Renewable Energy Technologies in Asia: Analysis of US Patent Data

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Abstract
The paper explores the link between patent trends and national innovation systems for a selection of Asian countries, namely China, India, Japan, Russia, South Korea and Taiwan, in the case of renewable energy. It uses 1975-2007 data from the US Patent and Trademark office. The concept of technological trajectory is also analysed suggesting that we are yet to witness an uptake in renewable energy. The imperatives of climate change however pose serious challenges to the world and in particular to the Asian countries where most of the economic growth is likely to occur in the future. Japan is the dominant leader in foreign patenting in the US but renewable energy does not appear to be a national priority, as is also the case with South Korea, China and Taiwan. For Russia and India thou these technologies are emerging as an area of specialisation. All Asian countries will need to strengthen their innovation systems in order to allow for transformations towards a less fossil-fuel dependent global economy to occur.

Key words: innovation, international comparison, national innovation system, technological specialisation, technological trajectory

1 Introduction

This paper explores the development of renewable energy technologies and capacity in Asian economies by analysing patent data as a way of describing their relative performance in this part of the respective national innovation systems.

Technological development seems to happen along certain clusters of solutions where a particular concept becomes dominant over a period of time and guides the majority of innovative ideas. Abernathy and Utterback (1978) and Dosi (1982) referred to these practices as establishing a technological paradigm which according to Dosi is: "a 'pattern' of solutions of selected technoeconomic problems based on highly selected principles derived from the natural sciences, jointly with specific rules aimed at acquiring new knowledge and safeguarding it, whenever possible, against rapid diffusion to the competitors " (Dosi, 1988, p. 1127). The patenting system which has been in existence for more than 200 years in the Western world (Marinova et al., 2005) is an example of the mechanisms that society has put in place to protect and encourage innovation.

Dosi (1982), Perez and Freeman (1988) also point out that over the period of time when a certain technological paradigm is dominant, innovations tend to happen along technological trajectories which follow more or less a Bell distribution curve (see Figure

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1). At the early stage of the trajectory, the number of new technologies is relatively small but as the paradigm is adopted in full force the inventions keep coming (many of them improve or replicate earlier innovations) until they reach a level of stabilisation and then slowly vanish. The period when the innovative activities along the old technological paradigm start to disappear is also the time when a new technological paradigm is being born.

In order to encourage such innovative behaviour, many governments have particular policies and institutions (including enterprises, universities and research institutes) in place which in their complexity are known as national innovation systems (Freeman, 1988; Lundvall, 1992; Nelson, 1993; OECD, 1997; Marceau and Manley, 2001). The national priorities also translate into sectoral innovation systems (Malerba, 2005) and related industrial policies. Therefore countries "differ in the level of their investment in innovation, the roles of the public and private sectors, the industries and technology fields of greatest importance and the rates of change in those patterns, the level of cooperation among organisations, the modes of financing innovation, attitudes to risk taking, the regulation of the labour market and the role of large and small firms" (Scott-Kemmis, 2004, p. 1).

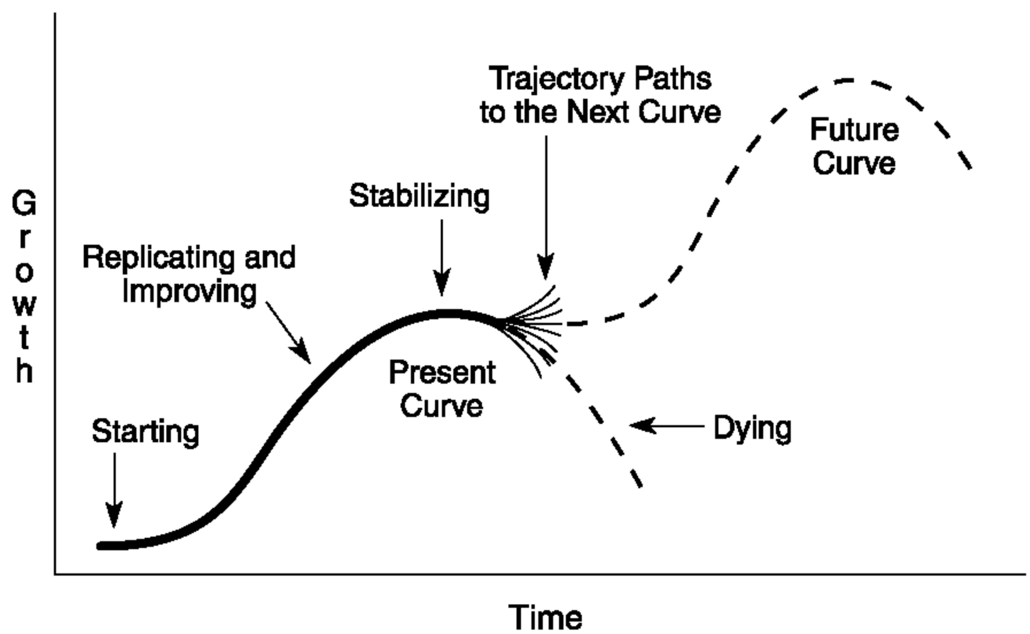

Figure 1. Technological trajectories

Source: Abraham and Knight (2001, p. 24)

Of interest to this paper is how Asian countries are placed in relation to technology development under the current global imperatives of climate change (IPCC, 2007). Its aim is two-fold. Firstly, it analyses the emergence of new renewable energy technologies within a global social and political environment that is concerned about anthropogenic climate changes. Secondly, it examines the positioning of Asian countries within this newly emerging technological paradigm.

The choice of renewable energy technology is not surprising given that fossil fuels are being proven to be the main cause for the constantly increasing levels of greenhouse gas emissions in the earth's atmosphere (IPCC, 2007). This technological group can also be seen as being a major representative of technologies that are sustainable or in other words, technologies that can simultaneously and synergistically include market profitability, environmental considerations and social accountability (Marinova, 2005). These technologies need not only be economically viable but also environmentally friendly and socially acceptable and desirable. Hence their development requires understanding of the interactions between technology and the social, ecological, economic, cultural, political and governance systems within any one country.

2 Methodology

Despite the many flaws of the patenting system (e.g. Edgerton, 2006) and many recommendations for its improvement (e.g. Merrill and Levin, 2004), it remains one of the best sources (if not the best source) of information that we have about new technology development. Its growing importance within society is manifested with the larger and larger numbers of new applications and consequently new patents issued. The Patent and Trademark Office in the US (USPTO) alone receives more than 300,000 patent applications per year (Merrill and Levin, 2004). Patent information has been extensively used to describe innovation activities and new trends in technology (Pavitt, 1988; Acs and Audretsch, 1989; Archibugi and Pianta, 1992).

Patenting activities, and particularly patenting in foreign countries, are also highly indicative of technological achievements and specialisation. In the last thirty years, the US has been the most competitive and in many ways the most desirable market for the best technologies developed from around the world. Because of the significant burden associated with patenting, including among others financial commitments, application requirements, waiting times and operating in a foreign organisational environment, companies and individuals who pursue obtaining of US patents tend to be representative of the technological strengths of their home countries. According to Scott-Kemmis (2004), these national patterns of specialisation tend to persist over prolonged periods of time. However, what is interesting to capture is the dynamics of the emergence of such technological trends and specialisations.

Archibugi and Pianta (1992) compared the national and global patenting activities of the OECD countries and came up with categories which describe how well they respond to global trends in particular technology classes. Australia, for example, was categorised as a follower with high specialisation as its new patented technologies were in areas where there was overall low global patent growth. This reflects the nature of Australia's industry sector with its strong connection to natural resources. At the time of the study, Japan emerged as the most technologically advanced country with very low specialisation (ahead of US, Germany, UK and France). Japan was pursuing technological strengths, and consequently technological and economic advantages, across the entire range of patenting classes. More recent studies based on US patent data also confirm Japan's strong technological presence but relatively low specialisation, particularly in the field of renewable energy technologies (e.g. Marinova and Balaguer, 2008).

Patenting as representative of technology development is also linked to other knowledge creative activities within a country's innovation system, such as publications, R&D investments and personnel. Scott-Kemmis' (2004) analysis for example linked technology cycle time (i.e. the median age of the references used in a patent) and science level (i.e. number of patent citations to scientific literature). Australia was identified as a slow moving science-based country, but what is of interest from the perspective of this study is the group of fast moving Asian countries, namely Japan, South Korea and Taiwan, which had low science linkage levels. These countries have concentrated their patenting activities in the areas of semiconductors, telecommunications and computers to the detriment of other technologies, e.g. biotechnology (Balaguer et al., 2003).

Given the imperatives of climate change and the challenges for the energy sector globally, how are these countries performing in relation to renewable energy technologies? Are there any other Asian countries that have reached out to the US market to build technological strengths in renewable energy? Where are China, Russia and India, in particular, knowing the additional pressure that their fast economic development is putting on the planet's ecological environment? China with its fast GDP growth, urbanisation and industrialisation in particular has become since 2006 the world's largest greenhouse gas emitter (NEAA, 2008) and is now continuingly contributing to raising CO_2 concentration levels which already are getting closer to the planet's tipping point due to the development in the West.

The section to follow uses patent data from the USPTO for the 1975-2007 period (by date of patent application) retrieved on the basis of key words, to describe trends in patenting renewable energy technology (excluding nuclear energy). These patents cover technical solutions in solar, wind, wave, tide, geothermal, hydro and biogas technologies. A patent is identified as belonging to the class of renewable energy if the key words (or truncated key word expressions) related to the range of renewable energy technologies are found in the patent's abstract, description or claims.

Some parallels are drawn with nanotechnologies which are considered to be inherently sustainable as they have the potential to reduce the total volume of material per product function (less material waste); to reduce energy costs during the use-phase of products; allow for efficient energy conservation and storage and also include nanoscale processes for environmental improvement (such as screening, treatment, remediation, benign manufacture, used in solar and fuel cells). Despite these positive characteristics the Centre for Responsive Nanotechnologies raises a range of concerns about their sustainability (www.crnano.org/dangers.htm), including the possibility of economic oppression from artificially inflated prices; personal risk from criminal or terrorist use; personal or social risk from abusive restrictions; social disruption from new products and lifestyles; unstable arms race; environmental damage or health risks from unregulated products; free-range self-replicators and black market in nanotechnology. The list can be expanded to include further possible environmental damage, such as nanoscale contamination of water and air, and as with most types of technologies their development and application will depend on the policy decisions and moral value held within society.

As nanotechnologies are not renewable energy technologies per se, the parallel with them is included in this paper as their development has significant potential to facilitate any further development of specific renewable energy technologies.

In addition to general trends for renewable energy and nanotechnology, the paper specifically analyses data for Japan, South Korea and Taiwan by using three indicators:

- technology specialisation index (TSI):
  $TSI_{ij} = (P_{ij}/\sum_i P_{ij}).(\sum\sum P_{ij}/\sum_j P_{ij})$,
  where TSI_{ij} is the index for i sector of j country and P is number of patents (Paci et al., 1997);

- share of total patents (%):
  $PS_j = P_j/\sum_j P_j * 100$,
  where PS_j denotes the patent share of country j to total patents (Patel and Pavitt, 1991); and

- rate of assignment of patents (RAP):
  $RAP_j = AP_j/P_j$,
  where AP_j is the number of patents assigned to residents of country j (Marinova, 1999).

As its title suggests, the first indicator describes the technological specialisation of a country compared to the average patenting trend in a particular class of technologies (which is 1). A country value higher than 1 indicates that this particular technological class is relatively more important for the country than the average; similarly, a country value lower than 1 indicates that the importance is lower than the average. The second indicator, ie share of total patents, is a quantitative description of the presence of a particular country within a particular class of technologies. The third indicator, rate of assigned patents, is indicative of the closeness of the patented invention to being commercialised.

The policy environment influencing the patent trends is then analysed and parallels are drawn with Australia within an innovation policy framework, taking into consideration actors, networks, institutions and markets (Malerba, 2005).

3 Results

Figures 2 and 3 present the annual numbers of US patents issued on the basis of applications from 1975 to 2005 in absolute (Figure 2) and relative terms (Figure 3). As it takes more than two years for a patent to be issued after an application is being made (in some cases it can take much longer and delays of 7-10 years are not unknown), it is likely that the number of approved applications in more recent years will increase. Despite the apparently increasing trends of US renewable energy patents since the early 1990s, their relative share in total US patents remains very low at below 1% (see Figure 3). The number of new renewable patents issued reached 1668 for applications lodged in 2002 but even in that year their relative share was only 0.77% of total US patents.

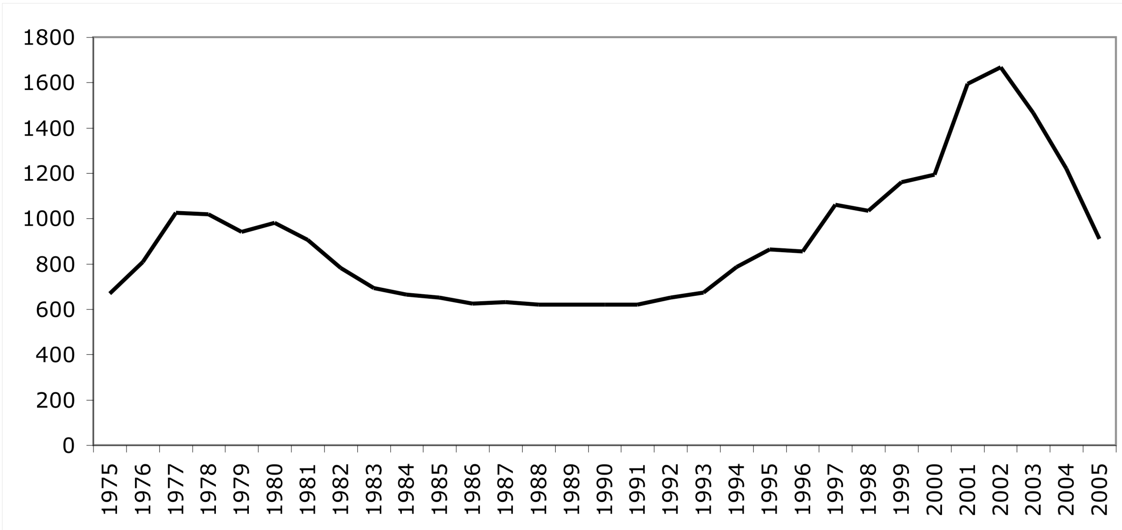

Figure 2. US renewable energy patents, 1975–2005
(by date of application, as of 16.10.2008)

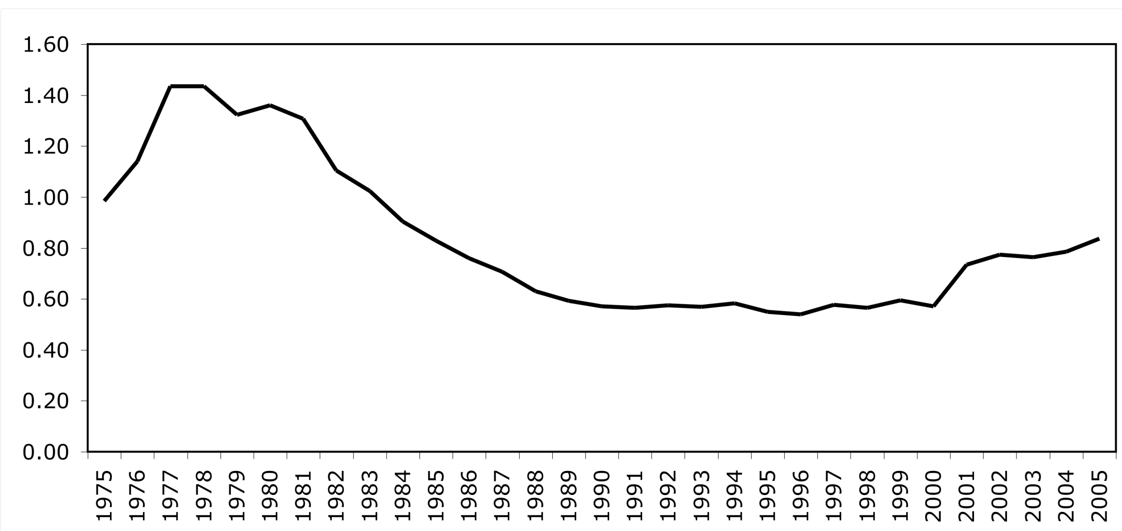

Figure 3. Relative shares of US renewable energy patents (%), 1975–2005
(by date of application, as of 16.10.2008)

It is estimated that more than 70% of the US renewable patents are domestic, a much higher share than the average of 50% for all technology classes (Griliches, 1990). Apart from the fact that the predominant capacity in renewable energy still remains with American inventors, this could also mean that the US market was less attractive to foreign technology developers. The relatively low numbers of renewable energy patents at less than 1% is indicative of the fact that this area has not yet taken speed. If we compare the graphs from Figures 2 and 3 with the S-curve describing technological trajectories, it is clear that this class of technologies is still at the beginning stage.

Compared to renewable energy, patented nanotechnologies exhibit a striking different trend (see Figures 4 and 5). They are clearly on a steep increase with absolute numbers reaching as high as 9908 in 2001 and a relative share just below 5%. This is a good indication that the nanotechnology trajectory is taking shape.

Out of all foreign countries patenting in the US, Japan is a leader in the class of renewable energy technologies (in fact, the same holds true for any class of technologies). Between 1975 and 2007 this country had a total of 3178 renewable energy patents issued. However as Table 1 shows, the national importance of renewable energy technologies is relatively low as its TSI is only at 0.59 (a value at 1 indicates average level, >1 means that the technology is a national priority and <1 that it is below the average for the world).

Renewable energy does not appear to be a national priority for Taiwan, Korea and China either. On the other hand, Australia[1], Russia and India have a small number of patents, but with TSI indices above 1 (as high as 1.69 for Russia) renewable energy is building up as a national strength in terms of inventiveness.

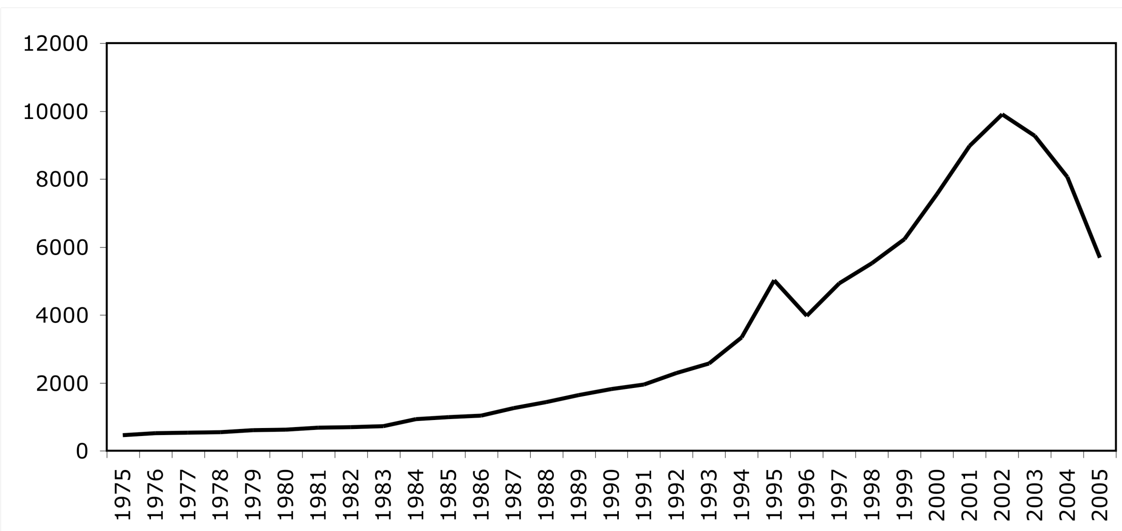

Figure 4. US nanotechnology patents, 1975–2005
(by date of application, as of 1.1.2009)

[1] Australia is added to the table only for the purpose of comparison. Also this country is not technically in Asia, it is situated very close to this geographical region of the world. Its national and sectoral innovation systems however are not discussed.

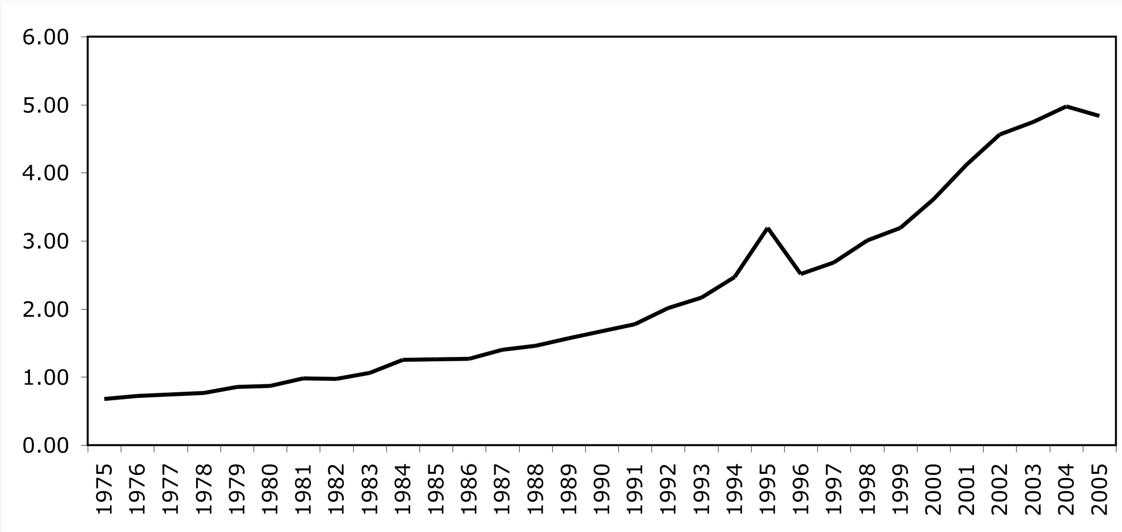

Figure 5. Relative shares of US nanotechnology patents (%), 1975–2005
(by date of application, as of 1.1.2009)

With the exception of Japan, the patents of all other countries do not appear to be close to a commercialisation stage as they are not explicitly assigned to a company or organisation and are still being held by their inventors (only Japan's rate of assigned patents is 0.93, meaning that roughly 93% of all issued patents are in ownership of a particular legal entity). The rate of assignment by Russia is drastically low which shows that despite interest in renewable energy, the actual implementation on the ground will take longer, if at all.

This delay between invention and innovation can be understood if we examine the characteristics of the respective innovation systems within these countries. Japan has had a proactive national innovation system since the 1960s (Freeman, 1988) and a very well developed sectoral renewable energy innovation system which encourages inventiveness and products ready for the market (Marinova and Balaguer, 2009) as witnessed by the high assignment rate.

Taiwan has had a more proactive innovation policy since the early 1990s which has encouraged technology development programs for academia and industry research centres. This has brought significant results in the area of information technologies (Chen, 2007) but is yet to be repeated in the energy area. As Wade (2004) describes it, the Taiwanese government "governs the market". The country's government-led networks have evolved from their original technology diffusion purpose to technology creation (Dodgson et al., 2008) as witnessed in its growing numbers of renewable patents. South Korean innovation policy is quite centralist, directed towards upgrading the industrial and economic competitiveness of the country (Roper et al., 2007). In the tradition of this approach, the country only recently started to aim at delivering large-scale renewable energy solutions. In addition to the world's biggest tidal plant already under construction, the world's biggest solar power plant was announced last year (www.iht.com/articles/2007/05/09/business/solar.php). Korea and Taiwan are both aiming to provide 10% of their energy renewable sources by 2020. The policy initiatives encouraging an innovation environment with actors, networks and markets (e.g. links with universities or innovation partnerships between leading edge companies) in these countries are relatively new. This explains the delay in the uptake of renewable energy technologies, the lack of a sectoral innovation system and overall, the low technological specialisation.

Table 1. Country rankings, Asia – renewable energy patents, 1975-2007

	Total	Renewable Energy	TSI	Share of total patents [%]	RAP
Japan	708188	3178	0.59	11.01	0.93
Taiwan	87313	216	0.33	0.75	0.44
Australia	22954	192	1.10	0.67	0.66
South Korea	62193	150	0.32	0.52	0.75
China	10547	49	0.61	0.17	0.24
Russia	3576	46	1.69	0.16	0.09
India	5254	45	1.13	0.16	0.40
Total	3801164	28867	0.0076	100.00	

Source of data: Compiled from USPTO, 16.10.2008.

After a long tradition of first class research, only recently did Russia start to orient its science toward the needs of the economy and some radical changes started to be seen in its development but are yet to translate on the international arena. According to Gokhberg (2004, p. 12), Russia's innovation system "exists, but it does not work" as it elements function in isolation of each other.

China is expected to be the world's next innovation powerhouse (Farhoomand and Tsang, 2005). In the past, it had centrally commanded and segregated innovation system geared mainly towards military technology but in the 1980s the Chinese government started to proactively guide changes towards civilian technology development (Sun, 2002). Since the 1990s it has put a lot of emphasis of universities as centres for frontier research networks involving spin-offs to industry (Wang et al., 2006). Although still centralised, China's innovation system is very much geared towards practical applications with fast economic outcomes (e.g. Gu, 1997). Co-invention patents by applicants from firms, universities and public research institutes are becoming a distinctive feature of China's innovation system (Motohashi, 2005). Under the constant pressure for energy demand from its fast growing economy, China is likely to soon turn to renewable options at a much greater scale but this is yet to be seen.

India is a very interesting case in terms of innovation as it recently has become a global research and development centre for major international corporations which are making good use of the country's skilled labour force. Its own research institutes and universities have also achieved international reputation. Another important feature of India is that it is expected to soon become the most populous country in the world and even now its market is ranked third largest by the 2007-2008 Global Competitiveness Report. The government has played a major role and in most cases singularly in the development of India's innovation system (Herstatt et al., 2008) and it is hoped that this huge potential will soon translate into important renewable energy solutions.

4 Conclusion

The climate change agenda requires concerted efforts from the entire humanity, including the countries of Asia where most economic growth is likely to occur in future years. Technological development as outlined by patent trends is only one aspect of the changes that are expected to happen. They are however representative of the country's national innovation systems which "capture the rich and organic relationships between institutional evolution and dynamic corporate strategies in the context of macro-economic challenges and changing policy frameworks" (Dodgson et al., 2008).

Between 1975-2007 Japan has been an absolute leader in terms of the volume of renewable energy patents which are also ready for commercialisation. The government-geared policies of Korea, Taiwan and China although targeting fast application of research and development, have left renewables as a lower national priority. By contrast, for Russia and India these technologies are emerging as important but these countries are yet to benefit from a developed entrepreneurial spirit as they lack a sectoral renewable energy innovation system and their national innovation systems are in a process of transition. All Asian countries will need to strengthen their innovation systems in order to allow for a transformation towards a less fossil-fuel dependent global economy to occur.

5 Acknowledgement

The author wishes to acknowledge the financial support of the Australian Research Council. She is also grateful for the comments of two referees and the feedback received from the participants in the 2nd International Association for Energy Economics (IAEE) Asian Conference, Perth, Western Australia in November 2008 where this paper was presented.

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