Pattern of patent-based environmental technology innovation in China

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Abstract

Technology innovation benign to environmental preservation is one of the key strategies to address sustainable development. Understanding the pattern of environmental technology innovation in a country is necessary for making policies and decisions in environment management. Temporal and spatial distribution of environmental patents was analyzed to identify innovation capability of environmental technologies in China. In terms of features the patents were classified into invention, utility model (performance improvement) and design. The patents belonged to the individuals, enterprises and research institutes in terms of ownership. Through analyzing the pattern of environmental patents by features and ownership, it was found that individual-owned patents and utility model patents accounted for the biggest percentage of all the environmental patents applied by the domestic applicants. Eastern provinces had the majority of environmental patents. The cluster analysis showed that invention patents and enterprise-owned patents were concentrated in the eastern provinces. In general, the innovation capability of environmental technologies in the east is strongest among the regions. Though it had been improved in the last two decades, the percentage of invention patents was still small and enterprises did not play the most important role in innovation. Applications of environmental patents increased gradually but had a declining share of all the patents in the last two decades. The innovation capability of environmental technologies in China is still not strong on a global perspective.

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1. Introduction

Technology innovation plays an important role to address sustainable development [1–4]. Only the innovation of technologies that are environmentally sound can ensure the realization of sustainable development. It is difficult to imagine how sustainable development can be achieved without innovations in environmental technology [5,6].

Competitive advantage, governmental regulation, international trade, individual capability, and public pressure are all important factors that can stimulate innovation [7–14]. Organizations have a variety of incentives to pursue environmental technology innovation. Empirical data have identified legislative and regulatory pressures as the main external forces that promote the adoption and innovation of environmental (or green) technology [15–19].

In this article, environmental technology refers to the technology which can be used in production or consumption to prevent or reduce the pollutant emissions and conserve resources, such as end-of-pipe pollution control technology and energy saving technology [5,6]. Much research has been done on the innovation of environmental (or green) technology. Patents are the most commonly used indicator of technology change in the literature [20]. In general, technology innovation encompasses three stages: invention, innovation and diffusion. The classical differentiation between invention and innovation suggested in the literature is approved in this article [21,22]. Invention is the course to create new technical ideas or devices, while innovation is the first commercial or practical use of an invention. Diffusion is the adoption of innovations by others. It seems that patents measure invention activity, but they are also important indicators for the understanding of adoption and diffusion, as inventors typically file patents and turn in registration fee on time because they expect to market their inventions. The fact indicates that patents also imply the potential value in other processes such as diffusion. Therefore, the most accepted and widely used measure of innovation activity is patent counts [23]. In this study technology innovation is tracked using historical data of patents filed.

The article is structured as follows. In Section 2, the searching process, to identify environmental patents from all the patents, is introduced in detail, and the methods adopted in this article are also described. Section 3 analyses the temporal and spatial distribution of patent-based environmental technology innovation in China and discusses the outcome of data analysis. Section 4 provides some concluding remarks.

2. Data and method

2.1. Data

International Patent Classification (IPC) is used in Chinese patents. Since no specific patent classifications or sub classifications are assigned to environmental technologies, environmental technology may be involved in every classification or sub classification of patents. In order to identify environmental patents, a program of Environmental Patent Filter was compiled.

Firstly a knowledge base of filter terms was designed for recognizing the technologies if they were sound to environment, such as sulfur dioxides or nitrogen oxides removal. There’re 81 terms in total, which were assumed to be most relevant to the definition of environmental technology.

Secondly a Search Program was compiled by using Visual Basic language, with patent titles or abstracts as searching objectives. If the filter terms appeared in the title or abstract of a patent record, the
A patent would be taken into the database of environmental patents. All the patents were retrieved derived from the database of State Intellectual Property Office of P. R. China. The search work ended on June 30, 2006. The iterative search process identified 41,838 environmental patents.

After the searching these patents were then filtered randomly. Through reading the abstract in detail the patent was checked whether it was in line of the definition of environmental technology. Finally, 41,511 patents passed through the filter.

The time span was from 1986 to 2005. According to the Patent Law of the People’s Republic of China the date of the initial application is referred to as the priority date. If the patent is granted, protection begins from the priority date. In terms of the priority date the application year of every environmental patent was determined.

In terms of the applicant’s address, patents were assigned to region or country that they belong to. The regional data contained both domestic and foreign sections. The domestic section included the applications from 34 provinces which were divided into eastern region, central region and western region. The foreign section included the applications from 51 countries.

In terms of the features the patents were classified into invention, utility model and design. Invention patents are of innovative technologies, products and processes; utility model patents are applied technologies to reform the structure of products; Design patents are aesthetic and applied redesigns of the configuration and outfit of products. Invention patents are most valuable.

In terms of ownership the patents were owned by individuals, enterprises and research institutes. Enterprises play a crucial role in economic development, they are also important part in technology innovation process. Enterprises develop new products and reform technologies based on market demands, technology innovation brings them competitiveness and benefits. In this regard, the patents owned by enterprises are most valuable and practical for applications, which could be used as a good indicator to measure the quality of patents.

2.2. Method

Spatial analysis was conducted using ArcView, a GIS software package from ESRI. The activity index (AI) was used to analyze the discrepancy of environmental patents in different provinces in this article.

The activity index \( A_{ij} \) or location quotient index \( LQI_{ij} \) is defined as the ratio of the percentage of \( j \) kind of environmental patents in \( i \) province to the percentage of \( j \) kind of environmental patents in the whole country \([24,25]\). An \( AI_{ij} > 1 \) implies that \( j \) kind of environmental patents is more concentrated in \( i \) province than the general level in the whole country, in other words, \( j \) kind of environmental patents shows concentrated phenomenon in \( i \) province. If \( AI_{ij} < 1 \), \( j \) kind of environmental patents shows non-concentrated phenomenon in \( i \) province. T.J. Nameroff compared green chemistry patent activity across different sectors using AI \([24]\). Expression of AI was shown as follows:

\[
AI_{ij} = \frac{A_{ij}/A_i}{A_j/A_t}
\]

\( AI_{ij} \) activity index of \( j \) kind of environmental patents in \( i \) province

\( A_{ij} \) count of \( j \) kind of environmental patents in \( i \) province
Cluster analysis has proven useful in classifying cases or variables into groups, or clusters [26]. K-means cluster analysis was performed to study the quality of environmental patents.

3. Results

3.1. Changing trends of environmental patents

41,511 items of environmental patents in the last two decades were identified by the search program. The trend for common patents activity and environmental patents activity were shown in Figs. 1 and 2. The number of common patents and environmental patents increased gradually from 1986 to 2005. The count of environmental patents experienced two rapid increase phases. One was from 1990–1992, with average growth rate of 20%. Annual count of environmental patents continued to grow after 1992, but at a lower rate of about 12%. Another distinct increase appeared in 1999–2001, with average growth rate of 27%. In the following years the growth rate was close to that in the period of 1993–1998.
Though the total count of environmental patents increased year after year, environmental patents account for a small proportion of the total common patents, and in general the growth rate of environmental patents was lower than that of all the patents (Fig. 2). From 1985 to 1995, the average percentage of environmental patents to the total common patents was 2.6%, which was higher than that from 1996–2005. The rate of environmental patents to common patents show a descending trend in general and the average proportion was less than 2%, since environmental industry is still at initial stage and not as profitable as information and energy industries. There is a dilemma that on one hand increasing emissions need more advanced technologies to provide systems solutions, on the other hand a few innovative environmental technologies are available. Therefore, more efforts and focus on environmental technology innovation are needed to enable sustainable development.

3.2. Pattern of environmental patents by feature

To analyze the pattern of environmental patents by feature, the percentage of every kind of environmental patents (invention, utility model and design) to all the environmental patents was calculated respectively as shown in Fig. 3a and b.

![Fig. 3. a. Pattern of domestic application of environmental patents by feature. b. Pattern of foreign application of environmental patents by feature.](image-url)
Among the environmental patents applied by domestic applicants, utility model patents took the biggest percentage and the average was 76% in four periods (Fig. 3a). After 1990 the percentage of utility patents to total environmental patents decreased gradually, but the percentage of invention patents to total environmental patents increased. Invention patents took only 21%, not very high percentage, but it was shown that more and more valuable patents came out of environmental technology innovation. Design patents held the least percentage, and its count increased slowly.

Among the environmental patents applied by foreign applicants, invention patents held the biggest percentage and the average percentage was 95% in four periods (Fig. 3b). But the percentage of invention patent shew a descending trend in twenty years. On the contrary, the percentage of utility patents increased gradually, by 10 times especially from 2001 to 2005. Design patents held the least percentage and its count increased slowly, similar phenomenon to the environmental patents applied by domestic applicants.

3.3. Pattern of environmental patents by ownership

To analyze the pattern of environmental patents by ownership, the percentage of every kind of environmental patents (enterprise-owned patents, individual-owned patents and research institute-owned patents) to all the environmental patents was calculated respectively, as shown in to see Fig. 4a and b.

![Fig. 4. a. Pattern of domestic application of environmental patents by ownership. b. Pattern of foreign application of environmental patents by ownership.](image-url)
Among the environmental patents applied by domestic applicants, individual-owned patents accounted for the biggest percentage (Fig. 4a). It was not surprising given that most of the patents were applied by the individuals in China according to the annual report of State Intellectual Property Office of P. R. China (http://www.sipo.gov.cn/sipo/ghfzs/zltj/2003ngjzscqjtjb/).

Individual-owned patents accounted for 75%, and enterprise-owned patents took up 16%, with research institute-owned patents the least percentage (Fig. 4a). From 1986 to 2000 the percentage of individual-owned patents increased, but the percentages of enterprise-owned patents as well as of research institute-owned patents decreased. After 2000 the percentage of individual-owned patents showed the descending trend, but the percentage of enterprise-owned as well as research institute-owned patents increased. It indicated that more attention has been paid by enterprises to environmental technology development for meeting the environmental protection target, and the linkage between research institutes and enterprises has been strengthened for technology innovation.

Among the environmental patents applied by foreign applicants, enterprise-owned patents accounted for the biggest percentage (Fig. 4b). In four periods, the average percentage of enterprise-owned patents was 82%, individual-owned patents 15%, and research institute-owned patents held the least percentage.
similar to environmental patents applied by domestic applicants. After 1986, the percentage of individual-owned patents increased, but the percentage of enterprise-owned patents as well as research institute-owned patents decreased.

### 3.4. Environmental patents activity per five years in provinces

Discrepancy in spatial distribution of environmental patents was analyzed using GIS. The results were shown in Fig. 5a to d. In general the four figures showed a similar phenomenon, environmental patent counts in eastern provinces were greater than that in the center and the west.

Because of the rapid industry development and diversified industry structure the pollution cases are more verified in eastern region than those in the west, such as pollution medium and pollutant type. Therefore the pressure and requirement for environmental protection faced in the east stimulates environmental technology innovation. At the same time there are more research institutes and universities in the east, with stronger research teams and greater R and D expenditures than that in the west. As a result, technology innovation in the east is much better than that in the west.

From the above four figures, it was found that the absolute counts of environmental patents had increased over time in most provinces, which indicated that the proliferation of environmental technology innovation was a nation-wide phenomenon in China.

### 3.5. Cluster analysis by activity index

AI of environmental patents of invention, utility model, and design types was calculated respectively using formula (1), and AIs of environmental patents owned by individuals, enterprises and research institutes were calculated using the same method. Different AIs of six kinds of environmental patents

<table>
<thead>
<tr>
<th>Environmental patents</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invention</td>
<td>2.1430</td>
<td>1.5038</td>
<td>0.0000</td>
</tr>
<tr>
<td>Utility model</td>
<td>0.6863</td>
<td>0.6020</td>
<td>1.3725</td>
</tr>
<tr>
<td>Design</td>
<td>0.0000</td>
<td>5.5258</td>
<td>0.0000</td>
</tr>
<tr>
<td>Individual-owned</td>
<td>0.8423</td>
<td>0.6738</td>
<td>1.3476</td>
</tr>
<tr>
<td>Enterprise-owned</td>
<td>2.3191</td>
<td>2.9294</td>
<td>0.0000</td>
</tr>
<tr>
<td>Research institute-owned</td>
<td>0.0000</td>
<td>0.2734</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster group</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provinces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beijing, Shanghai, Hainan, Taiwan, Tianjin, Tibet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fujian, Guangdong, Hong Kong</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhui, Macao, Gansu, Guangxi, Guizhou, Hebei, Henan, Heilongjiang, Hubei, Hunan, Jilin, Jiangsu, Jiangxi, Liaoning, Inner Mongolia, Ningxia, Qinghai, Shandong, Shaanxi, Shanxi, Sichun, Xinjiang, Yunnan, Zhejiang, Chongqing</td>
<td></td>
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</tr>
</tbody>
</table>
were taken as the variables of K-Means Cluster. Through cluster analysis 34 provinces were sorted into three groups (Tables 1 and 2). In the first group AI of the environmental invention patents and environmental patents applied by enterprises was greater than 1, so the first group was the sort that the invention patents and enterprise-owned patents were concentrated, including Beijing, Shanghai, Taiwan and etc. The invention patents, design patents and enterprises patents were concentrated in the second group, including Fujian, Guangdong and Hong Kong. The third group was the sort that utility model patents and individual patents were concentrated including Anhui, Gansu, Guizhou, Ningxia etc.

It was found that most members of group 1 were the coastal and more developed provinces. The majority of environmental patents in most provinces were utility models and individual-owned patents. In other words, environmental patent quality in the eastern region was better than other regions.

4. Conclusions and discussions

Counts of environmental patents had been increasing in the last two decades, but the share of environmental patents to all the patents showed a descending trend in recent years. Moreover, individuals owned the majority of environmental patents, most of which were utility model patents. Comparing with the foreign application, the domestic application of environmental patents did not show an optimistic pattern since the most valuable patents such as invention patents and enterprise-owned patents took a small share.

There were more environmental patents in most of the provinces in the eastern region than that in the western region. Through cluster analysis of environmental patent AI by region, most of the provinces in the eastern region were sorted into the first group that the invention patents and enterprise-owned patents were concentrated, while most provinces in other regions were sorted into the group with individual patents and utility model patents concentrated. Invention patents and enterprise-owned patents were most valuable and could be used as good indicator to measure the quality of patents. In this regard, the quality and quantity of environmental patents in eastern provinces were greater than that in west and central regions.

Spatial distribution of environmental patents shows the close relationship between technology innovation and economic development. Since the successful opening up and economic reform policy implemented in 1978, China has achieved significant economic development [27]. The same pace of development has not yet been seen across the whole country. It is not surprising since the vast majority of China’s industrial development has occurred in the east and central east portions of the country, especially along major rivers and coastal lines with industrial concentration as manufactured goods could be easily shipped to their final destination [28,29]. The region has been at the front of China’s reform and open door [30]. The rapid economic development has caused big impact on technology innovation in eastern region so that the quality and quantity of environmental patents in most eastern provinces, especially coastal provinces, were greater than that in west and central regions.

A coordinated regional development strategy has been adopted by the central government since 1992 with increasing concerns over the less developed central and west regions of China [30–32]. The absolute counts of environmental patents in most provinces had increased over time, which indicated that the proliferation of environmental technology innovation was a nation-wide phenomenon in China. A general conclusion could be drawn that innovation capacity of environmental technology innovation
was strengthened in China, and the innovation capability in the east, especially the coastal provinces, was stronger than that in the west, but the capability was not strong in the whole country.

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References


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