Original Article

Beyond investment: Advancing the biotechnology sector in the countries of the Gulf Cooperation Council (GCC)

Received (in revised form): 1st October 2010

Leonard Lerer
is at the Foundation for the Promotion of Health Services Improvement and Sudarskis & Partners Ltd.

Brett Bowman
is at the School of Human and Community Development, University of the Witwatersrand, South Africa.

ABSTRACT **Despite substantial investment in healthcare, biomedical education and R&D facilities, the countries of the Gulf Cooperation Council (GCC) face challenges in building an impactful and sustainable biotechnology sector. After providing an overview of the state of the region's biotechnology sector, we assess the impact, both real and potential, of such investment against innovation proxies including patent outputs, clinical trial registrations, bibliometric footprint, knowledge economy rank and global competitiveness. Our analysis indicates that resource allocation alone, be it in physical infrastructure (biotechnology 'parks' or large academic institutes) or incentives (such as subsidies, prizes and bringing in international experts on a short-term basis) will not drive the sector growth required to make the GCC a truly globally competitive biotechnology player. Although significant money has been committed by governments to the development of an R&D infrastructure, supporting agencies and institutions, patent registrations remain limited, manufacturing centres sparse and the region has yet to attract world-class industry leaders and intellectual capital. The GCC faces considerable structural challenges in building the requisite human capital and appropriate environments to foster innovation. These shortcomings will continue to curtail bioscience R&D efforts and the region will remain at the tail-end of biotechnology development unless the GCC's relatively uncoordinated capital outlays are more strategically harnessed. We provide some proposals concerning best practice aimed at the development of a thriving and sustainable sector in the GCC that is more valuable than the sum of its parts.**

Journal of Commercial Biotechnology (2011) **17,** 53–72. doi:10.1057/jcb.2010.25;
published online 30 November 2010

Keywords: biotechnology; GCC; R&D; patents; UAE; Saudi Arabia

Correspondence: Leonard Lerer
LB Segment SARL, 5 rue de Castiglione, 75001, Paris, France
E-mail: leonard.lerer@yahoo.com

INTRODUCTION

The countries of the Gulf Cooperation Council (GCC)[1] are a regular source of news concerning high-profile projects in biotechnology, including

the recent establishment of Saudi Arabia's King Abdullah University of Science and Technology (KAUST), described as 'an international, graduate-level research university dedicated to inspiring a new age of scientific achievement in the Kingdom that will also benefit the region and the world' to the Dubai Biotechnology and Research Park (DuBiotech) that regards itself as the 'Middle East's first and foremost Science and Business Park dedicated to global Life Science'.

The growing interest in biotechnology, especially R&D, is being driven by a number of forces, including the rapid growth of the health care sector (it is estimated that GCC expenditure on health care will exceed US$60 billion by 2025), economic development strategies to build 'knowledge economies' that prioritise the pharmaceutical and biotechnology industries reducing dependence on oil revenues and a growing recognition of the need to build up R&D and academic institutions for human development.

Currently, about 90 per cent of all private sector positions in Saudi Arabia are occupied by expatriates, reflecting a long-standing weakness in all aspects of the educational system in the GCC. The impact of the tremendous wealth that has been unlocked in the GCC since the 1970s has still to be seen in terms of a generation of well-educated professionals that form the foundation of an entrepreneurial layer in a society. There are also considerable challenges to individual mobility when it comes to seeking overseas training (for example, women have generally been discouraged from travelling to obtain post-graduate degrees), and while large amounts are spent on sending GCC citizens to universities, especially in the USA, many graduates return only to find little opportunity to obtain practical training or post-doctoral research opportunities. Similarly, the lack of sufficient depth in the public sector management cadre means that many specialist-level trained local health professionals are given onerous administrative and leadership positions and, as a result, they have little time for academic teaching and research.

The vast majority of health-care professionals and researchers currently come from outside the GCC. For example, fewer than 20 per cent of the physicians in Saudi Arabia and 10 per cent of the nursing staff in Kuwait are nationals. The GCC has to a large extent benefited from the presence of scientists and health-care professionals who for security, political and economic reasons since the 1980s left countries such as Lebanon, Iraq and Egypt and based themselves in the region.

There is no substantial 'tradition' of direct investment in the biotechnology sector by Sovereign Wealth Funds (SWFs), institutional or individual investors from the GCC. In fact, there are only a small number of professional investors in the GCC that are interested in or focused on the biotechnology sector. Activities that lie at the core of the growth of the biotechnology sector in industrialised countries, such as angel investment and focused local industrial development funds, are at a very early stage within the GCC. Similarly, multi-lateral agencies charged with regional industrial development such as the Islamic Development Bank have very little in-house expertise in the biotechnology space. The life sciences investment environment is dominated by an interest in hospital and health-care services development and the private equity/venture capital community has little internal expertise or appetite to enter into greenfield biotechnology ventures. In the absence of a sufficient volume of companies, it is difficult to develop a 'value chain' of knowledge-based companies that interact with each other to drive knowledge-based innovation.

Notwithstanding, the SWFs of the region have interests in many of the top-tier US and European venture capital and private equity players in the biotechnology space. There is also growing interest in the role of the SWFs in building a local bio-science sector, and the Saudi Arabian General Investment Authority has recently undertaken a number of initiatives to strengthen the pharmaceutical industry and life sciences education. The

GCC has, with its substantial oil revenues, been a natural 'port of call' for biotechnology fund raising. Companies seeking GCC investment have often considered establishing operations in the region, but most have been discouraged by the limited development of the pharmaceutical industry (limited to a number of generics companies), the lack of trained manpower and the current size of the local market.

The commitment to biomedical research in countries such as Saudi Arabia has generally manifested through the activities of academic medical centres such as King Faisal Specialist Hospital and Research Center (KFSHRC). Following the events of September 11, 2001, many research collaborations languished and countries such as Saudi Arabia focused on developing local R&D capacity and strengthening regional biomedical research collaborations. More recently, GCC governments have committed themselves to building the R&D sector, with biotechnology generally being regarded as vitally important, given its linkage to health care and universities.

Several countries across the GCC have established centralised agencies that drive scientific research. In Saudi Arabia, the King Abdul Aziz City for Science and Technology was established in 1977 to advance science and technology by providing oversight and directly implementing scientific research programs in collaboration with various institutes and scientific centres across the country. Other organisations such as the Arab Science and Technology Foundation established in Sharjah (in the United Arab Emirates (UAE)) in April 2000 are expressly committed to creating the type of enabling R&D environments required to nurture and consolidate the region as a global player in the biotech sector. As such, it aspires to act as a mediator and facilitator in securing and developing the human capital, finance and infrastructure that characterise the world's leading knowledge economies. This vision is supported by a range of country-specific agencies established to strengthen the R&D capacity and biotech footprint of the Council. For example, the Bahrain Centre for Studies and Research mobilises and administers private sector funding towards water, marine life, environmental pollution, food security, nutrition and health studies programmes overseen by multi-sector research partnerships. Similarly, the Qatar Foundation is spearheading the country's drive to become a world-class knowledge economy through preparing the country's people and the region 'to meet the challenges of an ever-changing world, and to make Qatar a leader in innovative education and research' (www.qf.org.qa). The Foundation has invested heavily in biotechnology research by channelling some $7.9 billion towards the construction of SIDRA Medical and Research Centre that houses the Weill Cornell Medical College and aims to establish Qatar as a global health sciences research player through the anticipated outputs anticipated of its biomedical research centre. In 2009, the UAE committed approximately $27.2 million annually to its National Authority for Scientific Research as part of a funding strategy aimed at securing long-term public–private partnerships to drive cutting-edge international research programmes in fields including water studies, agriculture and medicine.

SETTING THE SCENE – INNOVATION AND RESEARCH IN THE GCC

Developed countries have long since identified the importance of innovation to grow their economies. To ensure that this innovation increases at a consistent pace, these countries have grown spending on R&D. As Figure 1 demonstrates, countries that lead the world in innovation capacity also top the list of global spenders on R&D over the last 8 years. China, one of the fastest growing economies in the world, has more than doubled its expenditure on R&D from 0.65 per cent of GDP in 1998 to 1.33 per cent of GDP in 2005.

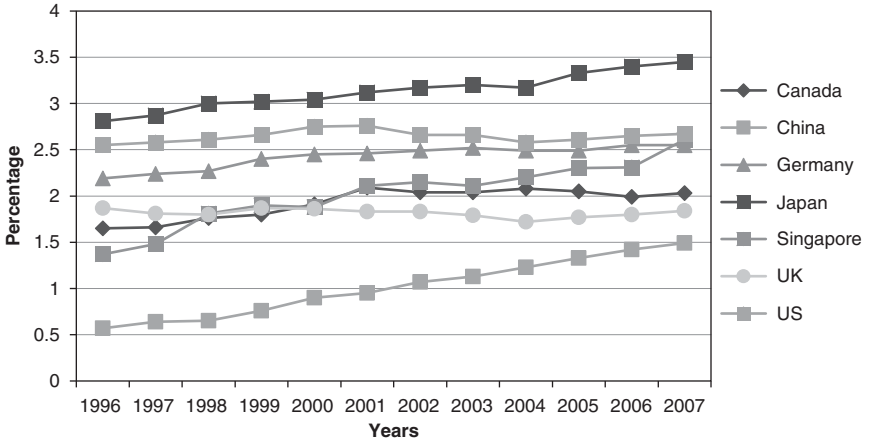

Figure 1: R&D spending as a percentage of GDP for leading global innovators, 1996–2007. *Source*: World Bank, 2010 (http://data.worldbank.org).

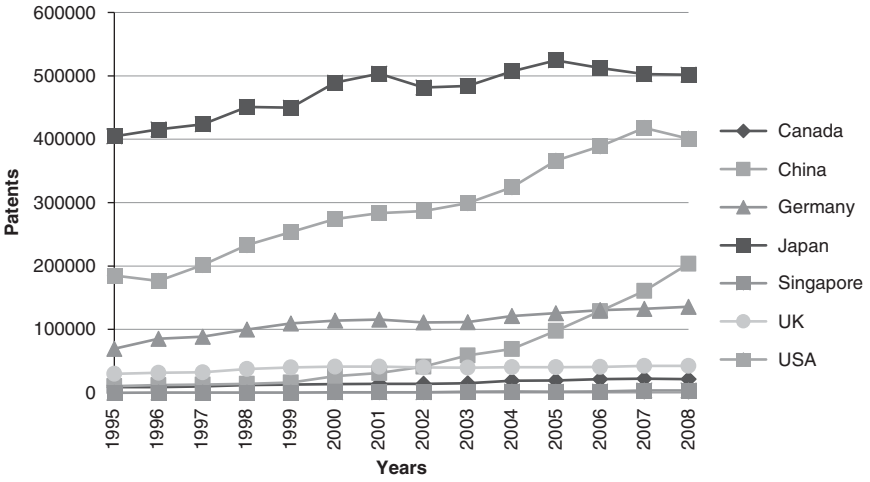

Figure 2: Patents applications by country of origin for leading global innovators, 1995–2008. *Source*: WIPO Database.

Recent data show similar increased outlays on R&D over time in the Gulf. For example, Kuwait approximately doubled its gross domestic expenditure on research and development between 2000 and 2007, whereas Saudi Arabia increased its R&D spending by 39 per cent between 2003 and 2007.

A key measure of research output yields is patent applications.[2] Again, the world's leading innovators have consistently increased the number of patents lodged within their respective countries from 1998 to 2005. As Figure 2 clearly indicates, Japan has approximately doubled the number of patents lodged by its country-based researchers during this time. China's increased R&D investments have yielded measurable patent gains with the country registering approximately 47 000 patents in 1998, a figure that increased by some 370 per cent to 173 000 in 2005 only 8 years later.

In September 1992, the GCC Patent Regulation and the statute of the GCC Patent Office was approved by the Supreme Council of the GCC. As of October 1998, the GCC

Patent Office, located in Riyadh, began receiving applications. Certificates of patents granted by the GCC Patent Office secure legal protection of the inventor's rights in all member states. A patent is immediately validated in the GCC member states as of the date of grant. As such, data housed in the office represent the best source of patent information for the region.

We acknowledge that patent counts may be more useful for gauging levels of innovation in mature knowledge-based economies (KBEs), and that the value of such a measure may be undermined by the fact that the countries of the GCC are only in the very early stages of orienting their economies in this direction. However, constraints on other sources of data make patent and clinical trial counts a useful entry-point for a formative evaluation of performance in the region.

In the GCC countries, the number of patents filed grew enormously from 57 in 1998 to approximately 1900 in 2006 (see Figure 3). However, although actual patent registration within the GCC countries exceeds even China's exponential patent output growth at approximately 404 per cent, the low baseline of patents lodged in 2002 undermines the global significance of 158 granted as its 2006 figure. Furthermore, the vast majority of patent applications relate to innovations from other countries seeking patent protection in the GCC. For example, we analysed the records of the GCC Patent Office for the period 1998–2008 and found only three 'home-grown' patent grants for innovations from the region. Two of these granted in Saudi Arabia were titled 'Herbal Composition for the Treatment of Skin Disorder' and 'A Device for Burning Incense or Heating Fragrance with a Rechargeable Battery' in 2005 and 2006, respectively. The single UAE patent titled 'A Natural Herbal Antibiotic for the Treatment of the Infections of the Upper Respiratory System and Various Diseases in the Body' was granted in 2003. These patent data paint a relatively bleak picture of the state of innovation in the region. Other more comprehensive indices also attest to a relatively low range of innovation yields generated from the substantial spending on research and development in the GCC countries. For example, data gleaned from the World Bank's Knowledge Economy Indices and the Global Competitiveness Report do well to make this point.

The World Bank's Knowledge for Development Program provides a Knowledge Assessment Methodology that is an interactive

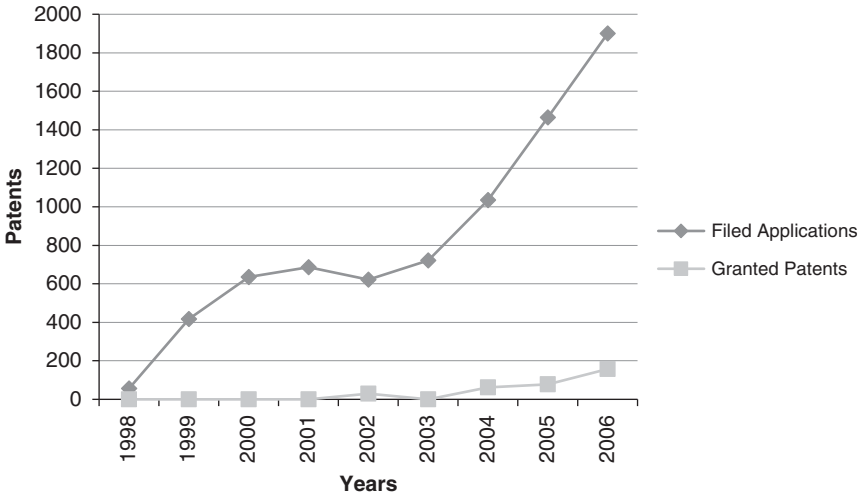

Figure 3: GCC patents (filed applications versus granted), 1998–2006.
Source: GCC Secretariat General website.

Table 1: Selected knowledge economy indicators as rankings over time in the GCC

Variable	Bahrain		Kuwait		Oman		Qatar		KSA		UAE		GCC	
	'95	'05/6	'95	'05/6	'95	'05/6	'95	'05/6	'95	'05/6	'95	'05/6	'95	'05/6
KEI[4]	35	49	51	52	68	66	53	44	77	68	46	45	66	65
KI[5]	42	56	59	59	84	79	56	45	80	73	53	44	75	71
Innovation system[6]	40	80	59	70	60	71	73	48	69	86	42	46	69	80

benchmarking tool used to describe the state of the development of a knowledge economy in a pool of 146 countries. The data are most commonly used to identify challenges and opportunities towards transitioning into KBEs. Information extracted from this system is therefore valuable for isolating the drivers and inhibiting factors involved in this trajectory.[3]

Despite increased general R&D investment beginning as early as the 1970s in Saudi Arabia, longitudinal data show that growth towards knowledge economy 'readiness', as measured by the World Bank, has been disproportionately slow or in some cases negative in the GCC countries. As Table 1 shows, drastic losses in innovation rankings may be partly responsible for this lag. For example, although both the KEI and KI boast marginally better rankings, the aggregate innovation rank for the GCC states has lost ground, indicating a negative difference of 11 places during ongoing R&D investments from 1995 to 2005.

In Appendix we provide an overview of selected development and innovation indicators of the GCC countries against Middle East and North Africa (MENA), High-income Countries (HICs) and World benchmarks in an attempt to isolate the variables that may underpin this poor innovation performance. The GCC states outperform HICs in annual GDP growth and science enrollment ratios. However, they remain markedly behind even the MENA region in variables shown to accelerate and sustain innovation. These include R&D researchers per one million eligible inhabitants, university–private partnerships and science and engineering journal article outputs.

Such innovation lags may exert formidable pressure on overall competitiveness as is predicted by the Global Competitive Index (CGI) annually compiled by the World Economic Forum.[7] Notwithstanding a range of criticisms levelled at the measure,[8] the index has become an important means to assess the relative standing of states and regions within the global competition environment.

As shown in Table 2, Qatar, KSA, the UAE and Bahrain have made substantial gains in enhancing their global competitiveness rankings between 2007 and 2010. However, this is largely despite disproportionately lower rankings on the innovation pillar of the score. In each and every GCC state, the overall innovation score sits well above the CGI. What is clear among the diversity of data presented above is that general R&D investments within the GCC states appear to have yielded less than optimum innovation gains during recent years. This may be especially true of the biotechnology sector, targeted by many GCC states as important R&D conduits to a flourishing knowledge economy.

INITIATIVES TO PROMOTE BIOTECHNOLOGY R&D IN THE GCC

Almost every GCC country has committed to developing the R&D sector – those with substantial oil and gas export revenues have allocated substantial funding and a number of high profile initiatives are underway. Qatar has allocated 2.8 per cent of its GDP towards R&D and Saudi Arabia has allocated approximately $32 billion towards public

Table 2: GCC countries by overall CGI and innovation pillar ranks, 2009–2010

	Bahrain	*Kuwait*	*Oman*	*Qatar*	*KSA*	*UAE*
Overall GCI Rank (2009–2010)/133	38	39	41	22	28	23
Overall GCI Rank (2008–2009)/134	37	35	38	26	27	31
Overall GCI Rank (2007–2008)/131	43	30	42	31	35	37
Innovation Indicators (Rank/133)						
Innovation overall	60	83	55	36	32	27
Capacity for innovation	58	85	87	109	31	39
Quality of scientific research institutions	112	83	63	32	37	53
Company spending on R&D	87	100	62	64	34	30
University–industry collaboration on R&D	101	99	53	38	37	39
Government procurement of advanced technology products	18	114	12	5	22	2
Availability of scientists and engineers	42	72	102	13	47	28
Utility patents	90	30	40	46	45	38

Source: Global Competitiveness Report 2009–2010, World Economic Forum.

education, higher education, workforce training, science and technology, academic research and expeditions. In October 2008, the Kuwaiti government announced a 5-year $131 billion development plan spreading across 2009–2014 to reform the country's policy on science and technology.

There are a number of impressive attempts to build biomedical facilities underway in the GCC countries. In the UAE, the Dubai Healthcare City (DHCC) houses the Mohamed Bin Rashid Al Maktoum Academic Medical Center that comprises of a 400-bed university teaching hospital scheduled to begin operations in 2011. The Harvard Medical School Dubai Centre (HMSDC)'s Institute for postgraduate education and research aims to attract world-class dental researchers to the area. The Al Maktoum Harvard Medical Library will boast a unique patient and family education centre and a world-class library of health-care resources for professionals. In Dubai, the Harvard Foundation for Medical Research aims to develop, nurture and consolidate leading medical and life sciences professionals in the region. Unfortunately, it is unclear whether, following the recent global economic crisis, this project will continue in its current ambitious form. Qatar has established Education City that houses the Carnegie Mellon University and Weill Cornell Medical College. In Saudi Arabia, establishments such as King Saud University have been conducting biotechnology research in anticipation of the formal inauguration of KAUST, a world class R&D facility opened recently.

Several national-level funding agencies for research and development such as the UAE's National Research Fund, the Kuwait Foundation for Advancement of Sciences and the Qatar National Research Fund currently offer funding intended to attract world-class researchers to the region. In addition, a number of local university-specific grants have been established to incentivise intellectual capital migration. In the UAE, Zayed University has established a Research Incentive Fund. The fund offers internal competitive grants to facilitate and fast-track new research projects. At its current capacity, the fund makes provision for the allocation of approximately $10 900 for individual researchers and a maximum of approximately $20 400 to small team or interdisciplinary research. The UAE's University of Sharjah offers substantial seed money aimed at enabling new faculty members to fast-track their projects.

There are also a number of efforts underway to channel existing financial and human capital across the GCC into a variety of well-established initiatives. For example, Abu Dhabi's Zayed University sends students

for internships to the nearby Zayed Complex for Herbal Research and Traditional Medicine (ZCHRTM). The ZCHRTM aims to lead the region's attempts to integrate modern scientific knowledge of phytomedicine with mainstream approaches to ensure the safety and efficacy of a range of traditional medicines used in the UAE. At present, the initiative prioritises the collection, analysis and classification of local medicinal plants towards the compilation of a commercially viable Pharmacopoeia for the country. Other partnerships are aimed at advancing agricultural biotechnology capacity and outputs across the GCC member states.

Sultan Qaboos, the only public university in Oman, boasts a now 20-year long focus on agricultural research. The Sultanate's agricultural biotechnology projects are primarily overseen and administered by the Directorate of agriculture and livestock research consisting of some 146 Omani researchers housed within the Agriculture Ministry. A strategic alliance established between King Saud and King Abdul Aziz universities in Saudi Arabia is currently pursuing a number of biotechnology advancements in the agricultural sector, including studies on the genetic diversity of bean, wheat and tomato plants and plant pathology research.

Veterinary health science is another well-developed research area across the GCC. The Central Veterinary Research Laboratory (CVRL) founded in 1985 in the UAE is perhaps the most well-known research complex in the region. The Centre is the only EU-accredited laboratory in the Middle East. Some of the innovative discoveries of CVRL include a camelpox vaccine, Ducapox (commercially produced in South Africa), vaccine against Newcastle disease in falcons, falcon pox and houbarapox vaccine and falcon herpes virus vaccine. Since the founding of CVRL, the scientists of this institute have published three books and more than 250 papers in various scientific journals throughout the world. Avian health research is also a priority field of study in the GCC. The National Avian Research Centre operates under the aegis of the United Nations Environment Program, within the Convention on the Conservation of Migratory Species of Wild Animals (CMS Convention). Its mission involves the reconciliation of the tradition of Arab falconry with a sustainable use of resources throughout the bustard and falcon species. Research generated from such programmes informs veterinary care protocols in the region's state-of-the-art facilities such as the world famous Falcon Hospital in Abu Dhabi.

Although an appropriate quota of health investment resources are nominally allocated to research necessary for the sustainable development of the GCC countries' natural resources, the region's epidemiological transition from a history of communicable health threats to contemporary non-communicable disease burdens in its human populations has also stimulated a number of highly advanced genome projects. There is already a high prevalence of non-communicable diseases in the UAE. Non-communicable diseases are set to increase, as they arise not only from genetic predisposition, but also lifestyle choices – too little exercise, poor nutrition, smoking and rising alcohol and drug use. These will be compounded by rapid urbanisation and industrialisation and the inevitable move towards a sedentary lifestyle. Cancers[9] and diabetes[10] have been identified as the leading causes of this disease burden.

The Center of Excellence in Genomic Medicine research at King Abdul Aziz University intends to attack national health problems on a 'genomic scale' by a variety of disciplines using genomic protocols, developmental genetics, evolutionary genetics, and cell and molecular biology. King Fahad Medical Research Center at the University currently carries out research in AIDS and dengue fever, but particularly cancer and infection prevention and gestational diabetes. The National Technology Enterprises

Company (NTEC) is a wholly owned subsidiary of the Kuwait Investment Authority. NTEC has pursued new discoveries in the treatment and/or diagnosis of cardiovascular diseases, diabetes, obesity and cancers prevalent in the region. These include breast cancer, Non-Hodgkin's lymphoma, leukemia, colorectal and thyroid cancer. Cutting-edge cancer research is shared in the region, and informs centres such as King Faisal Specialist Hospital. Established in 1975, the Hospital is equipped with globally advanced medical facilities and infrastructure and is widely recognised at a leading global centre for tumour treatment. Teaching, training and outreach infrastructure in the region may also be considered world-class. For example, KFSHRC built in the 1990s in Jeddah functions to foster high-end, world-class clinical practice, health education promotion and disease management.

The establishment of a number of biomedical research parks in each of the GCC states perhaps represents a key component of its biotechnology R&D strategy. These include the iTeknoCity in Bahrain, the Kuwait Technology Park, Sultan Qaboos University Science Park in Oman, the Qatar Science and Technology Park (QSTP), Jeddah BioCity Science Park and perhaps the most ambitious DuBiotech launched in 2005 in Dubai. The costs associated with the development of DuBiotech are estimated at $50 million. The complex attracts and incentivises foreign biotechnology investment by promoting itself as being 100 per cent tax-free, allowing 100 per cent foreign ownership, and permitting 100 per cent repatriation of profits abroad. However, early indications suggest that it is the QSTP model that has provided the greatest yields thus far. The park is primarily charged with commercialisation, but has been notably successful in at least two substantial areas. First, it has attracted a large cohort of global education leaders, currently deployed under the broader Education City infrastructure. Second, QSTP has led the charge towards attracting a sizable number of global technology corporations, including Microsoft and Cisco. This level of membership bodes well for attracting leading biotechnology players.

Beginning in the 1970s with the identification of an imperative to align the economy base of the countries of the GCC with the knowledge-economy aspirations of developed countries, the GCC has invested heavily in building and then accelerating biotechnology sector growth. This investment has realised a formidable 'hive of activity in the sector', boasting world-class infrastructure and funding potential. However, an assessment of conventional tangible measures of the yields of this considerable 'buzz' indicates that the sector has not yet made any demonstrable gains in carving a place for the GCC countries in the global biotechnology environment.

IMPACT OF BIOTECHNOLOGY R&D

The current state and growth potential of the biotechnology sector in any given state or region may be assessed in a number of ways and against numerous indicators.[11] A well-established and useful proxy by which to assess such growth in this domain in particular is the number of clinical trials registered in any region. Table 3 describes the state of clinical trials currently listed at clinicaltrials.gov, an up-to-date register of all federally and privately funded clinical research located in the United States and the rest of the world. At 108 trials currently listed, Saudi Arabia is by far the best represented of GCC states in the register. However, this level of activity is dwarfed by other players in the larger region, following Israel (2326 trials), Turkey (624 trials) and Iran (231 trials) on the register. Most of the active trials in these regions concentrate on the region's disease burden drivers such as cancer and diabetes. The GCC states' poor performance on innovation, as measured in general R&D by their own patent register, has been discussed

Table 3: Registered trials by activity status and country

	Bahrain	*Kuwait*	*Oman*	*Qatar*	*KSA*	*UAE*	*GCC*	*World*
Trials approved for marketing	0	0	0	0	1	0	1	—
Trials enrolling by invitation	0	0	0	0	3	0	3	—
Trials not yet recruiting	0	0	0	0	3	0	3	—
Trials recruiting	5	7	3	7	50	15	87	—
Trials active not recruiting	0	1	0	1	15	2	19	—
Trials suspended	0	0	1	1	1	0	3	—
Trials complete	3	9	1	4	35	15	67	—
Trials listed	8	17	5	13	108	32	183	87 184

Source: Clinicaltrials.gov (accessed 4 April 2010).

previously, with only two original health care-related patents appearing on the register during an 18-year period.

Bibliometric analyses of high-impact outputs per state and region provide another important measure of biotech productivity. Again, the use of this alternative proxy indicates that despite increasing R&D the GCC countries continue to lag behind other countries in the Middle East.[12] Together, 16 high- and middle-income Arab countries[13] produced less than 30 per cent of the comparison group (Israel, Iran and Turkey) in total biomedical publication outputs. The publication output capacity of the Arab countries is not merely constrained to lack of quantity. For example, of the 1996 biomedical publications produced by UAE-based researchers between 1988 and 2007, only five (0.3 per cent) appear in high-impact-factor journals.[14] Findings such as these stand in strong contrast to the fact that R&D expenditure has been found to be one of the best predictors of biomedical research productivity worldwide.[15]

Another interesting indicator of the relatively low return on human capital investment is that despite the provision of world-class medical training and research facilities many of the students, in the UAE for example, are not from the GCC and there is anecdotal evidence that a disproportionate number of graduates in the health sciences sector continue to leave the GCC. Local graduates need to go abroad for further training and often do not return to the GCC (or may return for a short period owing to obligations related to state funding of their training, whereafter they depart again). This brain drain continues despite attempts to offset an overwhelming dependence on foreign medical workers. In Saudi Arabia, only 18 per cent of doctors and 40 per cent of nurses are nationals. This has encouraged the Kingdom to pursue an aggressive indigenisation policy aiming to limit the number of non-nationals to one-fifth of the overall labour system by 2013.[16] These policies are guided by a formal drive to recruit and retain locals in the labour force. Notwithstanding the impressive array of initiatives underpinning this aim in health care, only 2 of the 17 students who graduated from Weill Cornell Medical College in Qatar were local citizens. Investment in cutting-edge training and higher education in health has therefore done very little to curtail the problems of the Arab medical 'brain drain' identified as early as 2002.

There is now sufficient evidence that despite initiatives to develop competitive knowledge economies within the GCC states from various reports compiled as far back as 2002[17] very little progress has been made in meeting the R&D output targets required for driving and ultimately meeting the GCC's innovation objectives. The primary objective of this article is to better understand the players and key success factors involved in building a thriving biomedical R&D base within GCC states. To this end, we examined the current state of R&D in the sector in the GCC countries, assessed best practices such as

Box 1: Lessons from Singapore – coordinated biotechnology sector development

To foster its economic growth and long-term competitiveness, Singapore has been steadily raising its R&D expenditure, from 0.85 per cent of GDP in 1990 to 2.6 per cent of GDP in 2007, with the intention of reaching 3 per cent of GDP by 2010. The government decided to develop biotechnology in 1988 through creating an entire 'value chain', beginning with basic research.[18]

In 1991, Singapore also established a National Science and Technology Board to 'raise the level of science and technology in Singapore'. The NSTB was subsequently restructured to form the Agency for Science Technology and Research (A*STAR), and mandated to build Singapore's scientific knowledge base through a series of 5-year plans.[19]

In 2004, Singapore formed the Ministerial Committee on Research and Development (MCRD) chaired by the Prime Minister. The MCRD drafted a bold vision for Singapore's economic future, starting with the implementation of a National R&D Framework. To co-locate researchers from the public and private sector, a purpose-built biomedical research hub called Biopolis was built.[20] Phase 1 of Biopolis was developed at a cost of S$500 million. The aim is to provide a fully functional platform for private bioscience companies with dedicated research capacity in bio-informatics, bio-processing, genomics and molecular and cell biology. In addition to putting in place strong government institutions, policies and infrastructure, Singapore also attracts talented human capital, from domestic institutions as well as from abroad through building up strong facilities for research and training and local universities and scholarships to pursue higher studies, research and training abroad in biomedical science disciplines. In addition, academics have the mandate and means to incubate high-tech start-ups and create spin-offs.

The success of all these efforts in the biomedical sector is seen in outputs ranging from increasing numbers of patents being registered as well as the growing presence of leading pharmaceutical, medical technology and biotechnology industry players in Singapore. Two large pharmaceutical MNCs established R&D centres in Singapore – Eli Lilly set up a Systems Biology lab and Novartis set up an Institute for Tropical Diseases at the Biopolis. A number of pharmaceutical companies have announced plans for setting up R&D facilities at the Biopolis.

Despite political commitment and the substantial resources committed to biotechnology development in Singapore, the true impact of the substantial investment remains controversial. A 2007 publication[21] boldly calls into question the capacity of the country to secure real returns on its substantial investment into its biotech sector.

those that exist in Singapore (see Box 1), and derived insights into actions that can be initiated to advance and accelerate the biotech R&D potential in the GCC.

UNDERSTANDING THE R&D INNOVATION VALUE CHAIN

From the example of Singapore and other countries, we observe that the development of a deep research base in a country is supported through an innovation value chain, which starts with academic education and ends with products launched into markets. At each stage, different entities play a role, while governments play an overarching role for the development and progressions of the innovation product from one link to the next. The innovation value chain and its supporting entities are depicted in Figure 4.

High-quality academic education is the first, critical element in the value chain. This is supported by entities such as schools, colleges and, particularly, educational institutions.[22] The success of this element depends on the quality of the education system[23] and the resources available for the system. The second element of the value chain consists of basic research, applied research, and the conversion of this basic and applied research into industrial applications. This element succeeds when it is supported by colleges, educational institutions and public and private research organisations coordinating research and providing conditions for efficient technology transfer.[24] The final element of the innovation value chain is production and market launch. This element facilitates the conversion of basic and applied research into products that can be launched into the marketplace. For this to take place, start-ups need to be formed with support from entities such as venture capital firms, government funding agencies and corporate entities.[25] At every stage, the government plays a major role, providing inputs into shaping and structuring all the supporting entities.

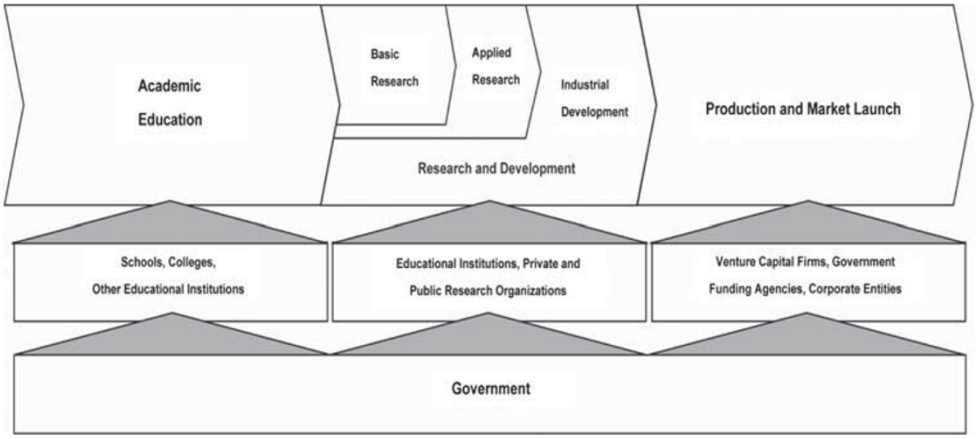

Figure 4: The innovation value chain and its supporting entities.

CHALLENGES TO THE ESTABLISHMENT OF A STRONG BIOTECHNOLOGY R&D BASE IN THE GCC

The value chain analysis is a crucial benchmark against which to assess the current R&D potential of the GCC states at each of its various links. Such analyses are required both within its individual levels and across the links of the chain.

OVERARCHING GOVERNMENTAL SUPPORT

Government has a key role to play across all the participating components and supporting institutions that constitute the R&D value chain. In addition to establishing high-level policies that ensure long-term macroeconomic stability, the government must also ensure the presence of stable financial regulatory systems to encourage the unfettered flow of capital into countries. Governments must also minimise unnecessary 'red tape', thus facilitating the rapid establishment and expansion of stakeholder companies. Furthermore, intellectual property (IP) laws must be robust enough to effectively protect the intellectual products developed by researchers. The immaturity of the IP landscape in the GCC countries significantly impacts on their ability to file patents locally. While this landscape is developed, filing via the PCT would be advisable in the short term. The in-flow migration system must also be both conducive and attractive to the early and complication-free settlement of a targeted talent pool.

Although governments have articulated strong support for R&D and the high-technology sector, the reality of the GCC is that the region is still at an early stage of development of the academic–private sector–government partnership that sits at the heart of a flourishing biotechnology sector.

SECURING AND RETAINING HIGH-QUALITY HUMAN CAPITAL

The quality of research output depends on the collection and management of bright, talented and motivated individuals. To ensure this, relevant courses need to be established in domestic universities (see Box 2) and graduate students must be encouraged to pursue R&D careers. In addition, students from foreign universities should be attracted through the provision of research grants to carry out intense R&D projects. As a first step to ensuring such attractiveness, leading pioneers in particular research fields should be incentivised to seek residence and tenure within the country.

The GCC is forced to seek talent from the Middle East and further afield to staff all levels of a biotechnology sector. Top-tier researchers

Box 2: The competitive advantage of biotech clustering: The case of Novartis

When Novartis was deciding where to locate its Global Research & Development Headquarters it chose Cambridge, Massachusetts, USA. Dr Daniel Vasella, Novartis Chairman and CEO, explained why they were attracted to Cambridge: 'Analysis shows that it is more and more difficult to attract and retain scientific talent, so we have to go where the talent is. Cambridge is a pool of scientific talent that is not found elsewhere in the world'. The areas surrounding Cambridge have fostered pioneering biotechnology, spawning discoveries that have earned Nobel prizes. It is home to Massachusetts Institute of Technology (MIT), Harvard, Massachusetts General Hospital, Beth-Israel Deaconess Medic Center, the New England Medical Center, the Whitehead Institute/MIT Center for Genome Research, and 60 biotech and pharmaceutical companies. Two of the largest biotech firms globally, Biogen Idec and Genzyme, were founded there.

need more than financial inducement to move to new institutions – they seek high-level scientific interaction, research material and opportunities and the longer-term promise to grow their work within substantial R&D operations, whether in the academic or private sector. In addition, the long-term settlement prospects for these international recruits are limited as citizenship remains unattainable and local retirement is untenable at present. Furthermore, even vicarious expert international contributions to shaping R&D policy are constrained by the fact that the appropriate consultative and advisory structures either do not exist or are underdeveloped or have a tenuous link with the complex local public policy development process.

Even Singapore has struggled to retain international R&D talent, especially high-potential young researchers who are extremely mobile. This problem was foreseen and pre-emptively addressed in India's attempt to grow its biotechnology sector through a well-crafted endogenous capacity development strategy through which its universities and research institutions prioritised the long-term development of local science expertise.[26] The yields of such a strategy have been shown to be impressively high. For example, the number of biomedical publications from Indian authors registered in *PubMed* doubled between 2002 and 2007.[27]

The development and commercialisation of research requires the establishment of an entrepreneurial, risk-taking culture. Countries that encourage learning through failure have been seen to generate many more start-ups that arise out of research platforms. A culture that promotes enquiry at the expense of possible failure must be incentivised and sustained. There are very few drivers of entrepreneurship in many GCC countries. In the UAE, for example, the small number of talented, trained nationals with an interest in business ventures are often torn between business careers and their duty to work in government and state-owned enterprises desperately in need of their experience.

Many GCC institutions have sought to develop service-based collaborations with major research institutions in the United States and Europe. Examples include the Weil Medical College–SIDRA collaboration in Qatar, the Imperial College Diabetes Center–Mubadala partnership in Abu Dhabi, the Cleveland Clinic–Mubadala partnership in Abu Dhabi and long-standing educational activities such as the Royal College of Surgeons of Ireland Medical University in Bahrain. A paradigm of this model is DHCC established in 2005. DHCC planning included housing the Mohamed Bin Rashid Al Maktoum Academic Medical Center, a state-of-the-art health-care research and training facility established in partnership with Harvard's Medical School. The University Hospital, a 400-bed teaching hospital is set to open in 2011. HMSDC, in which the Institute for Postgraduate Education and Research plans to establish the Office for Research Administration and the Research Council that will govern the conduct of clinical research at DHCC, thus ensuring world-class outputs and products. Advancements in dental research and teaching are overseen by The Boston

University Institute for Dental Research and Education. The Dubai Harvard Foundation for Medical Research forms a central institutional endowment vehicle established to drive a sustainable community of leaders in medicine and life sciences to advance scientific knowledge. The recent economic crisis has resulted in a considerable scaling down of this ambitious project, and it is currently unclear whether the research and training components will be fully implemented. What has become clear from the DHCC experience is that R&D tends to be the first victim of economic cutbacks and that it is difficult to demand sustainable commitment from top-tier international partners to human capacity development in the absence of substantial financial resource commitment from the project sponsors.

Although many GCC hospital projects claim to have activities in the areas of translational research and R&D collaborations focused on chronic diseases of the region, this area seems to receive minimal resources and attention as compared to the more profitable service delivery activities. Despite the scale of a number of the large-scale hospital and health-care services projects, R&D has either been ignored, given a cursory mention in the project plan or been promised and not fully delivered upon. The conventional measures of output and yield presented clearly illustrate that the substantial financial and human capital investments remain channelled into the biotechnology sector remain at the level of capacity and potential. This level of inertia is exacerbated by the fact that there is a discernible degree of disconnection between the overall R&D imperatives of the GCC and their lack of performance in innovation in the biotech sector as one of their target development frontiers.

PATIENT AND POOLED INVESTMENT CAPITAL

Substantial returns on R&D investments are contingent on the successful commercialisation of the research outputs. In the case of health care and life sciences, this takes many years and millions of dollars. Thus, both private and public sector participation is essential to ensure that adequate amounts of capital are available for research efforts over significant periods of time. This availability can only be ensured through the pooling of public, corporate and university funds, jointly directed towards dedicated R&D budgets and centres established within countries.

In addition to not having a strong culture of R&D investment, the GCC suffers from the short-term horizon of its investor-base. The recent events in Dubai have illustrated the dangers of a near-exclusive focus on real estate investment in some parts of the GCC. Very few investment bankers and private equity professionals are interested in life sciences, and the nascent venture capital industry suffers from both a lack of expertise and a paucity of local investment opportunities in the high-technology space.

A STRONG RESEARCH–CULTURE–INDUSTRY INTEGRATION

Although the provision of cutting-edge equipment is imperative, the value generated by the creation of spaces that encourage researchers to communicate and socialise is often overlooked. These spaces extend beyond the confines of their research hubs. Therefore, sound transportation networks and communication infrastructures should be prioritised as enablers and sustainers of a solid formal and informal research culture. The GCC currently does not have good models of a fully integrated biomedical R&D 'hub' where researchers can interact with both nearby academic institutions and biopharmaceutical companies. On the other hand, industry, whether start-ups, spin-outs or established companies, seeks to develop and commercialise products – this is the foundation of a self-sustaining research base in a country.

The biopharmaceutical industry remains underdeveloped across all the states of

Box 3: The entrepreneurial edge in the industry: The case of HIKMA Pharmaceuticals

Founded in Amman in 1978, HIKMA's formative focus centred on developing a significant brand within the MENA region through the manufacture of patented products under licence. In 1991, the company entered the US drug market through the acquisition of Westward in New Jersey. Leveraging off its new international presence, HIKMA began exporting branded pharmaceutics to Eastern Europe. The company became the first FDA-approved pharmaceutical manufacturer in 1996. A year later a manufacturing site was acquired in Portugal, enabling the firm to fast-track the development of the infrastructure required to manufacture injectable powdered cephalosporin for the MENA Region and Portugal on site. Focused on further European expansion, HIKMA broke into the lyophilised segment of the injectables market through the acquisition of a specialised plant in Italy in 2005, the year in which it first listed on the London Stock Exchange. By 2007, it had consolidated its place as a European pharmaceutical force through the acquisition of Thymoorgan, positioning itself as an integrated oncology platform.

the GCC. There are 26 pharmaceutical manufacturers, all focused on generics and no fully integrated pharmaceutical companies undertaking R&D in the region. The GCC states together with Tunisia, Syria, Iraq, Libya, Yemen, Egypt Palestine and Jordan have established the Arab Company for Drugs Industries and Medical Accessories. Located in the private sector, the company has in turn set up four pharmaceutical plants (Al-Mahaleel Medical in Jeddah, Saudi Arabia, Gulf Pharmaceuticals Company in Ras al-Khaimah, UAE, Kuwait Pharmaceutical Company in Kuwait and the Saudi Medicines and Medical Requirements Company in Qassim, Saudi Arabia). The majority of pharmaceutical manufacturers operate out of Saudi Arabia and the UAE, with no single enterprise currently located in Qatar or Bahrain. The preponderance of manufacturers operating out of KSA and the UAE is unsurprising given their joint market share. Saudi Arabia's pharmaceutical market was estimated to be worth $1.48 billion in 2007, accounting for an estimated 60 per cent of the GCC region's market. Market constraints together with limited R&D infrastructure that lacks attractive centres for direct funding seem to represent the biggest obstacles to the expansion of the industry. Yet, it is possible for the MENA region companies to have become multinational players (see Box 3). Presumably, this is because emerging markets are attractive as potential hubs for regional marketing operations and there is a growing belief in the potential of the MENA markets.

CONCLUSIONS

Our scan of the state of R&D in the region indicates that the GCC states are devoting considerable resources to their endeavours to transform their economies from primarily resource-driven to knowledge-based. There is evidence of strong commitment to channelling significant resources to science and technology. This bodes well for the development of a competitive biotechnology industry. However, resource allocation that does not strategically target the key success factors gleaned from the biotech success stories in other states will not drive the type of sector growth required to make the GCC a truly globally competitive biotech player. Although significant money has been committed to the development of an R&D infrastructure by governments, supporting agencies and institutions, patent registrations remain limited, manufacturing centres sparse and the region has yet to attract world-class industry leaders and intellectual capital. These shortcomings will continue to curtail R&D efforts and the region will remain at the tail-end of biotech development among the emerging economies. In order to strengthen existing biotech growth efforts, the region must better align itself with the best-practice actions listed below.

PROMOTE R&D AS A NATIONAL PRIORITY

Diversifying away from resource-based economies to KBEs has been identified as a priority for governments in the GCC countries. A strong R&D base is a critical

component for a transformation of this kind. To achieve this, governments need to develop, communicate and execute long-term R&D strategies with clear roadmaps, milestones and deliverables. But most importantly, a culture of research and entrepreneurship must be strengthened, starting with students and academic institutions.

Porter argues that developing economies need to establish well-functioning clusters in order to transform themselves into high levels of advancement.[28] In advanced economies, clusters have been seen to constitute tightly interlinked companies and institutions in specific fields. In a self-sustaining virtuous cycle, clusters foster the availability of high-end intellectual capital that is itself surrounded by accessible top class learning institutions strongly supported by governments. In developing economies, however, clusters involve few participants with limited communication and linkages. Cluster formation in developing economies is 'impeded by low local education and skill levels, weaknesses in technology, lack of access to capital, and poorly developed institutions. Government policy may also work against cluster formation. Restrictions on industrial location and subsidies artificially spread out companies. University and technical school curricula, centrally dictated, fail to adapt to cluster needs. Finally, protected from competition, companies engage in monopolistic behaviour that further retards cluster development'.[29] While the majority of the GCC programs are still in the development stages and considering that time is an influencing factor the consolidation of emerging clusters, the GCC countries should pre-emptively take note of these aspects while focusing on building clusters rather than islands of R&D work.

IMPLEMENT TECHNOLOGY TO BUILD INTEGRATED R&D CHAMPIONS

'Technology transfer' describes the means by which the right to use an invention is transferred from the inventor to the market. It includes disclosing and managing inventions, evaluating, protecting and marketing the invention, and then negotiating and managing licences for its use.[30] The most recent estimates on the overall costs involved for a pharmaceutical manufacturer to bringing a drug into the market range from $500 million to $2000 million,[31] most of which goes towards commercialising an academic invention. Given the near-improbability of taking products all the way from basic research to commercial applications single-handedly, governments, in the United State, for example, have granted ownership of inventions that have been developed from publicly funded research to the universities from which the research originated. These universities in turn have established Technology Transfer Offices (TTOs) and Technology Transfer Investment Funds (TTIFs) to manage and commercialise patents and inventions. The GCC countries should therefore establish linkages to TTOs and TTIFs globally to seek joint opportunities for the commercialisation of promising patents and inventions.

Evidence has shown that the presence of a large, local, R&D-intensive firm – an 'anchor tenant' – enhances the productivity of local innovation systems by making local university research more likely to be absorbed by and to stimulate local industrial R&D. Anchor tenant firms are therefore an economically important aspect of the institutional structure of local economies.[32] The presence of GSK and Novartis at Singapore's Biopolis attracts researchers and resources, thereby leading to greater R&D and innovation. GCC countries should similarly establish anchor clients in their R&D institutions.

A LAST WORD ON 'FUTURING' THE SECTOR

While the countries of the GCC evidence different amounts and forms of investment (with Qatar and KSA leading the Council on almost all indices), overall, the GCC is in the

fortunate position of having substantial funding available for building its biotechnology sector. Private sector investments, endowments and direct state funding total over $20 billion. However, the GCC states have not been able to translate this sizable funding capacity into real returns. Our research demonstrates that some of the components of the R&D value chain are indeed present, but that no coordinated strategy driven by a future vision is in place.

The precedent provided by Singapore's approach to developing the biotechnology sector from the 'outside in' through the formative harnessing of external expertise for long-term internal growth has demonstrated that accelerated expansion is possible but requires a broad and coordinated strategy that enlists the inputs of all stakeholders, present and future, local and international. Furthermore, India's emergence as a global biotechnology player attests to the availability of large-scale investment being necessary but insufficient for rapid expansion.[33] Much of the success of this country's now global penetration can be attributed to its prioritisation of the foundational components of the value chain, rather than a diverse spread of investments across it. For example, following independence, the Indian government made a deliberate attempt to massify[34] its graduate output. Although gross enrollment remains small at 11 per cent, the size of the population together with substantial funding from the private sector has resulted in the production of a large number of quality graduates in science, engineering and technology. Cultivation of this pool of local talent allows for the selective harvesting of top-tier scientists to drive the local R&D agenda. This appears essential to ensuring the type of sustainable local talent required to leverage the full benefits of developing and expanding a home-grown biotechnology sector.[35]

Although the GCC states have again invested heavily in growing the tertiary education sector, their university systems do not yet deliver the type of science, engineering and technology skills required for cutting-edge biotechnology innovation.[36] Thus this key anchor of the value chain requires strategic revision. Obviously, the creation of a more expansive and robust university system directed towards the throughput of endogenous human capital would go some way to addressing this problem. However, the attractiveness of migration to more mature R&D country contexts that drive more developed health systems by recently graduates nationals will continue to undermine efforts in this regard.

The run-on effects of uncoordinated diverse capital outlays across the value chain generate a fragmented and disparate research network rather than an integrated R&D culture. The strategic rather than myopic allocation of funding towards building this culture as a long-term driver of biotechnology R&D should therefore be prioritised by the sector's key players. The translation of a research culture into a critical mass of industrial innovators also requires a greater synthesis of existing networks overseen by experienced knowledge managers. Again, this critical human capacity weakness rather than financial shortfall presents as the sector's greatest obstacle to research-to-industry-translation. Finally, catapulting biotechnology products from industrial viability into the international marketplace requires a visionary and entrepreneurial aggression rather than the introverted regionalism that characterises the GCC's pharmaceutical preoccupations. Beyond question, the states of the GCC have developed a sturdy financial base from which to launch a global biotechnology presence. Each link in the value chain can be bountifully funded. What is required, however, is the strategic harnessing of these links toward the development of a thriving biotechnology sector that is more valuable than the sum of its parts.

Finally, it is vital to reflect on the sustainability of potential investment in building up GCC's biotechnology R&D capacity. Biotechnology R&D is not simply

the 'feather in the cap' of a national technology and industrial development strategy, nor should it be looked upon as an exclusively philanthropic exercise. It makes a difference in terms of improving health and well-being (agriculture, environment and other industries). Hence, it makes eminent sense for GCC policymakers to consider not so much what can be done with the huge financial resources at hand, but rather what needs to be done to ensure that the biotechnology sector can be grown to make a real, long-term contribution to regional development. This is a high stakes game, as at the moment, the GCC does not feature at all in the burgeoning 'North–South' biotechnology sector interaction,[37] and risks, despite all of its substantial R&D investment, not playing its deserved role in the development of a truly global biotechnology sector.

ACKNOWLEDGEMENTS

We gratefully acknowledge the contributions of Vinod Janardhan for his assistance in sourcing many of the data for analysis in this article. We also thank Nada Albakar for her assistance in sourcing data from the GCC Patent Office. Some initial findings of this research were presented by Value Edge and Santeum Partners AG at Abu Dhabi-GCC Health and Development Investment Forum, Emirates Center for Strategic Studies and Research, May 2009.

REFERENCES AND NOTES

1. This council is bound by an economic agreement signed in Riyadh in 1981 and comprises the states of Bahrain, Kuwait, Oman, Saudi Arabia and the United Arab Emirates.
2. Acs, Z.J., Anselin, L. and Varga, A. (2002) Patents and innovation counts as measures of regional production of new knowledge. *Research Policy* 31: 1069–1085.
3. Chen, D.H.C. and Dahlman, C.J. (2005) *The Knowledge Economy, the KAM Methodology and World Bank Operations*. Washington DC: The World Bank Institute.
4. The Knowledge Economy Index (KEI) takes into account whether the environment is conducive for knowledge to be used effectively for economic development. It is an aggregate index that represents the overall level of development of a country or region towards the Knowledge Economy.
5. The Knowledge Index (KI) measures a country's ability to generate, adopt and diffuse knowledge. This is an indication of overall potential of knowledge development in a given country.
6. This knowledge pillar is calculated using three variables. Inputs to the system are royalty and licence fees payments and receipts. Output variables are patent applications granted by the US patent and trademark office and scientific and technical journal articles.
7. Schwab, K. (2009) *The Global Competitiveness Report, 2009–2010*. Geneva: World Economic Forum.
8. Lall, S. (2001) Competitiveness indices and developing countries: An economic evaluation of the global competitiveness report. *World Development* 29: 1501–1525.
9. Al-Hamdan, N. *et al* (2009) Incidence of cancer in Gulf Cooperation Council countries, 1998–2001. *Eastern Mediterranean Health Journal* 15: 600–611.
10. Shaw, J.E., Sicree, R.A. and Zimmet, P.Z. (2009) Global estimates of the prevalence of diabetes for 2010 and 2030. *Diabetes Research and Clinical Practice* 87: 4–14.
11. Edquist, C. (ed.) (1997) *Systems of Innovation: Technologies, Institutions and Organizations*. London: Pinter Publishers/Cassell Academic.
12. Benamer, H. and Bakoush, O. (2009) Arab nations lagging behind other Middle Eastern countries in biomedical research: a comparative study. *BMC Medical Research Methodology* 9: 26.
13. This country cluster included Morocco, Algeria, Tunisia, Libya, Egypt, Sudan, Lebanon, Jordan, Syria, Iraq, Saudi Arabia, Qatar, Kuwait, UAE, Oman and Bahrain.
14. Bissar-Tadmouri, N. and Tadmouri, G. (2009) Bibliometric analyses of biomedical research outputs in Lebanon and the United Arab Emirates (1988–2007). *Saudi Medical Journal* 30: 130–139.
15. Rahman, M. and Fukui, T. (2003) Biomedical research productivity. *International Journal of Technology Assessment* 19: 249–252.
16. Maben, J., Al-Thowini, K., West, E. and Rafferty, A.-M. (2010) Uneven development: Comparing the indigenous health care workforce in Saudi Arabia, Bahrain and Oman. *International Journal of Nursing Studies* 47: 392–396.
17. United Nations Development Program (UNDP). (2002) Arab Development Report 2002, http://www.arab-hdr.org/publications/other/ahdr/ahdr2002e.pdf(UNDP, New York).
18. Tsui-Auch, L.S. (2004) Bureaucratic rationality and nodal agency in a developmental state: The case of

state-led biotechnology development in Singapore. *International Sociology* 19: 451–477.

19. Lee, Y.S., Tee, Y.C. and Kim, D.W. (2009) Endogenous versus exogenous development: A comparative study of biotechnology industry cluster policies in South Korea and Singapore. *Environment and Planning C: Government and Policy* 27: 612–631.
20. Parayil, G. (2005) From 'Silicon Island' to 'Biopolis of Asia': Innovation policy and shifting competitive strategy in Singapore. *California Management Review* 47: 50–73.
21. Yusuf, S. and Nabeshima, K. 2006 *Post-industrial East Asian Cities. Innovation for Growth*. New York: Stanford Press.
22. Anselin, L., Varga, A. and Acs, Z. (1997) Local geographic spillovers between university research and high technology innovations. *Journal of Urban Economics* 42: 422–448.
23. Vandenbussche, J., Aghion, P. and Meghir, C. (2006) Growth, distance to frontier and composition of human capital. *Journal of Economic Growth* 11: 97–127.
24. Smits, R.E.H.M. and Boon, W.P.C. (2008) The role of users in innovation in the pharmaceutical industry. *Drug Discovery Today* 13: 353–359.
25. Gans, J.S. and Stern, S. (2003) The product market and the market for 'ideas': Commercialization strategies for technology entrepreneurs. *Research Policy* 32: 333–350.
26. Kumar, N.K., Quach, U., Thorsteinsdottir, H., Somsekhar, H., Daar, A.S. and Singer, P.A. (2004) Indian biotechnology-rapidly evolving and industry led. *Nature Biotechnology* 22: DC31–DC36.
27. Dandona, L., Raban, M., Guggilla, R., Bhatnagar, A. and Dandona, R. (2009) Trends of public health research output from India during 2001–2008. *BMC Medical Research Methodology* 7: 59.
28. Porter, M.E. (1998) Clusters and the new economics of competition. *Harvard Business Review* 76: 77–90.
29. Porter, M.E (2008) *On competition*. Boston, MA: Harvard Business School Press.
30. Allen, K.R (2003) Bringing technology to market: A macro view of technology transfer and commercialization. *International Journal of Entrepreneurship Education* 1: 321–358.
31. Adams, C.P. and Brantner, V.V. (2006) Estimating the cost of new drug development: Is it really $802 Million? *Health Affairs* 25: 420–428.
32. Agrawal, A. and Cockburn, I. (2003) The anchor tenant hypothesis: Exploring the role of large, local, R&D-intensive firms in regional innovation systems. *International Journal of Industrial Organization* 21: 1227–1253.
33. Kale, D. and Little, S. (2007) From imitation to innovation: The evolution of R&D capabilities and learning processes in the Indian pharmaceutical industry. *Technology Analysis & Strategic Management* 19: 589–609.
34. Agarwal, P. (2007) Higher education in India: Growth, concerns and change agenda. *Higher Education Quarterly* 61: 197–207.
35. Natesh, S. and Bhan, M.K. (2009) Biotechnology sector in India: Strengths, limitations, remedies and outlook. *Current Science India* 97: 157–169.
36. Harry, W. (2007) Employment creation and localization: The crucial human resource issues for the GCC. *International Journal of Human Resource Management* 18: 132–146.
37. Melon, C.C. *et al* (2009) A survey of South-North health biotech collaboration. *Nature Biotechnology* 27: 229–232.

Competing interests statement The authors declare that they have no competing financial interests.

APPENDIX

See Table A1.

Table A1: Development and innovation indicators by GCC countries against MENA, High-income Countries and world average

Variable	*Bahrain*	*Kuwait*	*Oman*	*Qatar*	*KSA*	*UAE*	*GCC*	*MENA*	*HIC*	*World*
Annual GDP Growth (%), 2003–2007	7.00	12.33	4.33	10.00	5.00	10.33	8.17	5.72	4.36	5.43
Human Development Index, 2005	0.87	0.89	0.81	0.88	0.81	0.87	0.86	0.77	0.92	0.74
Science and Engineering Enrolment Ratio (%), 2007	17.83	n/a	20.98	29.83	25.86	20.93	23.09	24.49	23.42	21.50
Science Enrollment Ratio (%), 2007	9.24	n/a	13.57	12.22	20.57	10.37	13.19	13.07	10.10	9.52
Researchers in R&D, 2006	n/a	200.00	9.00	n/a	n/a	n/a	104.50	14.817.63	100 974.43	65 432.74
Researchers in R&D/Mil. People, 2006	n/a	74.07	3.43	n/a	n/a	n/a	38.75	683.56	3.199.92	1.604.72
Total Expenditure for R&D as % of GDP, 2006	n/a	0.18	n/a	n/a	n/a	n/a	0.18	0.90	1.77	0.89
University–Company Research Collaboration, 2008	2.80	3.10	3.70	4.20	3.80	3.40	3.50	3.35	4.33	3.46
S&E Journal Articles, 2005	33.25	234.14	110.85	39.02	576.30	229.26	203.80	767.74	13.577.51	4.929.04
S&E Journal Articles/Mil. People, 2005	45.88	92.35	44.22	49.01	24.93	55.86	52.04	85.83	465.26	154.06
Availability of Venture Capital (1–7), 2008	4.00	3.80	4.10	4.10	3.70	4.30	4.00	3.56	4.00	3.20
Patents Granted by USPTO, avg 2003–2007	0.00	5.80	0.20	0.80	18.40	4.40	4.93	67.88	3.974.36	1.239.97
Patents Granted by USPTO/Mil. People, 2003–2007	0.00	2.29	0.08	0.99	0.80	1.07	0.87	10.03	68.49	21.33
Private Sector Spending on R&D (1–7), 2008	2.90	2.80	3.50	3.80	3.60	3.40	3.33	3.34	4.26	3.41
Firm-Level Technology Absorption (1–7), 2008	5.40	5.50	4.50	5.30	5.20	5.90	5.30	5.09	5.53	4.83
Value Chain Presence (1–7), 2008	3.90	3.40	4.00	4.00	4.20	4.10	3.93	3.89	4.71	3.82
S&E articles with foreign co-authorship (%), 2005	37.78	46.11	53.94	54.39	40.26	58.77	48.54	56.18	49.46	65.53
Avg number of citations per S&E article, 2005	0.76	0.87	0.92	0.43	0.90	0.95	0.81	0.97	1.86	1.43
Adult Literacy Rate (% age 15 and above), 2007	88.76	93.91	84.37	90.23	84.95	90.45	88.78	82.15	97.44	85.84
Gross Secondary Enrollment rate, 2007	102.09	88.71	89.77	103.47	94.21	92.37	95.10	80.92	101.43	77.39
Gross Tertiary Enrollment rate, 2007	32.05	17.56	25.49	15.93	30.24	22.85	24.02	27.91	55.68	35.36
Computers per 1000 People, 2007	180.00	240.00	70.00	190.00	150.00	330.00	193.33	117.65	470.68	194.30

Source: World Bank, 2010 (http://info.worldbank.org/etools/kam2/KAM_page5.asp).

