Knowledge Diffusion through Good Knowledge Governance: The Case of Singapore's Marine Cluster

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Introduction: Growth through Knowledge Clusters and Hubs

Exploitation and application of knowledge is a central feature of economic growth; knowledge that is diffused through the variety of channels by which human capital spills over within and across economies. Trade and investment are the best known channels but behind these aggregates are the choices and challenges faced by businesses and governments. International trade involves technical choices as well as the training and transfers of people. Knowledge embodied in stocks of R&D in the more advanced countries diffuses across borders through trade, foreign direct investment as well as alliances among unrelated firms. Modern information technology permits coordination of production and R&D activities with affiliates and unrelated partners. Production and assembly of components, marketing, procurement and, increasingly, R&D capabilities are locating in a growing number of Asian centers.

A deeper understanding is required of what is being transmitted, how that knowledge is used and lessons as to how to absorb knowledge effectively. When knowledge, data and information are imported without the necessary understanding of how they are used it is possible to fall into a "knowledge trap" (Menkhoff et al. eds. 2011) where efforts fail to raise productivity, increase innovation and, ultimately, sustain long-term growth. Even so, knowledge 'clusters' and 'hubs' have been developed across East Asia in the past few decades.

Knowledge clusters are central places within a wider structure of knowledge production and dissemination. More specifically they are agglomerations of production–oriented organisations in which knowledge is an output or input. We conceptualise a successful knowledge cluster as a local innovation system organized around universities and colleges, research institutions, think tanks, government research agencies and knowledge-intensive firms with the organisational capability to successfully drive innovations and create new industries (Evers, Gerke, Menkhoff 2010). The term *knowledge hub* refers to knowledge sharing and dissemination (Chay et al. 2010), which is distinct from the knowledge cluster concept that emphasises the organisational aspect of agglomerations. We define knowledge hubs as localities with high internal and external networking and knowledge sharing capabilities. Both form a new knowledge architecture of knowledge creation and dissemination.

Why do similar businesses tend to congregate geographically ("agglomerate"), a process which is deliberately planned and governed in land scarce Singapore? Once talent is attracted to a cluster, more businesses are pulled in in search of competent human capital as well as buyers or sellers. As clusters concentrate geographically, other market participants might anticipate foregone advantages if they do not join it which in turns enhances its efficiency and potential hub function. While rising business costs can theoretically lead to the decline of a cluster, proactive planning and good governance can work against such trends. Ideally, a spatial concentration of

knowledge producers and users (initially formed by agglomeration) can attract many new (dependent) businesses in the same area or region which in turn can increase its competitiveness.

A number of clusters have developed in Southeast Asia, the focus of this paper, some of them successful and others not. The primary aim seems to be to kickstart development processes. In the late 1980s, for example, Singapore, Malaysia and Indonesia created the so-called "SIJORI Growth Triangle" to leverage the competitive strengths of Singapore's infrastructure, capital, and technological knowhow and Johor's (Malaysia) and Riau's (Riau Islands, Indonesia) labour and land resources in order to attract more foreign and regional investment. Nearly thirty years later the spillover effects have been limited. More recently, Malaysia has developed a sophisticated development plan for the further development of the South-Johor Economic Region known as "Iskandar Malaysia" as a corridor for economic development. A key objective is to transform the physical and economic landscape of the Johore Bahru metropolitan area and to turn its cluster vision into reality, for example, by leveraging on its proximity to Singapore (see Map 1).

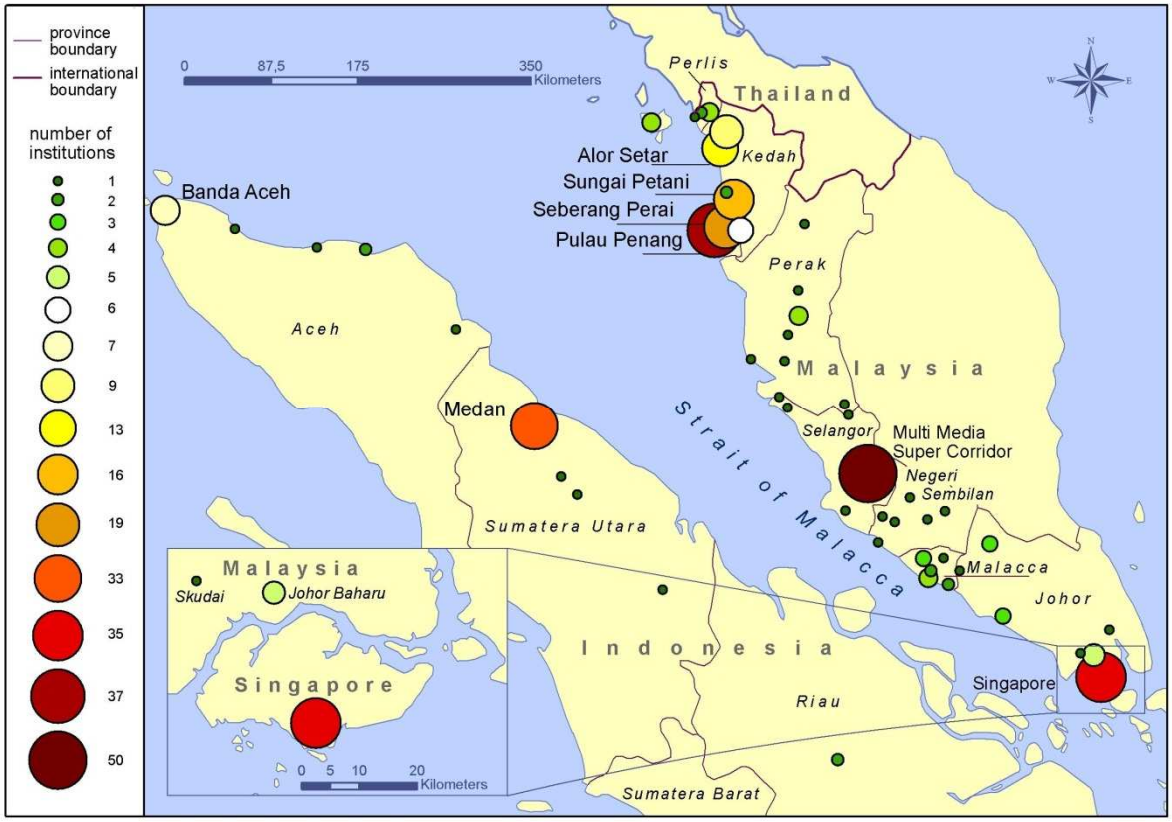
A significant policy assumption inherent in many efforts to take advantage of potential regional economic complementarities is that knowledge spillover will naturally occur in one way or another (Evers 2011). But as we argue in this paper, a key driver of realized complementarities is *good governance* in the sense that planning and action may be necessary to attract firms with strong knowledge bases to exchange with other entities; to create incubators and ecosystems that promote exchange and the creation of new knowledge.

Besides banking on an increased transfer of knowledge through FDI, as well as increased investment in education and R&D, experts are advocating the creation of knowledge hubs as the incubators of future economic development. In layman terms, a hub forms the effective center of an activity, region, or network. In academic terms, knowledge hubs (where the innovative action is) are nodes in networks of knowledge production and knowledge sharing where spillover and dissemination happens (Pinch et al. 2003; Henry and Pinch 2006). They are characterised by high connectedness and high internal as well as external networking and knowledge sharing capabilities. As meeting points of communities of knowledge and interest, knowledge hubs generate knowledge, transfer knowledge to sites of application, and transmit knowledge to other people through education and training. Knowledge hub creation know how is arguably a key enabler of knowledge-based development.

It takes time to develop knowledge hubs. They often emerge on the basis of earlier social and economic conditions; in other words they are strongly path-dependent. The institutions that were created in earlier times show their own dynamics and strongly influence outcomes at a later date. This statement goes beyond the simple assertion that history matters and argues that the *knowledge architecture* of clusters and hubs, as defined earlier, has its roots in local conditions and local knowledge as well as local concepts of knowledge (Hornidge 2007). Development strategies aiming at the creation of knowledge hubs and ultimately knowledge societies will produce different outcomes dependent on which location is chosen. Evers et al. have substantiated this argument on the basis of their case study of knowledge hubs in the Straits of Malacca region (Evers and Hornidge 2007).

The purpose of this paper is to illustrate the importance of good knowledge governance for creating robust and value-added knowledge clusters and hubs. In the next section we examine how Singapore has managed knowledge diffusion through knowledge clusters. The focus then shifts in the next section to the oil and gas industry in Asia and how knowledge spillovers are managed. The fourth section, a case study of the Singapore Marine Cluster, examines its knowledge architecture including some of the key actors, the roles of R&D, research and education collaborations and learning. Factors in the evolution of this cluster to regional hub status in the global industry are also examined. The fifth section concludes the paper.

Map 1: Knowledge Clusters along the Straits of Malacca



Source: (Evers, Gerke and Hornidge 2008; Evers and Hornidge 2007:426)

Knowledge Governance: Managing Knowledge Diffusion through Knowledge Clusters

We have argued that development-related knowhow requires effective mechanisms of transmission. Singapore has effectively managed *knowledge diffusion* via its export-led growth, continuous skills upgrading and human capital development, broadening of its industrial clustering, value added production and services and R&D (Koh 2006). Many of the multinational companies who have invested in Singapore helped to create training institutes and other learning mechanisms in support of the Government's development vision to systematically upgrade skills in line with industry needs. Policy-makers continue to access foreign markets through a web of free trade agreements led by IE Singapore, formerly known as the Trade Development Board (TDB). Today, Singapore's FTA trading network includes 18 regional and bilateral FTAs with 24 trading partners (http://www.fta.gov.sg/sg_fta.asp).

Since becoming independent in 1965, the small city-state has followed a policy of designating specific areas to house industrial (knowledge) clusters and identifying special areas of research and development to set up knowledge hubs. Besides the Economic Development Board (EDB), other key participating national planning bodies include Jurong Town Corporation (or JTC Corporation in short) whose mission is to plan, promote and develop a dynamic industrial landscape, in support of Singapore's economic advancement and the Urban Redevelopment Authority (URA), Singapore's national land use planning and conservation authority. URA's core purpose is to "make Singapore a great city to live, work and play in". Due to strong governance, political credibility, good and consistent planning and many other factors (Low 2001), Singapore successfully moved from the phase of labour intensive development in the 1960s-70s to the capital intensive stage in the 1980s-90s and eventually to the knowledge intensive stage (since 2000) with a stronger focus on an innovation-driven economy. The "committed developmental" (Low 2001) city-state provides a sustainable environment for high value-added products and services and qualifies as so-called knowledge city (Johnson 1982; Carrillo 2004, 2006; Hornidge 2006, 2007; Law 2008).

Singapore's knowledge-intensive industries include electronics / IT, chemicals, pharmaceuticals, petroleum refining, ship repair, offshore platform construction, financial services and life sciences / biotechnology. The emergence of high-tech clusters and hubs has been embedded in a wider knowledge-intensive landscape. Singapore's national knowledge capital was created by visionary policies supporting universities, research institutes and centres of applied research and development, and *tacit* knowledge imported through the immigration of foreign talent and overseas training schemes. This facilitated the leverage of an important principle of knowledge management, namely that knowledge is required to use and create more knowledge. It also entails deleting barriers to knowledge flows, building an ICT backbone, increasing knowledge assets, closing knowledge gaps, and developing a legal infrastructure that allows and encourages creative and diverse knowledge production.

The Singapore story suggests that without good knowledge governance and the skillful implementation of a suitable knowledge architecture, the successful development of a knowledge-based economy and society will be highly unlikely. We argue that Singapore's development success underlines the benefits developing countries and emerging markets can

achieve when policy-makers as knowledge architects govern knowledge effectively and succeed in crafting a specific institutional frame, i.e. a robust knowledge architecture to enable the marshalling of tacit knowledge and the use of proximity for competitive gains (Menkhoff, Evers, Chay and Gerke 2011). In ICT research, the term 'architecture' typically describes how a system or program is constructed, how it fits together, and the protocols and interfaces used for communication and cooperation among modules or components of the system. Similar to good governance at firm level, policy-makers charged with 'good' knowledge governance need to develop a sound basis for a k-economy to rise such as an effective national ICT architecture (as one of many enablers of knowledge clusters and hubs which drive value creation) or mindful decision-making when it comes to knowledge related policy reviews and strategy change in order to stay competitive.

While there is little empirical knowledge about the impact of different governance approaches, architectures or ICT regimes on knowledge flows, there is evidence that agglomerations develop a cluster-specific form of knowledge management that facilitates the rapid dissemination of knowledge throughout the cluster by increasing the learning capacity of proximate firms and thereby conferring cluster-specific competitive advantages. In short, good knowledge governance in conjunction with an effective knowledge architecture (and strategic knowledge management) are crucial determinants for the innovative capacity of firms, knowledge hubs and, indeed, entire knowledge clusters at national level.

Managing Knowledge Spillover in the Oil & Gas Industry

Evidence for Singapore's capability to make knowledge work is arguably its success in becoming a regional centre of the Asia-Pacific oil & gas industry. Shell, for example, was the first multinational which built a crude oil refinery on Pulau Bukom shortly after Singapore's attainment of self-government (1961). It was also the first company to make use of the Government's Pioneer scheme. Shell has been doing business in Singapore since 1891, when it established an oil storage installation here. While multinationals elsewhere continued to operate in at times dysfunctional ways, the Singapore Government managed to successfully engage the oil & gas giant as perhaps exemplified by the fact that Shell's performance management system became the basis for the talent management approach adopted by Singapore's civil service. As Singapore's Founding Prime Minister Lee Kuan Yew explained during the 120th anniversary celebration of Shell Singapore 2011:

> "I was intrigued by Shell's ability to have its talent pool spread out over more than 100 countries, yet be able to promote the right people. I found out that they had a panel that went around rating its people in all the different countries, assessing them for their Hair qualities - their helicopter ability, their powers of analysis, their sense of imagination and their sense of reality. I found that their criteria made a lot of sense" (Teo 2011).

The oil & gas industry continues to be of strategic importance for Singapore's economy. The Asia-Pacific oil & gas market (which includes Australia, China, India, Indonesia, Japan, New Zealand, Singapore, South Korea, Taiwan and Thailand) grew by 34.8% in 2010 with a market

value of $815.5 billion. By 2015 the market value is expected to reach $1,157.1 billion. Revenues from crude oil sales in Asia-Pacific totaled $710.8 billion which represented 87% of global revenues in comparison with natural gas sales which generated revenues of $104.7 billion (or 13 % of global revenues in the sector) in 2010. China accounts for 34.4% of the Asia-Pacific oil & gas market, followed by Japan with 19.9%, India with11.7%, South Korea with10.1% and the rest of Asia-Pacific with 23.9% (Data Monitor 2011).

Large, diversified and highly vertically integrated international companies dominate the market; they engage in oil exploration, production, refining, transportation and marketing. The prices for oil and gas are set by the mercantile exchanges of New York, London and Dubai. Leading Asian oil companies include Sinopec, China National Petroleum or Nippon Oil who maintain their own fleets of drilling rigs and invest heavily into equipment, technology and product innovation.

To benefit from these leading players and to attract them to invest, several conditions have to be met which include political stability, geographical hub formation, availability of technical talent or efficiency. Another one is the existence of robust R&D capabilities. Singapore is developing new manpower and R&D capabilities to meet the industry's growing demand. Singapore already has the largest base of oil & gas equipment manufacturing companies in Asia which manufacture sophisticated products such as down hole tools & equipment, wellheads, christmas trees [1] and drill bits (EDB 2006). Major international oil and gas equipment and service suppliers include Schlumberger, Baker Hughes, Smith International and Halliburton.

Planners expect that the development of specialised engineering talent, together with Singapore's research infrastructure and intellectual property protection regime, will motivate more global engineering firms to locate in Singapore the R&D activities related to new technologies required to meet the challenges of extracting hydrocarbons from deeper and more complex oil & gas fields.

Essential for the overall effectiveness of Singapore's economic marine cluster ecosystem is also the synergy between its constituting core elements such as the oil & gas sector, precision engineering industries and the offshore marine cluster. While Malaysia is eager to catch up and to position the proposed Tanjung Bin Petrochemical and Maritime Centre in south Johor (near Singapore) as an alternative oil & gas hub, Singapore still has the first mover advantage in terms of cluster cohesion and depth, external linkages, R&D vision and performance excellence. Let us now take a closer look at Singapore's offshore marine cluster whose evolution is closely related to the expansion of the oil & gas sector in Asia-Pacific.

Case Study: The Singapore Marine Cluster (SMC)

Background and Location Specifics

Traditionally, shipping and port related sectors have formed the backbone of Singapore's economy due to the hub function of the city-state and its strategic location as an ideal place for the docking and repair of ships, incl. oil tankers. Singapore's marine industry with its more than

5,000 maritime establishments represents more than 7.5% of Singapore's GDP (Marine and Port Authority of Singapore 2010). The industry is divided into three main sectors: (i) Ship Repair and Conversion, (ii) Shipbuilding and (iii) Offshore. Together with maritime services such as shipping finance, marine insurance and maritime legal and arbitration services, they form the Singapore Marine Cluster (SMC).

Total employment in 2010 was 106,800 workers and industry revenue totaled S$13.47 billion, down from S$16.83 billion in 2009. The offshore sector provided 60 % of industry earnings according to the Association of Singapore Marine Industries (http://www.asmi.com/index.cfm?GPID=310).

Many of the marine cluster companies are situated in close proximity to each other in the south-western region of Singapore called Tuas. The Tuas marine cluster is located close to the sea (ports) and incorporates many other marine-related companies who supply complementary products and services. With 70% of the global market share of floating production storage offloading (FPSO) vessel conversion, 70% of world market share for jack-up rig [2] building and 20% of world market share for ship repair, Singapore's SMC offers comprehensive services for customers worldwide such as repairs, conversions and new constructions.

As a knowledge centre, the maritime cluster has successfully put Singapore on the world map due both to good knowledge governance at national level and effective business management within the hub and participating firms.

Inside Singapore's Maritime Cluster: Key Governance Actors

Good knowledge governance is a key factor in the success of this cluster. Decisive and visionary knowledge governance by institutions such as Singapore's Economic Development Board (EDB), the Maritime and Port Authority (MPA), Agency of Science, Technology and Research (A*Star) in collaboration with Jurong Town Corporation (JTC) or the Urban Redevelopment Authority (URA) has played a key role in creating, maintaining and expanding Singapore's marine cluster. One example of a key governance task is the visionary master planning and master development of so-called "community-centred" industries by JTC in order to shape and optimize Singapore's industrial landscape. JTC continues to offer future-oriented infrastructure solutions to its cluster customers in order to maintain and improve competitiveness. Plans are under way to transform Jurong Island (home to close to 100 petrochemical companies with over $34 billion of investments) into a so-called "living laboratory" to develop technologies to save resources like energy, carbon, water and land. This includes projects aimed at finding ways to utilise waste heat to power production processes in line with environmental demands and sustainability concerns. As far as the offshore sector is concerned, JTC continues to increase Singapore's limited water land resource by building new wharves and jetty facilities.

Besides business acumen, research and development (R&D), talent development etc., the authorities managed to attract various shipping finance-related companies in order to expand the industrial cluster such as banks, boutique shipping investment banks, private equity arrangers,

shipping finance advisers, shipping finance conference organizers and publishers of maritime finance transactional information etc. It also launched the first clearing facility for freight and energy derivatives in Asia, SGX AsiaClear (2006), to further strengthen Singapore's position as a key hub port for oil and maritime commerce to serve the Asian energy and Forward Freight Agreements (FFA) market. To nurture a culture of "maritime vibrancy and buzz" (which is important for networking and knowledge sharing), new flagship events were launched such as 'Maritime Week' or the maritime conference-cum-exhibition 'Sea Asia'. For the future it is planned, to further grow other maritime services such as shipping finance, marine insurance and maritime legal and arbitration services
http://www.maritimecareers.com.sg/maritime_industry_shipping_article2.html.

Inside SMC: The Keppel Offshore & Marine Hub

A key corporate actor within the SMC is the Keppel group of companies (Sabnani 2007). Incorporated in 2002, Keppel Offshore & Marine has over 300 years of combined experience from the three companies under its wings, namely Keppel Fels, Keppel Shipyard and Keppel Singmarine (http://www.kepcorp.com/en/content.aspx?sid=80). With its key competency in the area of offshore engineering, *Keppel FELS* is the world's leader in offshore oil rig fabrication for international clients such as Petrobras in Brazil (see Table 1).

Keppel Shipyard specializes in marine engineering and is a global leader in the conversion of floating production storage and offloading (FPSO), floating storage and offloading (FSO) and floating storage and re-gasification units (FSRU).

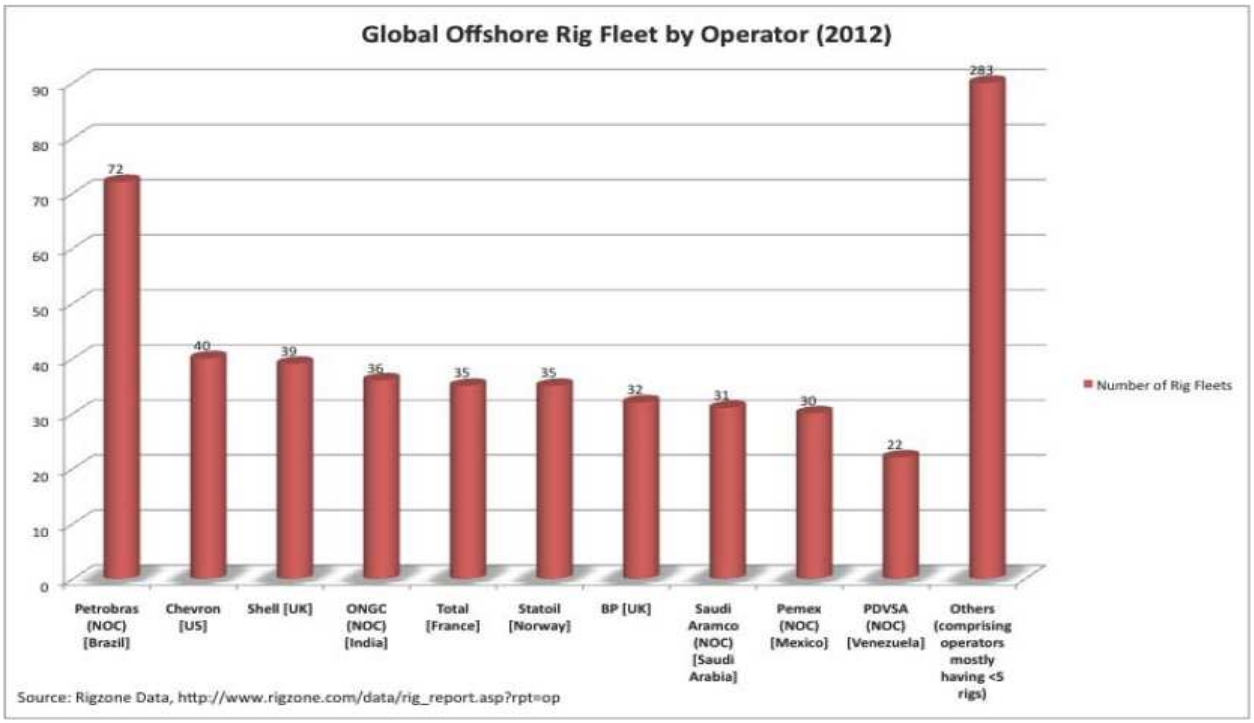
Specialized shipbuilder *Keppel Singmarine* creates value for both Keppel FELS and Keppel Shipyard because it provides the supporting vehicles required for ship conversion and oil rig fabrication.

In 2010, the Group managed to successfully complete 12 new built jackup and semisubmersible rigs, 5 major FPSP/FSRU conversion projects and 18 quality vessels worldwide 'safely, on time and within budget'.

As indicated in Table 1, the global offshore rig fleet is dominated by Brazil (Petrobras), followed by USA (Chevron), UK (Shell), India (ONGC), France (Total), Norway (Statoil), UK (BP), Saudi Arabia (Saudi Aramco) and Mexico (Permex).

Keppel Offshore & Marine's companies and yards are situated relatively close to each other within Singapore's SMC which facilitates knowledge sharing and creation, arguably key success factors in this business (Boschma 2005).

Table 1: Global Offshore Rig Fleet by Operator



Altogether, Keppel employs over 30,000 employees in more than 30 countries. In Singapore alone, the Keppel Group has a workforce of over 1,500 people. A substantial number of the workforce consists of foreign work permit holders who are recruited from China, India, Myanmar, Thailand, Bangladesh, Malaysia and Sri Lanka and work as welders, fitters, mechanics and other skilled laborers.

Keppel Offshore & Marine is well known for its innovative ultra deepwater solutions such as semisubmersibles, drilling tenders, or compact drill ships. It also built the first pair of icebreakers for customers in the West. Another project is the fabrication of ice-worthy jack-ups in collaboration with an international business partner.

Knowledge Creation through Research & Development (R&D)

Keppel's innovation capability in designing oil rigs is based on four specialized R&D departments (http://www.kepcorp.com/en/content.aspx?sid=80). The *Keppel Offshore & Marine Technology Centre* (KOMtech) concentrates on the R&D of new technologies, processes and competencies in line with business needs, including alternative energy applications as well as the development of designs, systems and critical equipments for rigs and ships.

The *Offshore Technology Development* (OTD) department is responsible for the technology-driven design of new generation jackup rigs and their critical systems. Through OTD, Keppel has developed a series of successful and highly sought after jackup rig designs such as the KFELS A

Class Series and KFELS B Class Series. Several critical rig components such as jacking, fixation, self-positioning and skidding systems which are used on Keppel FELS's jackup rigs have been patented by Keppel.

The *Deepwater Technology Group* (DTG) is specalised on deepwater rig designs. Through DTG, Keppel provides design and engineering solutions extending across semisubmersibles and various floating structures such as drilling tenders, accommodation semisubmersibles and drillships. Keppel continues to enhance its capability in the area of deepwater solutions through a joint venture with J.Ray McDermott that specializes in floating production systems.

The *Marine Technology Development* (MTD) unit focuses on the design and development of offshore support and maintenance vessels for various operating conditions. Through MTD, Keppel can provide customers with turnkey solutions in terms of equipment needs and ship design configurations. MTD's latest designs consisting of the first ice-class Floating Storage and Offloading vessel are deployed in the Caspian region. All R&D departments play a crucial role in Keppel's corporate strategy with its emphasis on customer needs, commercial viability, process improvement and knowledge building.

Collaboration with Research and Educational Institutions, incl. Joint Ventures

Keppel maintains linkages to various external stakeholders which helps the organization to create new knowledge and to innovate such as research and education institutes or joint ventures with related corporations. Reputable local collaboration partners include *A*Star, Ngee Ann Polytechnic (NP), National University of Singapore (NUS) and Nanyang Technological University (NTU).*

Like the other local institutions, NUS proactively supports Singapore's knowledge-based development aspirations (Wong, Ho and Singh 2007). Key elements include an offshore engineering program for talented students and the establishment of the *Centre for Offshore Research & Engineering* (CORE) in the Faculty of Engineering (NUS) together with the endowment of the Keppel Professorship in Ocean, Offshore and Marine Technology. The latter was launched in 2002 with a gift from Keppel Corporation Limited. Examples of joint Keppel-CORE projects are 'Improved Guidelines for the Prediction of Geotechnical Performance of Spudcan Foundations during Installation and Removal of Jack-up Units (InSafeJIP)' or the 'Spudcan-pile Interaction Joint Industry Project'.

Enhanced collaborations with local and international industry partners as well as international offshore marine experts (R&D) are aimed at further cementing Singapore's position as a top player in the global market for oil and gas drilling units and offshore support vessels. One example is Keppel's international collaboration with the Centre for Offshore Foundation Systems (COFS) at the University of Western Australia. Joint research areas include jack-up spudcan analysis, deep water anchoring systems and the application of geotechnical models in wind farm design.

Successful Knowledge Diffusion by Catalysing Real Learning

The Keppel success story points to a significant strength of Singapore's SMC cluster and the importance of what we call knowledge leadership on the basis of good strategic management, alliances, acquisitions, the ability to impart external knowledge into its own corporate system, knowledge sharing etc. As indicated on the website of Singapore's Association of Singapore Maritime Association (ASMI), Keppel's core competencies with regard to rig fabrication are also "anchored in Singapore history". Key ingredients include good timing, proximity to drilling sites, engineering capability, presence of foreign rig builders, acquisition of (foreign) rig know how and so forth. As Emeritus Senior Minister Mr Goh Chok Tong, then Minister for Trade and Industry, put it in Jan. 1981:

> "Through direct association with foreign rigbuilders, the industry has benefited from a transfer of technology and expertise. I believe that had our shipyards developed their rigbuilding capabilities on their own, the industry would not be in such a strong position today" (http://www.asmi.com/index.cfm?GPID=36#RIGBUILDING).

Like in other industrial sectors, Singaporeans were able to learn, master and expand newly acquired offshore marine skills quickly and with great efficiency. Heavy investment into education, particularly in science, technology and management, was conducive in building capacity based on a well aligned and well coordinated, systemic (cluster-oriented) national manpower planning approach with the active involvement of all relevant agencies.

Towards Regional Hub Status

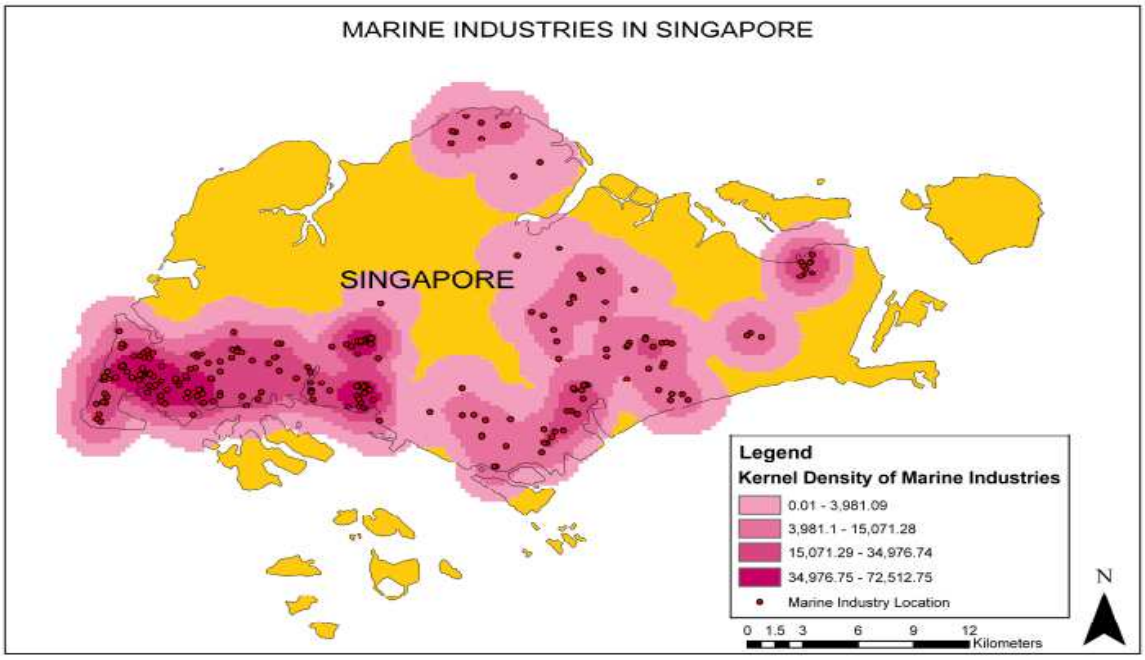
According to industry observers, Singapore's status as a "dominant force in the offshore marine sector" in conjuction with related services does support the growth of the industry across the region (Indonesia, Malaysia, Philippines), "positioning it as a regional offshore marine hub for the Asia-Pacific" (Hayman 2012). Like Dubai in the Middle East, Abuja in West Africa or Houston in the US, Singapore is seen a "natural choice" for Asia driven in-part by a growing demand for oil and gas, the desire across Asia to be self-sufficient in oil and gas, offshore marine capabilities, business incentives and strong support for innovation and the development of R&D talent in key areas. Over the past few years, the offshore marine cluster has become more diverse as evidenced by a growing number of firms who established a presence in Singapore. Sub-clusters within Singapore's offshore marine (oil & gas) sector include oil companies, oilfield and seismic survey services, oil & gas equipment, shipyards and drilling contractors as well as oilfield chemicals.

However, increasing diversity does not automatically imply new knowledge creation and collaborative innovation. One way of exploring the collaborative knowledge creation potential of agglomerations and to delineate a regional knowledge cluster is to compile directories of firms (incl. research centres and institutions of higher learning). When combined with geospatial coordinates, this method helps to identify potential areas of agglomeration of knowledge

transferring and producing organisations which we define as knowledge clusters (Evers, Nienkamper and Schraven 2011).

A calculation of the density of the clusters of establishments shows the landscape of Singapore's marine cluster as illustrated in Map 2. The darker the colour, the higher the clustering in terms of the average geographical distance between companies (note: the size of the companies in terms of capital, workforce etc. has not been taken into consideration so far).

Map 2: Density ("Clustering") of Singapore's Marine Industries



Map design by Hans-Dieter Evers; cartography by Sezali Darit (CenPRIS-USM)

What do such knowledge maps tell us? One easily observable fact is the dense clustering of marine firms in the West of Singapore (Tuas) near the sea which offers strategic (location) advantages with good linkage effects to other related industries within the cluster. Proximity can have a positive effect on knowledge sharing which in turn can enhance new knowledge creation (Chay et al. 2010). While firms are sometimes choosy in selecting business locations, a cluster (knowledge) map might help investors seeking business synergies to make wise decisions.

The density of Singapore's offshore marine cluster has been proactively shaped by various agencies such as Jurong Town Corporation, Urban Redevelopment Authority, Economic Development Board etc. who are doing their best in anticipating firms' long-term strategic interests. Good knowledge governance and potential synergies are obvious due to strategic physical and economic planning driven by Singapore's land scarcity.

Cluster performance depends on the extent of innovation related exchanges of knowledge, the quality of relationships to business partners outside the cluster as well as inter-organisational relationships within the cluster (Eisingerich et al. 2012). Firms located in the central area / old harbour front are arguably a bit disadvantaged. This part of the cluster appears to be less dense. One implication is that these organizations might lose their location advantages eventually in case the port facilities near Tanjung Pagar will be moved closer to Tuas in the West to free up (valuable and precious) land for expanding the business district further south.

Malaysia's South-Johor Economic Region may be another potential threat or opportunity. Much depends on efforts to create a powerful new oil & gas hub in the vicinity of Singapore. While the chances for synergetic networking between Singapore and Malaysia are good in theory, the vision of an emerging transnational knowledge region incorporating both Johor and Singapore is arguably still largely a dream.

Increasing diversity does not automatically imply problem-free knowledge flows, new knowledge creation and collaborative innovation. For Singapore's offshore marine sector to become a powerful knowledge hotspot (hub) with regional and global significance, a sustainable local innovation system has to be created characterised by high connectedness and high internal and external networking as well as knowledge sharing capabilities. As stated above, knowledge hubs generate (new) knowledge, transfer knowledge to sites of application, and transmit knowledge to other people through education and training. While empirical studies on the hub status of Singapore's offshore marine cluster are difficult to come by, there is some evidence that policy-makers continue to support and drive innovation in this sector. The newly set up *Singapore Maritime Institute* (SMI) exemplifies this determination.

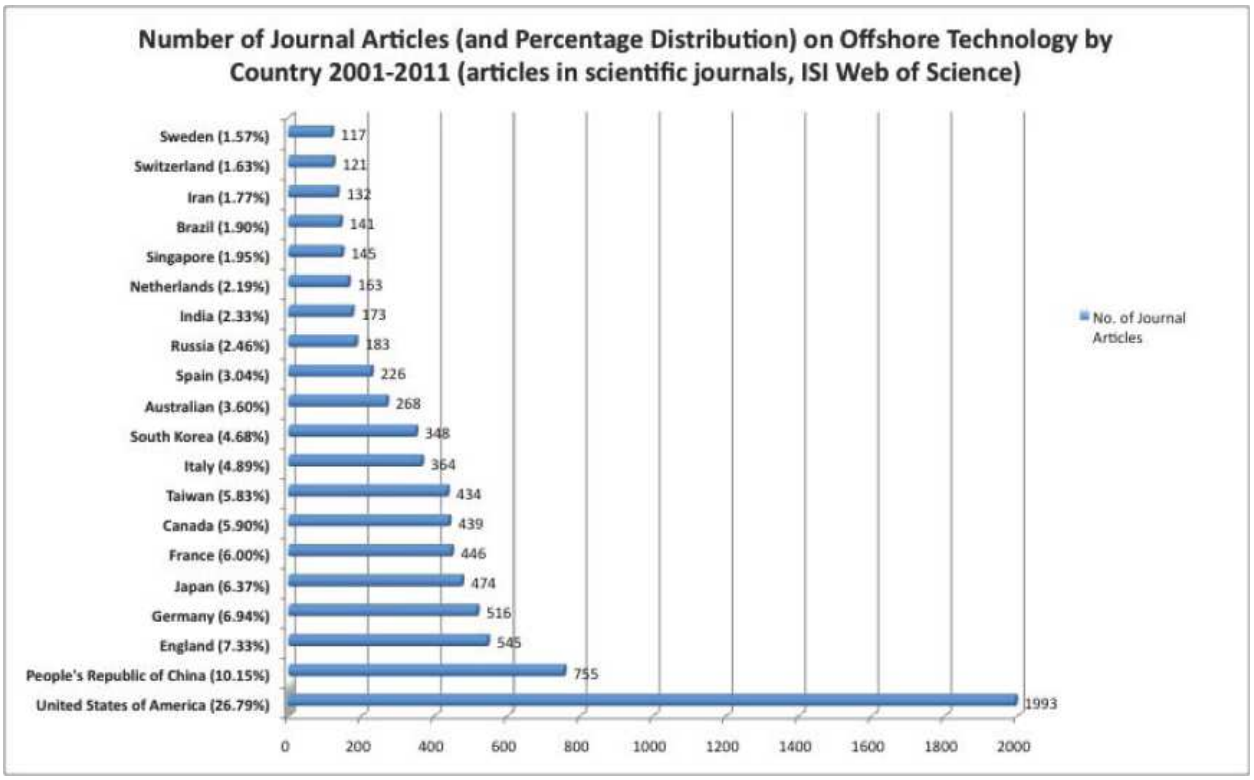
SMI is a joint effort by MPA, the Agency for Science, Technology and Research (A*STAR) and the Economic Development Board (EDB) in partnership with local institutes of higher learning. SMI has been tasked with developing strategies and programmes related to the academic, policy and R&D aspects of the maritime industry with an emphasis on shipping, port and maritime services, as well as offshore and marine engineering. Besides coordinating and aligning the strategic activities of the various maritime institutes at local institutes of higher learning, it is aimed at attracting renowned academics and researchers to work in Singapore, to groom local maritime talent and to help to kick start more industry R&D projects.

Altogether, the various participating agencies have committed $350 million to fund initiatives through the SMI (http://www.maritimeinstitute.sg/About_Us/Background.aspx). Collaborative R&D and capability development in key strategic areas such as subsea systems with local and international partners is seen as a viable strategy to achieve and retain Singapore's role as a global player in the offshore marine industry.

Nurturing Scientific Research & Development (R&D): Singapore as a Offshore Technology Hub

In cluster theory, knowledge in form of innovations, patents and research papers as well as close cooperation between relevant knowledge institutions (both locally and internationally) are essential in providing evidence for the knowledge hub function, including high knowledge productivity. Important research questions which need to be examined in future studies include: Who are the top Singaporean R&D institutions in the area of offshore technology know how? Where does Singapore's offshore technology hub stand internationally in terms of R&D vis-à-vis other key players in this field? Which are the top institutions doing R&D on offshore technology? Who are the key international science partners of Singaporean R&D institutions in offshore technology know how?

Table 2: Number of Journal Articles (and Percentage Distribution) on Offshore Technology by Country 2001-2011 (articles in scientific journals, ISI Web of Science)

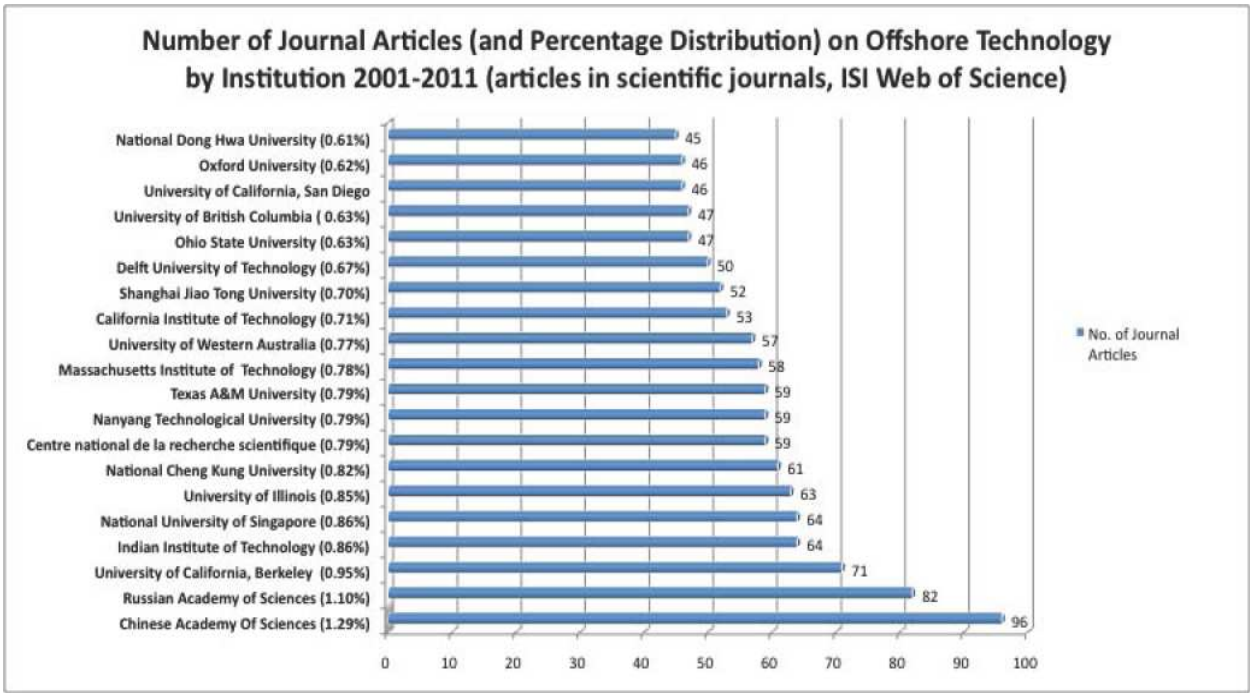


We tried to explore the global standing of Singapore's offshore R&D as well as the external connections of Singapore-based researchers with the help of an output indicator of published journal articles. Only scientific research results in internationally recognized journals are counted. As a result not all projects of cooperation with local and international institutions are measured; only those documented in publications that are recognized, visible and accessible on the Web of Science. In the following section we present preliminary results of our analysis to better understand the global offshore R&D landscape.

Using the Web of Science and keywords such as *offshore rigs*, *offshore engineering* and *dynamic positioning* yielded 7,439 journal articles published between 2001-2011 spread over several

categories such as Computer Science Information Systems, Electrical Engineering, Applied Mathematics, Automation Control Systems or Ocean Engineering. In terms of journal output, the top 5 countries appear to be the United States, the People's Republic of China, England, Germany and Japan (Table 2). And the top five research institutions are the Chinese Academy of Sciences, Russian Academy of Sciences, University California Berkeley, Indian Institute of Technology and the National University of Singapore (NUS) as indicated in Table 3.

Table 3: Number of Journal Articles (and Percentage Distribution) on Offshore Technology by Institution 2001-2011 (articles in scientific journals, ISI Web of Science)



We also tried to shed some light on the external science connections with an output indicator of joint journal articles to which Singapore researchers have contributed. In terms of science cooperation between researchers from Singaporean institutions and elsewhere, India is on top of the list (4), followed by the People's Republic of China (2), Australia (2), Norway (2) and the United States (2).

Singaporean educational institutions include the National University of Singapore (Faculty of Engineering, Department of Electrical & Computer Engineering; Centre for Offshore Research & Engineering; Department of Civil Engineering) and Ngee Ann Polytechnic (Centre of Innovation - Marine & Offshore Technology) as well as corporate institutions such as Keppel Offshore & Marine and KeppelFELS.

Partner institutions in India include institutes of technology and ocean engineering in Madras, Tamil Nadu. Collaborating institutions in the People's Republic of China are technology-oriented universities in Chengdu and Dalian. A key partner institution in Australia is the

University of Western Australia in Nedlands with its Centre for Offshore Foundation Systems. In Norway, key partner institutions involve institutes at the University of Science & Technology in Trondheim. In the US, a key partner institution is Texas A&M University (known for its petroleum engineering expertise) located in College Station, Texas.

The preliminary results of this analysis are similar to those from interviews with offshore marine experts and suggest that Singapore is working towards becoming a global leader in offshore R&D. It seems clear by looking at the ongoing investments into this sector and the number of companies expanding their presence in Singapore (e.g. Maersk Drilling), that it is only a matter of time when the official vision of planners with regard to the country's enhanced (global) role in offshore marine R&D will become reality. However, there are also challenges. As in other sectors, foreign scientists require certain incentives to set up shop in Singapore. While requirements for laboratory space and similar needs are relatively easy to fulfill in sectors such as biotechnology and life sciences, offshore marine scientists require special (at times huge) infrastructural facilities which in turn require space, sea water and land resources etc.

A strategic capacity building role is played by the *Centre for Offshore Research & Engineering (CORE)* at the National University of Singapore (NUS) which has helped to create an increased level of offshore geotechnical engineering according to observers. Important goal dimensions include building a full-time, world class academic group to work on offshore engineering, the transfer of knowledge from visiting experts to local talent and large-scale private sector engagement in terms of R&D funding. While agencies continue to build up capacities in terms of offshore marine R&D, Keppel already has strong capabilities as indicated by the firm's reputation in the fabrication of jack-ups. Particular strengths with regard to knowledge-intensive technical ingredients/elements of offshore oil rig fabrication include Singapore's project management experience, the ability to deploy systems effectively, steel fabrication know how and availability of motivated manpower at competitive cost. Future (R&D) opportunities may include diversification into areas such as floating production systems and subsea production systems beyond the traditional focus on jack-ups which bring in the revenues.

An interesting technology where other countries appear to be ahead involves Dynamic Positioning Systems (DPS). These computer-controlled propulsion units called thrusters are crucial for the stationing of semisubmersible drilling rigs at a specific location in the sea. Though drilling vessels mostly remain stable even under high wind and waves, they may drive off leading to breakage of equipment and create an emergency (Schlumberger Oilfield Gloassary). Asked to comment on Singapore's performance in this respect, one expert said that those technologies can be acquired from equipment suppliers in the US or Europe. As DPS is a worldwide and international technology, it's constantly moving and it is difficult to pinpoint the real technology leader. In general, interviewees praised the ongoing, high quality offshore marine R&D works within the Keppel group of companies.

Institutions of higher education across the causeway in Malaysia such as Universiti Teknologi Malaysia (UTM) in Skudai have also embarked on offshore technology R&D. One example is UTM's towing tank test facility for marine platforms aimed at conducting maritime hydrodynamic experiments. It seems that respective collaborations between Singapore and UTM (which has its own hydrodynamic laboratory) are not easily established. The arguably at times

challenging, 'coopetitive' relationship between Singapore and Malaysia has currently seen a revival in form of the so-called Iskandar Malaysia economic zone as mentioned above, and it remains to be seen how both countries and their respective petro-chemical clusters will progress further. Whether globally operating MNCs operating in Singapore and Malaysia with their own strategic R&D interests can establish R&D synergies beyond national aspirations in this dynamic border region along the Straits of Malacca needs to be examined, too.

Conclusion

Our purpose in this paper is to illustrate with a case study of the Singapore Marine Cluster the attributes of Singapore's successful knowledge governance and its contribution to Singapore's long term economic development. The case study also provides lessons on how to avoid the 'knowledge trap' that characterizes less successful policy interventions. This cluster is path dependent, very much rooted in Singapore's history, but as we have illustrated the cluster includes a key player in Keppel Corporation (the other key player not covered in this paper is SembCorp) which is marching ahead in the global oil rig fabrication business. Key attributes of Keppel's very effective business leadership are its ability to act on its glocal knowhow and to disseminate internally and externally generated new knowledge effectively both within its own cluster of companies and across significant stakeholders in business and society. Due to strong knowledge leadership and innovative capacity, Keppel is able to harness and manage knowledge through strategic R&D and great performance in various areas such as marine and offshore engineering, technology and talent management, operations management, innovation management or sales and marketing. As of 2007, Singapore held twenty-three patents for oil rig construction with nine out of eleven patents awarded to Singaporean companies between the years 2000 to 2007 (Wong, Ho, & Singh, 2007).

Another attribute is the steady increase in the number of researchers in the marine engineering industry due to the higher importance of global R&D for competitive advantage and the need to come up with new and greener business models. Keppel has identified several areas in terms of future expansion to remain competitive and to meet future needs, e.g. with regard to alternative energy sources. The marine cluster appears to be robust. Over time, the flourishing rig business has encouraged the growth of supporting firms in the local marine services sector such as logistics and procurement support services, chartering of offshore supply vessels, rig repair services or IT services for mutual advantage. The increasing number of firms which have expanded their presence in Singapore and our exploratory density data analysis suggest that cluster cohesion is rising.

Our analysis suggests that the rig cluster is currently entering its *'mature' stage* of cluster life cycles (SRI International 2001; Sass et al. 2009) which is characterised by stronger internal and external dynamics in the form of new firm creation through start-ups, JVs, spin-offs etc. As such, through constant knowledge innovation and adaptation to environmental concerns, it can be assumed that Singapore's oil rig business cluster will continue to do well in the fabrication of oil rigs and exploration of alternative energy thus contributing to Singapore's economic longevity.

The successful search for new technologies and markets as well as increasing emphasis on R&D in key areas will, we predict, contribute to the cluster's successful 'transformation'.

A key challenge facing the offshore & marine sector is likely to be environmental concerns related to oil drilling activities. Governments, corporations and communities at large have expressed concerns about the impact of offshore activities on the environment following events like the 2010 Deepwater Horizon disaster in the Gulf of Mexico. Rig builders are under increasing pressure to be more environmentally friendly. Other issues include the lack of skilled workers and ongoing initiatives by other Asian countries to upgrade their offshore marine capabilities. To remain competitive rig builders will have to respond to exploration of ultra deepwater oil, oil shales, oil in Arctic areas, and oil derived from other liquids. Higher oil prices will make oil sources such as deepwater or oil sands more economical in future (Helman 2010).

Considering the importance of Keppel and SembCorp as key players and cluster champions, Singapore's offshore marine cluster is relatively well 'localized'. But the search continues for other powerful R&D anchors that could attract more R&D players to set up Singapore operations that could further boost the entire system. As they do in other clusters, government agencies such as EDB play a crucial match-making role in identifying and attracting suitable foreign players to turn the city-state's R&D cluster vision into reality. The marine cluster is vibrant. Lower labor costs, the evolving infrastructure, a growing oil & gas ecosystem, availability of qualified manpower and supportive domestic institutions attract international oil majors, drilling contractors, specialized equipment manufacturers, oilfield service providers, and offshore engineering companies to Singapore. Linkages to the local business community (milieu) are being developed further which helps to push forward the 'indigenization' of the cluster.

Like others, Singapore's offshore marine cluster is vulnerable to external shocks, slumps in rig orders and government regulation. But the multi-sector composition of Singapore's economic clusters, the risks seem to be manageable. In the end the market will decide whether Singapore's offshore cluster will continue to flourish further as competition from South Korea, the People's Republic of China, and Indonesia is increasing.

One differentiating feature of Asian knowledge clusters and hubs from others elsewhere is the knowledge created and diffused through scientific research results in reputable journals, patents, innovations or competencies. R&D plays a major role here as it can lead to new knowledge creation (innovations), new technologies etc. provided real knowledge hubs are created with strong, actionable knowledge sharing and networking activities. Why do knowledge-based industries form clusters / hubs rather than making use of ICT to connect diverse locations worldwide? The best way to transmit tacit knowledge or experience and to create value is still by observation, face-to-face contacts and learning from doing. Routine work can easily be outsourced, but innovative, knowledge-based work needs teamwork and the existence of communities of practice, frequent social interaction and capacity building by direct face-to-face learning.

There is a difference between knowledge diffusion from knowledge clusters / hubs and the established notion of technology transfer. We regard knowledge diffusion as a much wider

concept than technology transfer because it includes local knowledge, organisational knowledge, knowledge about cultural practices, ethnic diversity management, knowledge transfer etc. From a policy (design) point of view, we argue that knowledge clusters are only effective (e.g. in terms of producing knowledge output or innovations), if they are also knowledge 'hubs' (or if they contain knowledge hubs), defined by real, value added knowledge sharing and creation activities. Today's knowledge intensive industries are different from the classical notion of "high-tech industries" because of the institutionalisation of knowledge management in both private and public sector organisations. The development of a robust knowledge hub function where knowledge intensive firms can flourish and grow is now recognised as a managerial and leadership challenge which requires special skills and talents.

While knowledge hubs are strongly path-dependent, the Singapore case shows that they can be successfully designed and government sponsored. But we also caution that they need historical antecedents, i.e. an existing culture of learning and knowledge production. The development of Singapore's marine industry is a story with various actors such as foreign rig builders / MNCs and effective policy-makers who succeeded in successfully acquiring and assimilating foreign technology and know how as well as visionary, determined and capable Singaporean leaders, entrepreneurs, business people, civil servants and workers. Our case study underlines the importance of both the embeddedness of clusters in socio-political structures and historical developments (in other words, the past) when it comes to understanding why some clusters succeed and others fail. Clusters are certainly not an end in themselves. They represent a key element in a country's institutional base that can promote national welfare if they are effectively governed. In that sense Singapore is indeed a special case because its governance system is efficient (World Bank 1993) despite new challenges such as leveraging on growth in emerging market economies.

There are a number of lessons latecomers in the knowledge race can derive from the Singapore cluster case. First, political stability and an excellent physical infrastructure, including IT architecture which leverages location and comparative advantages is essential. Second, a solid skills-based foundation is indispensable for international leadership in knowledge or technology. Third, the local education system must be aligned with the demands of a knowledge-based economy by attracting and producing 'world-class' R&D talent. Fourth, supportive industries and linkages are required; for example, Singapore's offshore business requires supporting clusters of efficient precision-engineering and transport engineering. Fifth, local and international industry partners need to be attracted by future cluster prospects, for example, in the context of public-private-partnership (PPP) frameworks, support for strategic R&D and good knowledge governance. Good knowledge architects in politics, planning bodies, business and education who coordinate and connect businesses, institutions and society, are indispensable to achieve competitive cluster advantages. Singapore's uniqueness arguably derives from the sizable infrastructure of shipyards and marine technology knowhow upon which the current marine cluster and rig building capacity are historically based, as well as the capability of "Singapore Inc." to lever effectively its externally-sourced knowledge for development.

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Endnotes

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[1] The term refers to various valves, spools and fittings connected to the top of a well to direct and control the flow of formation fluids from the well.

[2] A jack-up rig is a drilling platform with extendable legs that stabilize the platform on its electronically controlled location.