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Science and the Arabs: opportunities and challenges

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Tunisians and Egyptians sought recently to transform their political culture. Their political economy has rendered it impossible to develop the scientific infrastructure needed to benefit from science. This paper shows that, by comparison with China and India, the Arabs in 1999 had a substantially higher level of university enrolment, per million inhabitants abroad and at home; and were ahead in per capita R&D output. Yet both China and India were able to take off with these resources while the Arab countries were left behind. The research output of the Arab countries increased about 50-fold over the period 1967–2010. Egypt, the GCC and the Maghreb are in the lead, and the leading countries are Egypt, Saudi Arabia and Tunisia. Yet Arab governments provide minimal support to R&D at 0.2% of GNP and few countries have recently increased support to R&D. The paper discusses their research output as well international collaboration.

Keywords: Arab countries; political economy; corruption; science policy; self-reliance; human capital; research and development; collaboration in scientific research

Introduction

This article discusses the knowledge-based resources of the Arab world and their comparative standing in the world of science. It will also examine briefly the implications of the history of Arab countries in relation to their developmental crises and the formation of their current political economy. A state of partial paralysis has dominated the economies of Arab countries over the past several decades, where the most striking feature of these economies has been under-performance.

Societies capable of converting knowledge into useful and appropriate outputs are constantly increasing their distance from other countries that are not able to do so. This burgeoning gap between nations has, since 1800, dominated cultures, economies and power relationships. Advances in knowledge contributed to new forms of colonialism and imperialism, two World Wars and new forms of international relations. Those countries that have not been able to manage their relationship to knowledge production are left behind with diminished sovereignty and increasing dependence. The commitment of a country to scientific research is equivalent to its commitment to being sovereign.

The international pursuit of scientific knowledge is on a massive scale. Expenditure, or rather investment, in this activity is in excess of US$1 trillion per year. The United States invests half this sum, hence its dominant scientific, military and economic position in the world. The United States, the European Union, China and Japan account for about 95% of global investment in research and development

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(R&D). It is very likely that expenditure on R&D will grow at a rate of 7% annually as more nations join the knowledge club and competition intensifies.

The evolution of scientific knowledge in any society is a product of learning from others and a culturally self-generated drive to understand nature better. Both of these driving forces have been of paramount importance throughout history.

The ability of a country to benefit from the discoveries of others depends on its ability to learn about current advances in time and to possess the capacity for understanding them. The production of knowledge, its dissemination and use require a wide variety of national organizations and services; a complex system which must provide an enabling environment to 'local/national' scientists as well as to facilitate and encourage communication and cooperation among and between scientists, society and the economy.

The capabilities of the individual scientist are central to the process, and thus to the management of the scientific infrastructure of each country. The motivation of the individual scientist and the freedom to explore and investigate are of the essence. Science does not grow in countries and cultures that do not give a priority to the intellectual motivation of their youth.

Collaboration and cooperation among scientists themselves is of paramount importance. The freedom of association to form scientific societies, and to travel and participate in national, regional and international conferences is an integral part of the process of scientific production. Clearly providing the means to national scientific workers to travel and participate in relevant activities is critical to the flowering of national scientific communities.

International activity in science is highly decentralized as well as strongly competitive and it affects every scientist in the world. A major discovery anywhere changes the global scientific landscape in that field.

The speed with which scientists can work depends on their organization and resources. Clearly, those in the slow lane end up missing out on most major discoveries. The Arab governments devote an insignificant share (with minor exceptions, of the order of 0.2%) of their gross national product (GNP) to the support of R&D. Compare this with the range of 2–3% of GNP devoted to R&D in industrial and Tiger counties.

The acceleration in the rate of scientific advances makes it nearly impossible for countries that are not actively involved in research to learn in time of new advances, to benefit from them and to avoid collateral damage. The damage suffered by Asian and African countries during the 19th century, as a result of their ignorance of the scientific and technological advances under way elsewhere, was massive.

Countries that espoused learning and sought to develop their national capabilities may be called self-reliant. In other words, these countries could adopt policies based on national objectives, capabilities and organizations. Countries that do not seek to be self-reliant become derivative and dependent. Such countries fared badly when the technology gap grew rapidly after 1500: their technological dependence increased and they were reduced to importing their weapons from the countries that were essentially their enemies.

The behaviour of dependent people is typical. For example, the Egyptian fleet of the early 19th century was manned by French officers who 'gracefully' withdrew from their posts before the Battle of Navarino (20 October 1827). The officer-less fleet was sunk by the combined Western (British, French and Russian) navies in the ensuing battle.

Undeterred by this experience, Muḥammad ʿAlī resorted to the French (the enemy that had sunk his fleet) to rebuild his fleet at his Alexandria naval base. Being oblivious of rapid contemporary technological change, he built a fleet based on wind power, thanks to the advice of the 'French expert' employed for the job. Navarino was, in fact, the last battle in history fought by sailing-ships.[1] Subsequently all navies converted to steam power. Thus, a backward and dependent nation not only loses the battle of today, but also adopts policies that guarantee that it will lose its future battles.

This pattern of behaviour recurs often in the Arab World. For example, in the 1950s an Arab country imported a factory to manufacture radio tubes after the transistor began to replace radio tubes. A similar situation arose after the June war of 1967: a frontline state imported subsonic anti-aircraft rockets at a time when all fighter planes had become supersonic.

Self-reliant countries are constantly alert to scientific change anywhere. For example, much post-Renaissance scientific and technological progress was initiated, at various times, in a small number of countries (such as Portugal, Spain, Italy, the Netherlands, Britain and France). Yet their European neighbours quickly sensed what was taking place and deployed massive efforts to 'catch up'.

By contrast, in the non-European world of Asia and Africa (including the Ottoman Empire) the reaction was to pursue technological dependence: the development of a national technology base called for unacceptable cultural and political change. The creativity required by the new sciences demanded a more liberal political culture, which was not forthcoming.

As a result, all these countries became colonies or semi-colonies. In Asia only Japan, when forced to, had an effective reaction because it decided from the outset that it was prepared to take any measure needed to remain sovereign.

Opportunity for policy change

Fortunately, every society has the opportunity to change its attitude towards science. Thus, during the 20th century a number of countries in Asia adopted strong strategies to attain technological self-reliance. We now see that Korea, China, India, Malaysia, Taiwan and others are successfully pursuing such strategies, and that they are rapidly gaining ground.

In all these cases, whether 18th-century European countries, 19th-century Japan or 20th-century latecomers, one finds that the first step taken by a government is to pursue self-reliance. They all took strong measures not only to be learners from others, but also contributors.

In the Arab World we know of three attempts during the past two centuries to acquire military technology; all were made without significant effort to develop a self-reliant base to support these efforts. In all three cases (Muhammad Ali, Gamal Abdel Nasser and Saddam Hussein) they allowed themselves to be dragged into military confrontations for which they were not ready, and all three lost out. Clearly we live in a dangerous world, and setting up to build a capability that may affect the balance of power will be resisted by those who seek to benefit from the present gap.

Needless to say, the longer a country waits to realize what is happening in the world of science, the larger is its ensuing knowledge gap, and the greater the effort needed to catch up. In all such cases we note that the later the country decides to become self-reliant, the greater is the speed of developing its research capabilities.

Research in national organizations is the most authentic sign of self-reliance, and the only secure route to sovereignty. This is true from Cuba to China. The fact that in 2008 China became the second largest spender on R&D (superseding Japan) is a sign of Chinese determination. The fact that Arab countries are among the lowest spenders on R&D is a guarantee of continuing dependence.

Signs of change

In 2010 and 2011 there emerged in Tunisia and Egypt a movement of young professionals seeking to transform the prevailing national political culture. Henry and Springborg (2001),[2] amongst others, studied the political cultures of Arab countries and found them corrupt and their corruption places severe constraints on their national development. In fact it makes it virtually impossible to develop a scientific infrastructure to participate in the wonders of the 21st century.

The recent events in Tunisia and Egypt have captivated the attention of Arabs. Those in Arab countries have been patiently waiting to hear good news. The termination of the tenure of the presidents of both countries in one month was welcomed everywhere.

These events are the tip of the iceberg of current change throughout Arab countries. There are three simultaneous processes that are taking place. The first is the high rate of population growth resulting in two-thirds of the population below the age of 30 years. Thus the Arab World possesses a considerable 'capital' since the young are more creative than the old. In an ageing world this is a considerable asset if Arab governments learn how to benefit from this capital asset. This population growth has resulted in the expansion of population to some 330 million in 2010 and an expected 700 million by 2050.

The second is the high rate of expansion of the educational systems at all levels. Around 1950, when Arab countries began to secure their independence from Western colonial powers, there were ten universities for a population of the order of 60 million. During the past 60 years there has been considerable expansion in the number of universities and the number of university graduates. Between 1998 and 2008 Arab countries increased their appropriations to ministries of higher education from US$3.77 billion to US$16.26 billion. Enrolment expanded from 2.45 million to more than 6.62 million students.[3] There are more 400 universities in Arab countries today.

Very roughly, there are an estimated 1.5 million engineers increasing at the rate of 100,000 a year. There are probably some 200,000 persons who hold a PhD degree from Organisation for Economic Co-operation and Development (OECD) universities, also increasing at some 15% annually. However, the brain drain from this category of human capital is very high.

The third is the moderate R&D in the Arab World despite the miserably low support that Arab scientists receive.

These developments combined with other political and social changes in the region during the past 50 years have mobilized the young and inspired them to develop new approaches to deal with entrenched corrupt leadership. The Arab countries are bubbling with energy and there are expectations of much more social, political and economic innovations. Needless to say, unless the current eruptions mutate into an enabling environment the gains will be limited.

The Arabs and the Tiger countries

I will contrast the capabilities of Arab countries with those of China, India and others. I will argue that several Arab countries have reached a threshold from which they can launch a bid to join the Tigers if they can change their political economy. If the young revolutionaries can change the current political economy, they will be able to accelerate the rate of development and join the industrial club of nations.

I will show that in comparison with successful developing countries, Arab countries already possess considerable human capital and scientific expertise. They do not need to wait another ten or 50 years until a new generation of Arab scientists emerges. The human capital exists here and now.

The forces that drive development are well-known: science and technology, university graduates, and enterprise. I will show that Arab countries compare favourably with Tiger countries, *all prior to take-off by the Tigers*, in terms of absolute numbers of university enrolment, available professionals, and even in per capita scientific publications despite the fact that their expenditure on R&D is miserably poor.

Table 1 compares the educational performance of Arab countries with China and India. It compares Arab countries with these countries at the moment of their take-off in order to show the similarity of availability of human capital at that critical juncture. The data show that, on a per capita basis, Arabs have done well in comparison with China and India. These two countries are accepted as a good example of successful take-off.

Once a country becomes a Tiger country it seeks to expand these resources rapidly. As we see from conditions in Arab countries there is not much use for the available human capital since it either fossilizes at home or brain drains.

The next thing we need to do is to compare the quality of these graduates. I argue that in the absence of relevant data the brain drain can be used to compare the quality of education provided by countries. We find (Table 2) that Arab countries have been losing their human capital through the brain drain. Arab losses are even larger than those shown in Table 2 because Arabs emigrate globally and not primarily to OECD countries. Non-OECD countries do not publish statistics on such issues.

We note that the number of Arab emigrants at all levels of education is equal to the sum of Chinese and Indians. In other words, the per capita rate of emigration is some eight times larger than the rate for China.

The Arab World exports large numbers of medical doctors, engineers and a substantial proportion (possibly above 70%) of its PhD graduates from OECD univer-

Table 1. Study abroad and at home for selected countries.

	Study abroad		Population	Study abroad	Study at home	
Country	1999	1999 corrected	(1997, millions)	Per million	Enrolment in higher education	Per million
Arab	111 854	120 602	253.4	476	3 168 445	12 474
China	95 899	106 036	1227.0	86	7 364 000	6002
India	48 348	52 932	962.0	55	9 834 000	10 223

Source: Compiled from UNESCO statistics and others. The second column contains UNESCO data. The third column was obtained through the complementing of UNESCO data with European Union statistics (2004).

Table 2. Number of highly skilled personnel (HSP) in OECD countries, 1999.

Country	Expatriates	HSP (%)	HSP (*n*)
Arab World	4 462 391	22	967 548
China	1 928 199	51.9	1 000 735
India	1 649 711	39.6	653 286

Source: OECD (2004), table II.A2.6, SOPEMI 2004.

sities. I estimate that 66% of Arab medical graduates brain drain to Europe and North America. Judging from the notable performance of the brain drainees in the sciences, banking, industry, medicine and engineering implies a good level of education. Obviously, their performance also reflects the high quality of the environment in which they are working.

Table 3 compares the Arab World research output with that of industrial, Tiger and developing countries. Table 4 converts the data of Table 3 into research output per million inhabitants. Note the enormous gap between industrial, developing and Tiger countries.

There are considerable differences in R&D activities amongst Arab countries. Egypt is the leading producer of scientific research; Gulf Cooperation Council (GCC) countries are the leading countries on a per capita basis. The leading three Arab countries are Egypt, Saudi Arabia and Tunisia. These three countries are competing for first and second positions in terms of output. Tunisia and Saudi Arabia are racing each other neck and neck.

The availability of research and human capital in each Arab country separately is insufficient to enable Arab society. These capabilities have to be connected with each other to attain a critical size to enable a scientific community.

By examining the dynamics of R&D output of countries who take-off, it appears that the inflection point when rates of change accelerate is when a country reaches what I call the take-off point of 25 papers per million inhabitants per year. Countries do not necessarily take-off when they reach this level of output. However, those that aspire to do so do take-off. Egypt, Saudi Arabia and Tunisia, for example, have passed this point, but did not take-off. This level of research provides a measure of the readiness of human capital; however, the country has also to adopt the appropriate technology policies and provide the enabling environment to be able to transform its human capital into output.

As late as the 1990s and *on a per capita* basis the research output of the Arab World was 'numerically' ahead of both China and India. But Arab countries provide limited support to their scientific communities; and do not pursue a policy of self-reliance. They did not achieve any significant scientific attainments by comparison with China and India, except in the fields of health and agriculture.

Until 1985 Brazil and South Korea had a smaller R&D per capita output than the Arab World (Table 4). But South Korea, Brazil and China forged ahead while Arab countries did not. Once China, South Korea and Brazil decided to move full-steam ahead, their need for scientific capabilities increased dramatically and they acted accordingly. Thus China increased its output between 1995 and 2000; between 2000 and 2005, and between 1995 and 2007 by factors of 2.7-, 3.4- and 12.0-fold respectively. By contrast, the Arab World increased its outputs between 1995 and 2007 by 2.3; while South Korea increased it eight-fold during this same period.

In 2009 Manmohan Singh, Prime Minister of India, announced 'an increase in government investment in S&T [science and technology] from the present 1% of GDP to 2% over the next year or two'. Furthermore, India is establishing a number of new organizations to support and develop national scientific capabilities (Rao 2009, p. 126). China has been increasing its support of R&D at the rate of *20% annually* for the past decade.

Given the enormous resources that have been available to Arab countries during the past 50 years and their access to higher education, it is obvious that they under-performed spectacularly compared with such countries as Malaysia, Korea, Brazil, China and others. I will present below some likely causes to explain this under-performance.

Table 3. International comparisons of scientific output of selected countries, 1990–2007.

Years	1990	1990	1995	1995	2000	2000	2005	2005	2007	2007
Country	Population	Scientific output	Population	Scientific output	Population	Scientific output	Population	Scientific output	Population	Scientific Output
Arab World	218	5 589	249	6 652	278	8 501	310	13 052	341	15 194
China	1 134	8 998	1 205	16 866	1 260	46 245	1 304	159 046	1 321	204 160
India	834	12 418	935	13 156	1 015	23 454	1 094	36 576	1 129	46 409
Brazil	152	3 113	161	5 285	165	13 695	186	22 666	190	30 606
S.Korea	45	1 775	46	5 285	47	16 732	48	33 811	49	42 449
Australia	17	12 555	18	15 842	19	25 598	20	38 021	20	44 870
Spain	39	11 291	39	16 406	40	27 916	43	42 369	48	49 230
Sweden	8	9 955	8	12 164	9	17 799	9	22 308	9	23 458
Switzerland	6	8 422	7	10 558	7	16 699	7	22 966	7	25 091
France	57	36 109	58	48 296	58	58 984	61	71 686	64	95 252
Israel	4	6 780	5	8 507	6	12 447	7	15 261	7	16 293
Nigeria	95	1 268	109	731	124	1 206	141	2 107	146	3 435

Scientific Output: ISI to 2000 and SCOPUS from 2001 to 2010
Notes: Statistics are based on the percentage of growth shown in the Population Statistics History Website.
Sources: See http://www.geohive.com/charts/population2.aspx for Brazil, China, India, Nigeria and South Korea; see http://www.popline.org/docs/1444/066861.html for Australia; and see http://www.nationmaster.com/graph/peo_pop-people-population&date.1990/.

Table 4. Number of publications per million inhabitants.

Country	1981	1985	1990	1995	2000	2005	2007
Arab World	11	15	25.6	26.7	30.6	42.2	44.7
China	1	3	7.9	14.0	36.7	121.9	154.4
India	17	15	14.9	14.1	23.1	33.4	41.1
Brazil	–	–	20.9	32.9	85.1	121.9	161.1
South Korea	6	15	39.4	114.9	363.7	704.4	866.3
Nigeria	–	–	13.4	6.7	9.7	14.9	23.5

Sources: Table 6, ISI and demographic data from United Nations sources.

R&D activity in Arab countries

Figure 1 shows the total number of publications by scientists working in the Arab World over the period 1967–2010. The output has steadily increased (about 50-fold or more) over this period.

Wars, civil wars and economic change are averaged out when the outputs of all Arab countries are combined. However, when each Arab country is examined separately, national events can be seen to influence output.

The impact of the dramatic rise in oil revenues after 1973 shows clearly in the performance of Saudi Arabia; its R&D was insignificant before 1973. Note, however, a rapid increase after 1973 to reach a plateau in 1987; a modest rate of expansion was resumed in 1990.

Most GCC countries began to sponsor R&D after 1973. The United Arab Emirates (UAE) embarked on a moderate increase in research output in 1980 which stalled in 1996. A rapid increase was resumed in 2004. Research activity in Oman started in 1982 with the founding of its first university, and the output has maintained a steady rate of growth ever since.

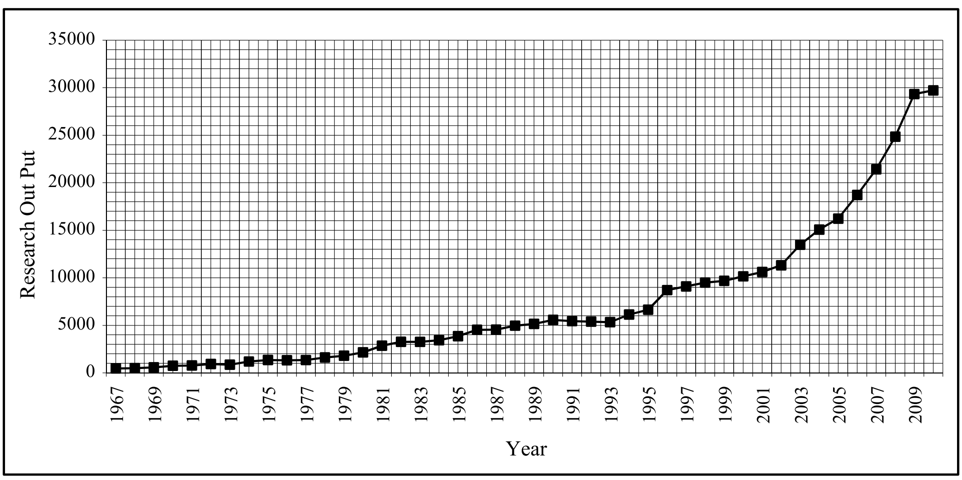

Figure 1. Research output of Arab countries, 1967–2007. Sources: ISI until 1995; and SCOPUS, 1996–2010.

On the other hand, Libya showed very modest growth beginning in 1969, and reached a low plateau in 1980, where it remained until 2004 whence it resumed modest growth.

The incubation period of Palestinian research output during the years 1980–1990 was erratic as a result of the repressive conditions under which Palestinians live. After this difficult start, research in Palestine grew to exceed, or to be comparable with, that of six Arab states in 2007–2010: Libya, Mauritania, Yemen, Bahrain, Sudan and Iraq.

Algeria did not show a response to the increase in oil revenues in 1973; its output increased between 1980 and 1989 when growth settled to a modest rate until after 2003 when it resumed rapid growth.

Tunisia, a non-oil-producing country, started its R&D growth in 1967 from a very low level and it has sustained this growth ever since. Currently, it is sometime the second largest Arab research producer; it is competing for first place with Saudi Arabia.

Generally, the economy has a direct impact on research output. However, Algeria, Libya and Tunisia are exceptions. The poor performance of several oil-producing countries such as Iraq and Libya indicate that other factors are also important. There are a number of additional interesting features:

- Egypt, despite wars and the long military confrontation between 1967 and 1973, maintained steady numerical growth. Saudi Arabia and/or Tunisia appear to be candidates for the position of the leading research producer of the region. Egypt has an enormous reserve of under-utilized human capital. It has yet to adopt effective policies to benefit from its science and technology capabilities or develop effective policies for managing its human capital. The political changes underway in Egypt today (as of February 2011) may very well transform the political economy and achieve an economic transition. Egypt is so rich with human capital that, given positive political change and a serious reduction in corruption, it should not take long to witness dramatic economic and scientific change in the country. One of the serious afflictions of the educational system of Egypt is its limited concern with standards and quality. Such a policy is suicidal.
- By contrast, Sudan's R&D, which was in third place after Egypt and Lebanon in 1967–1976, crumbled when the country suffered political unrest; similarly for Lebanon, which was the second largest producer of R&D until 1975. R&D activity in Lebanon semi-collapsed in 1975. Since then Lebanon has made some recovery (it is currently in fifth place), while Sudan is in 14th place among Arab countries in 2007.
- The GCC and the Maghreb had a limited presence in research until 1990, after which they exhibited steady growth. Table 5 shows the output of the Maghreb (Algeria, Morocco and Tunisia) and the GCC compared with that of Egypt during 2005–2010. The GCC has the highest output in four out of six years. The Maghreb was in first position in two of six years; while Egypt was in second position during 2005 and 2010 and in third place during the other years. The population of the Maghreb countries was 77.3 million; Egypt, 83 million; and the GCC, 37.9 million in 2009. The GCC countries lead in per capita output during the entire period.

The competition between these three regions is palpable. It is healthy and natural and has been noted in numerous other regions of the world, and between universities in most industrial countries.

Table 5. Number of research publications: the race between Egypt, the Maghreb and the Gulf Cooperation Council (GCC).

Area	2005	2006	2007	2008	2009	2010
Egypt	4408	4949	5508	6215	7748	7669
Maghreb	4382	5348	6061	8689	8689	7201
GCC	5042	5546	6136	6933	8314	9274

Source: SCOPUS.

Arab R&D and graduate education

The invention of graduate schools by Germany was in direct response to the country's defeat by Napoleon Bonaparte in the Battle of Jena (1806). The Germans studied the causes of their defeat and identified the role of science and the Ecole Polytechnique in providing Napoleon with enhanced capabilities. Ever since then the graduate school became a powerful instrument of development.

Graduate schools are essential organizations in national development. They provide the opportunities for researchers:

- to contribute to shaping national science policies and research priorities;
- to contribute to the development of sustained collaborative relationships between the research community and the economy;
- to intermediate the flow of knowledge;
- to provide a deep reservoir of high-quality advisors and consultants to government and industry; and
- to educate to high academic standards.

At the present stage of Arab development it is to be expected that most (about 40–90%) of R&D output is from universities (including medical schools) and hospitals. By contrast, in industrial countries universities are no longer the major producers of research, although they remain leading centres for fundamental research and scholarship.

Arab higher education has not yet opted for research-based graduate schools. Saudi Arabia, however, announced in 2008 its plans (being currently implemented) to establish a research-based graduate school. This will be the first fully fledged graduate school in the Arab World. When these plans fully materialize they are expected to have a massive impact on R&D in the region. Naturally, the Saudi initiative is expected to be adopted by other Arab countries – and to the intensification of competition.

The existing Arab educational infrastructure lacks deep commitment to quality and to research. The Arab countries cannot benefit from their vast reservoir of youth until and unless they seriously address this shortcoming of their educational systems.

Macro-national objectives: health and agriculture

Health and agriculture are two areas of science and technology that received serious attention in many Arab countries. Arab performance in health and agriculture will be compared with that of China and India to reflect their achievements.

Most Arab countries fell under colonial domination and could not undertake even modest improvements until they attained their independence after the Second World War. The approach of most Arab governments to both of these priorities was extensive. Their efforts entailed establishing educational organizations, supporting some research, sending students abroad to continue their studies, and setting up medical schools, hospitals and agricultural extension services. All these activities were associated with massive investments in the sector and especially in water-related projects.

Life expectancy at birth is an important indication of the quality of a country's health services. Life span in a country is the result of a combination of factors, the most important being:

- potable water and sewage disposal (this is an input by civil engineering and socially responsible government); and
- good nutrition and adequate primary healthcare (a product of socially responsible public health policies, medical schools, medical research).

Life expectancy in Arab countries can be compared with three developing countries (Brazil, China and India) and three advanced countries (Israel, Switzerland and Sweden). The highest life expectancy (78.4 years) in 2007 was attained in the UAE; most of the other Arab countries had a score above 70.0. Only three had their life expectancy below 70.0 in 2008: Djibouti, Sudan and Yemen. India, one of the three developing countries chosen for comparison, had a life expectancy of 64.0. China and Brazil had life expectancies of 72.7 and 72.0 respectively. All three advanced countries had life expectancy above 80.0 (United Nations Development Programme (UNDP) 2008).

Agriculture contributes to the management of the environment and produces food. Good government is concerned with promoting agricultural productivity as well as the improvement of nutrition. Agriculture is important to the Arab World for five additional reasons:

- More than half of all Arab food supplies are imported.
- Arab countries have fertile land that is either not utilized or is low in productivity.
- Water use in agriculture is of low efficiency and wasteful.
- Arab agriculture is a major employer: almost 30% of the labour force is employed in agriculture compared with less than 5% in industrial countries.
- Finally, rapid population growth is creating increasing demand for food supplies and leading to high levels of unemployment which is contributing to increasing poverty and accelerating emigration.

The Arab agricultural sector suffers from being located in the most arid region of the world. Water resources and management are crucial to agricultural production. Arab scientists have been contributing to the study of water resources.

To the credit of Arab governments, the progress made by Arab farmers between 1975–1985 and 1995–1997 was greater than the absolute value added by Chinese and Indian farmers in 1995–1997. But they have failed to make use of their scientific capabilities to seek parity with Europe and the United States in agricultural productivity (World Bank 2008). The value added of a farmer in Finland, France, the Netherlands or Singapore is some 30 times that of the Arab World (except for Saudi Arabia) (World Bank 2008). No Arab country compares well with European countries, whether we are examining water use or agricultural value added (World Bank 2007).

The Arab World has the internal market to absorb a doubling (or more) of agricultural production. Furthermore, both the human and natural resources (including water) and the capital required to transform the agricultural sector are either locally or regionally available. Organizational and institutional obstacles have so far held back the sector.

Between 1979–1985 and 1995–1997 Saudi Arabia registered a six-fold growth in value added per worker as a result of its investment in the sector. However, Singapore's value added in agriculture was nearly four times greater than that of Saudi Arabia in 1995–1997. The fact that the value added per Arab farmer is about 5% of that of a farmer in industrialized countries is a measure of the opportunities. Science and technology are available; the challenge is to apply them.

No significant industrialization has taken place in the Arab World in order to absorb surplus farm labour. Furthermore, some 30 million expatriate workers are imported to provide construction and other services instead of retraining rural labour.

Collaboration in scientific research

Science and technology are universal activities. Thus, cooperation and collaboration amongst their practitioners is necessary and natural. I have discussed this at length in my forthcoming book on *Science and Sovereignty* providing information on the performance of Arab scientists. I have shown that the rate of such collaboration as undertaken by Arab scientists is comparable with that of Chinese scientists and somewhat below that of scientists in industrial countries. What is weak or missing in Arab countries is cross-sectoral collaboration: between scientists and industry, agriculture, defence, service sectors, pharmaceutical sector, government and others.

The subject of scientific collaboration has been receiving increasing attention in industrial countries. Godin and Ipperseil (1996) note that in 1760 scientific collaboration was already responsible for 2% of articles, growing to 7% during the 19th century and reaching 80% in the natural sciences today.

The level of international cooperation by individual Arab scientists is the same or slightly higher than that of Chinese scientists in China. The number of joint research publications between Arab and OECD scientists has increased from 1064 in 1990 (22% of total output) to 1437 in 1995 (24% of total output), to 2324 in 2000 (23% of total output), and to 4385 in 2005 (27% of total output).

Some 36% of research output is the result of some form of international collaboration. The level of international collaboration in Arab countries is between 20% in most Mashreq countries and around 40% or more in Maghreb countries. European scientists are the major international collaborating parties. Inter-Arab collaboration is limited and reflects the lack of support for such activities, although all Arab countries could greatly benefit from collaboration in view of the commonality of the challenges.

A major problem that confronts Arab science is that governments do not yet see it as an investment. No adequate science policies have been adopted to enable them to deploy it in the solution of national problems. Thus Arab governments do not devote adequate financial support to this vital activity. The activity lacks adequate national and regional research centres where scientists could meet and collaborate. Furthermore there is an absence of well-funded and high-quality scientific societies. Moreover, the linkages between universities, research and industry are weak. Yet all these weaknesses can be easily overcome given the considerable human capital currently available. There are both underutilized scientific capabilities within Arab countries as well as a considerable number of experienced scientists in the diaspora. The solution of these problems has been within reach of Arab governments for some time. Things may change in the days ahead if the cooperative spirit that was seen in the Tunisian and Egyptian revolutions spreads within and across countries.

R&D in small and large countries

Does the size of a country affect the quality of the science it produces? Do large countries have 'better' science or just 'more' science?

Empirically one finds that the *quality* of scientific activity is not dependent on the size of a nation. Small nations such as Sweden and Switzerland have been able to attain a quality for their science on a par with that of leading nations such as the United States. Parity in the quality of science is more important than parity in scale: it allows a small scientific community to exchange with any other nation, while quantity, without quality, does not provide a similar advantage.

Countries such as Sweden, Switzerland, Australia and France all have a smaller output than the United States, the United Kingdom and Japan. Yet they have attained scientific parity with leading countries and can exchange knowledge with them without difficulty.

Some of the processes of scientific exchange are mechanical and may be carried out via the internet and the exchange of publications. However, 'front-line' research-related knowledge is transferred from one scientist to another, usually through personal contacts. This is where the parity in the quality of science is of vital importance: unless there is parity the scientists will not be able to belong to the same invisible colleges and enjoy the advantages of informal and direct communication with leading scientists.

Countries need little besides high-quality scientific capabilities to take-off. China and India became nuclear powers and likewise achieved many other scientific feats in the 1970s when their research output was fairly small. In both countries there was a firm national commitment to supporting, and benefiting from, their scientific capabilities.

Resources for development

Obviously, resources are needed to develop a country. Economists tell us we need science and technology (know-how), capital, labour, and various material resources such as land and water. Almost all Arab countries have these inputs.

Culture, often forgotten in the list of needed inputs, is probably the most important resource. A society must desire to engage in changing itself and must wish to industrialize. Culture is coded into the political economy in a manner that influences and controls every transaction. Whether a society decides to spend its resources on plastic surgery for beautification or on installing systems to bring potable water to every home and to recycle sewage is decided by culture. Whether corrupt persons are allowed to substitute poor-quality materials in construction or the government establishes construction codes and takes measures to implement codes and standards is also a cultural matter.

But once a society adopts relevant policies the process through which these policies are implemented is fairly complex. One needs testing services, supervisors and regulators. Every step in the application of science and technology has to be systematically monitored in a transparent manner.

The processes of making sure that the correct materials and methods are used to design and build a building are both simple and complex. Complexity arises from the enormous number of steps that have to be taken to complete such a project. Yet at every step standards have to be maintained and materials tested.

At every step in the economic process a variety of inputs have to be merged. Every transaction has to be verified that it meets specifications and standards. A myriad of transactions are subject to legal, financial and testing controls. It is the system management of transactions that is governed by the political economy. The political economy dictates how is a project undertaken. Japan, China and Korea set out to undertake a project using national capabilities. If they are short of some expertise they seek to learn it. Virtually all OECD countries have labour laws regulating the use of foreign labour. They all adopt self-reliant approaches.

The idea of importing 30 million expatriate workers in a region where there are 30 million unemployed would be unacceptable in most countries of the world. The concept of commissioning projects from foreign consulting and contracting firms without the association of local firms is unheard of in Korea, China or India.

Thus the key to development is not human capital or science separately but rather the triad that consists of the system relationships between human capital, science and enterprise. *Unless a society has successfully integrated these three different types of resources it cannot benefit from them*. Human capital is of limited value unless it is provided with an enabling environment. This enabling environment makes it possible to integrate cultural, legal, and financial organizational features and facilitate their fruitful combination.

Thus, in order to enable scientists and technologists to perform their magic they depend totally on the political economy imposed by whosoever is in power.

Why has it been so difficult?

The Arab countries have been in constant contact with Europe for a millennium. One would have imagined that they should have succeeded to industrialize long before Japan. Why did it take so long?

Most people working in the development field try to look at what is happening today, last year and possibly a period of a few years. Fortunately, in recent years researchers have been looking at longer time spans. Comin *et al.* (2010) explored the impact of technological activity over millennia. I will sketch what appears to me to be important factors in the slowness with which Arab countries responded to the industrial age.

Arab history provides some hints to enable us to understand the forces at work. There are *at least* three major factors that have slowed/delayed/curtailed Arab response to the challenge of the industrial revolution. The first, and probably the most critical setback, was the move in the 9th century by the Caliph al-Muʿtaṣtim[4] (794/6–842; Caliph 833–842) to go for Mamlukes to staff the imperial army and to become dependent on mercenaries for the most important function of government: national security. This paved the way for centuries of chaos and rule by mercenaries of the most important regions of the Arab Empire: Egypt and Iraq. Corruption, chaos, fragmentation of the Empire by warring Mamlukes dominated the history of the region.

This is a period that has not been studied from the point of view of its impact on culture, creativity and the economy. However, it is reasonable to assume that the golden age of Al-Ma'mun ended and there was progressive decline in the centuries that followed. Thus Arabs were not able to make a creative response to the challenge brought about by Prince Henry the Navigator's development of transoceanic navigation.

The second was a failure to appreciate the importance of the development of ship design in Portugal beginning in the 14th century by Prince Henry the Navigator (1394–1460). Prince Henry's efforts led to the invention of transoceanic ships that could handle the high waves of the Atlantic and moreover could carry up to 180 guns. Arab ships carried one gun. Prince Henry did not make it to the Arabian Sea; but in 1498 Vasco da Gama did.

Portugal was unable to destroy the Arab–Asian trade system. However, the French, the British and the Dutch were all watching and in the early 17th century they made their entry into Gulf waters. The rest is history: they invented the East India Companies which were endowed with sufficient capital to dominate trade with Asia rapidly.

The third factor was a peculiar characteristic of the Arabs. What kept the populations in the Islamic empire together, besides common culture and religion, was their massive system of trade and transport. The system of transport made it possible for people to circulate, trade and behave as if they were in one country. Yet the region was frequently fragmented into various independent regions. This fragmentation was overcome by the efficient and powerful system of trade and transport.[5]

The Arab trade and transport sectors were private enterprises. There were no roads to build – which is the normal way through which the public sector controls transport. Furthermore, trade was a major sector of the economy. Thus, when it imploded in the 17th century it created a large depression.

When in the mid-17th century the Arabs lost their monopoly of Asian trade they also lost a major source of employment and income as well a major instrument for the maintenance of the unity of the Islamic World.

The loss of Arab–Asian trade had widespread economic repercussions: the loss of employment in nomadic, agricultural and urban areas. Nomadic tribes served as the Detroit of Arab transport: they bred the millions of camels needed. The Arab tribes also managed the 'fleets' of camels needed for transport. Prince Henry had correctly assessed the situation: he was implacably hostile to the Islamic World. The Arabs not only lost Asian trade, but also the trade with Europe that was based on local production of sugar, paper, glass, their beautiful brocades and textiles known through Renaissance paintings, and others. The Arabs were unable to invent a positive response in order to retain a share of their previous markets.

These three factors contributed to a collapse, rather than to a decline, of the region. The collapse was so severe and creativity was at such a low point that the region went into semi-permanent decline that has lasted four centuries.

Napoleon landing in Egypt in 1798 exposed the weakness of the Ottoman Empire. This knowledge prodded European powers into conquering the entire region, except for Arabia and Yemen. The colonial period was an unmitigated disaster. The region is still suffering the consequences.

Under colonial rule the technological domination of the Western powers resulted in comprehensive technological dependence. The technological shift in Europe during the 17th–19th centuries was towards iron products and mechanical engineering. A prime invention was the use of fossil energy to replace animal muscle and wind as a source energy. Though the steam engine was discovered in Egypt over 2000 years ago and the invention was known to Egyptians, Greeks, Romans and Arabs, nobody did much with it. Until a miner in Britain used it to pump water out of flooded coal mines. Yet this invention would have been of limited value were it not for Sadi Carnot who sought to find out the determinants of its efficiency. In the process he discovered the science of thermodynamics and this lead greatly to an increase in the efficiency of the steam engine.

By 1800 Europe had moved beyond the Renaissance and entered the stage of industrial development. Adam Smith who recognized the significance of these advances was aware of the implications of these developments to political culture.

The level and nature of the creativity that was now required, as well as the social organization to support such creativity, was of a novel type.

Though most governments are for economic development, it takes further reflection to seek industrial development. The nature of human relations, the need for new forms of social organizations, the extent of freedom and free association amongst people in a society, the nature of the industries that society has to put in place, the perpetual change of knowledge, and the infinite supply of new ideas and inventions have all taken new directions and shapes since 1800 … and these processes continue to modify the world we live in.

The Arab countries began to terminate colonial rule after the Second World War. The liberation of Egypt began in 1952 with the First Egyptian Revolution. Algeria had to wait until 1962; while Palestinian colonization still goes on. The process of change continues.

Conclusions

The importance of science and technology has been evident since the dawn of history. Science was visibly important during the late Stone Age. The Agricultural Revolution; the construction of buildings and water systems; pottery, ceramics, metals, glass and dyes – all ushered new sciences which became progressively more widespread. Each of these advances led to advances in culture and politics.

However, with the advent of the Industrial Revolution there was an explosion of discoveries in physics, chemistry, mathematics and biology. These led to a massive increase in opportunities and complexity.

Science was no longer a small-scale activity. As scientific knowledge unfolded there was increasing demand for more talent, more practitioners, more resources, more organization and more long-term planning. All of these changes had massive implications on the political economy of nations.

What was most notable is that the new sciences required a more liberal society. Galileo was a turning point: he needed to be free to watch the Moon and *report freely what he saw*. Since then the frontiers of human freedom have been constantly expanding.

Primitive systems of government were no longer adequate. Such governments could not adapt or understand what was taking place. Societies unable to adapt to the requirements of the industrial age were left behind and became (and still are) a playground for imperial powers. Some of the dormant countries woke up during the past 50 years and joined the exciting race in science.

The interplay of culture, finance, politics and science is daily becoming more complex and interdependent. What we saw happening in Tunisia and Egypt is a mere beginning. The hope is that a courageous generation will take over Arab countries and push their frontiers forward.

At the time of the *futūḥāt* the Arabs not only conquered the world around them, but also they came with open minds and enjoyed their creative experiences, devoured the knowledge that previous civilizations had acquired, and built a rich and glorious culture. However, their political culture resisted the changes brought about by these achievements. Its rulers sought alternative forms of controls to resist the upsurge of creativity and search for freedom. Thus they imported the Mamlukes and these rapidly took over rule crushing the upsurge of creativity and discovery.

During the past two centuries colonial powers continued the role of the Mamlukes through the domination of imported technology. Although Arab society sought learning and knowledge, its rulers sought to secure independence from their populations by importing foreign firms and labour to provide the products of the modern world. Yet with 1.5 million engineers and a growing population of 300 million they had more than enough human capital and financial resources to pursue a different course.

The immediate future of Arab countries will be determined by whether their governments of the next decade are willing and able to construct an enabling scientific infrastructure. Little of the hopes and aspirations of the young who struggled so courageously in Tunisia and Egypt will otherwise be rewarded.

Notes

1. The research concerning the conversion to steam shipping was already well underway (Macleod *et al.* 2000).
2. Henry and Springborg provide the type of analysis that exhibits the functioning of the triad subject to political culture (also Murphy *et al.* 1993). For a seminal paper on the dynamics of the processes, see Baumol (1990). These different approaches provide a useful explication of how economic transactions are dominated by the political economy.
3. In fact the sums are larger because these figures do not include the figures for Algeria, Libya and Qatar (UNESCO Regional Bureau for Arab States 2009).
4. We are told by historians that Harūn al-Rashīd, father of al-Mu‘taṣtim, thought his son will never rule. Harun had ‘identified’ his three successors and arranged their terms of rule. Thus since al-Mu‘taṣtim was not interested in learning as a child, Harūn neglected his education. He grew up with the royal troops and became a good strategist and military commander. Alas the history of the caliphate did not follow the dictates of Harūn al-Rashīd.
5. This has been discussed at length elsewhere (Zahlan 1999).

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