, it is likely that scientific mobility and on-site collaboration in these areas will also increase and as these inter-country activities expand, they will offer new opportunities for both doctoral research and post-doctoral training. Sophisticated research infrastructure and the opportunities to collaborate with world class researchers in creative companies as well as in well-functioning public sector knowledge institutions are important factors pulling scientists to particular areas, including their home countries. It is *access* to this infrastructure, not ownership of it, that is critical for further local science development. Obtaining the return on years of investment in science and technology personnel may require some imaginative rethinking of local science and technology systems and policies, especially in small countries (such as Botswana) and the still mainly agricultural, such as Kenya which is already developing good international research and publication links with the world class agricultural research undertaken for decades in Australia.

Findings from both studies presented here underscore the importance of STHC personnel and policies for attracting and retaining them in the creation of emerging knowledge hubs in the Asian region, notably Singapore. Scientists and engineers move across both organisational (firm or public sector institution) and national boundaries as they pursue their research training, especially at post-doctoral level, and careers which usually involve collaborations and long term relationships. Their movements are critical to the process of network building and enable the less well-resourced to share in the investments of relevant others. Once such networks are formed they tend to continue to be powerful influences on career decisions taken by STHC from all countries. Nations seeking to gain benefit from these networks must recognise more explicitly that while where people *are* at any point is important, where they have *been* and the research, institutional and networks they have *left behind* or *brought with them are critical*. The movement of expatriates from specific countries into these dispersed networks brings a second benefit - diaspora networks which help to direct scientific discovery toward particular home-based issues. While the growth of the large economies of India and China may make it harder for some smaller and less developed countries to retain scientists within their own systems permanently, the integration between dispersed knowledge networks and diaspora knowledge networks is a promising phenomenon. International mobility does not necessarily mean that the 'losing' countries will have no benefit from their investment in the scientific education of their young people. Using the example of the health care professions, Maroum and colleagues suggest that sending and receiving countries could benefit by supporting links between senders and receivers in formalised development programmes. Capturing this benefit may require special policy initiatives and appropriate initiatives both by the countries concerned and/or international aid agencies.

The data presented in this paper on scientists' careers suggest at least one way forward. Post-doctoral studies offer powerful network building opportunities. Individual countries, perhaps in collaboration with others, may be able to devise career structures which enable their best and brightest who may be tempted to remain overseas after finishing their training to return for regular periods and teach or undertake specific projects at 'home'. Returning graduates of this kind bring with them much needed tacit knowledge about new scientific methods, equipment and promising areas of enquiry. Marceau and Preston (1994) showed how this worked in Australian science and how in at least one institution senior professors had long term strategies for maximising both the chances of their graduates going to the best places in their fields overseas and returning home from overseas. These senior scientists then rapidly integrated the knowledge returnees brought with them into the work of the labs to which they returned.

As Hassan (2008) and Olsson (2009) have argued, a sustainable home science base is essential for this to occur. Science policies in all smaller countries urgently need to be rethought to ensure access to the best centres overseas without the home countries losing out; much science can be undertaken through access to equipment and centres of excellence for periods and then followed through elsewhere. This approach makes returning much less of a 'once and for all' decision for scientists and provides access for the home country to regional knowledge hubs. The initiatives taken recently by Chile and Uruguay and briefly presented above are sensible ways into this issue.

International development efforts also could be usefully re-directed in similar ways. They could, for example, introduce post-doctoral awards for top young scientists to be taken up in *targeted* locations around the world, the location strategically selected according to the national scientific strength and research priorities of the various sending countries and locating specialists closer to regional knowledge hubs. Many policymakers may feel this is a risky option, one likely to further the loss of national talent from developing countries because it might potentially lead to a geographic 'brain loss'. Our view is that this approach should be seen as complementary to other development strategies that seek to build local scientific infrastructure and research management capacity at home. Non-Asian nations could usefully take deliberate steps to ensure that their region's growing 'diaspora' of science and technological personnel has benefits both for and beyond individual countries. The smaller and less developed nations also need to benefit from the mobility of their best and brightest innovation personnel. At present, it is not clear that they do so. Mobility without solid network building may create increasing inequalities in a poorer region but international arrangements, especially within the region, that enable STHC personnel to go 'home' but still regularly participate in leading edge science and technology development could act as a lever for the greater benefit of all. International donors could do well to coordinate their policies and collaborate themselves rather than competing with excessively specific project-based and ad hoc interventions and support policies.

In order to develop new policies that can be used to create well-functioning intra-regional or broader international scientific and technological knowledge networks, the managers of national science and technology (and innovation) policy need to understand how strong research networks emerge, the factors motivating the movement of the knowledge personnel who can create the networks and the push-pull factors that are likely to influence future patterns of international mobility. We have presented data in this paper which could underpin such new policies and hence the creation of better integrated and effective intra-regional arrangements among countries beyond Asia.

The data presented and our policy suggestions raise further important policy questions. These concern both the choice of areas in which to develop strength at home and the choice of which fields and countries to invest in to develop linkages leading to new knowledge generation and diffusion via publications. Choices may well need to be long term and consistent since the more publications a scientist in a country can show in a field, the more he or she is able to gain entry to international science networks, especially with the USA and Japan. Once some capacity is built, international co-publication seems to stabilise, in the examples here converging at around half of all publications as knowledge production levels grow. This highlights the importance both *of collaboration and of developing internal capacity in tandem* so that later multilateral collaborations become possible and enable even closer targeting on international strengths in selected fields.

Undertaking collaborative projects, a particular form of the trans-national organisation of knowledge production, involves the co-ordinated production of knowledge or knowledge-derived outputs through organisations distributed across trans-national space and may well involve the circulation of research personnel at several points during a career. Some links clearly persist for long periods, despite differing cultural attributes, such as language, political conditions in particular locations and socio-economic factors affecting access to research infrastructure or other resources. Specific research projects involve goal-directed activity so research collaborations are more often formalised institutionally (and supported financially) than are the more informal activities of research networks. Technology transfers can occur through both these avenues, building and extending DKNs in the process, but may have different roles and come into play at different times.

In order to develop new policies that can be used to create well-functioning intra-regional or broader international scientific and technological knowledge networks, the managers of national science and technology (and innovation) policy need to understand how strong research networks emerge, the factors motivating the movement of the knowledge personnel who can create the networks and the push-pull factors that are likely to influence future patterns of international mobility as they affect the chances of their countries. We have presented data in this paper which could underpin such new policies and hence the creation of better integrated and effective intra-regional arrangements among developing countries, especially if international donor agencies fund infrastructure and coordinate at least of their knowledge investment policies.

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