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Forecasting of Quantum Dots Technology using Simple Logistic Growth Curve

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***Abstract*— Mastery of technology is the key to the success of a nation. One of the rapidly developing technologies in the fourth Industrial Revolution is nanotechnology, which is also said to be the beginning of the 5.0 industrial era. This paper is intended to forecast the life cycle from one of nanotechnology, quantum dots (QDs) technology, using patent literature and technological growth curve models. Patent data is taken from United States Patent and Trademark Office (USPTO) from 1988 to 2016 using web scraping technique. From the literature study, logistic growth curve is considered as a common method to forecast the life cycle of technology. The upper limit used in this analysis is defined and a formula to evaluate is proposed. The fit of the transformed logistic curve is determined with the help of R-Square value. Parameters of logistic curve are estimated using nonlinear least square method and regression. The forecasting errors over the forecast region are estimated using Root Mean Square Error (RMSE). From the analysis, the QDs technology is categorized as an MATURE TECHNOLOGY. Current forecast of QDs technology maturity is that QDs is an important technology with high competitive impact and great integration into products and processes. Appications of QDs are now found in bioimaging, solar cells, LEDs, diode lasers, transistors, etc. Technology developers must be clear in understanding intellectual property boundaries and evaluating the benefits of forming strategic alliances to trade IP (intellectual property).**

Keywords—nanotechnology, patent analysis, quantum dots, technology life cycle

I. Introduction

Mastery of technology is the key to the success of a nation. This can be witnessed from the success of Japan, South Korea and Taiwan which grew from developing countries to developed countries, even though they did not have sufficient natural resources. These countries have increased R & D activities to obtain the best and competitive technology.

The industrial revolution has evolved over 16 centuries, and as a result, the world economy has changed dramatically. Now, the world has begun to welcome the fifth era industrial revolution with its headline, "The fifth industrial revolution of nanotechnology". Even more striking is that nanotechnology is said to be able to reach the target of a country's economic achievement for a quarter of a century in just ten years [1].

Nanotechnology, a field that is prioritized and promoted by governments in almost all the world, is one of the fastest growing research fields in the scientific and technical fields [2]. With nanotechnology, materials can be arranged in order of atoms per atom or molecule per molecule so that no waste is not needed. By rearranging or engineering the material structure at the nanometer level, the material will have far more special properties that outperform the previous material. This is the background of countries in the world to compete to allocate funds for the development of nanotechnology [3].

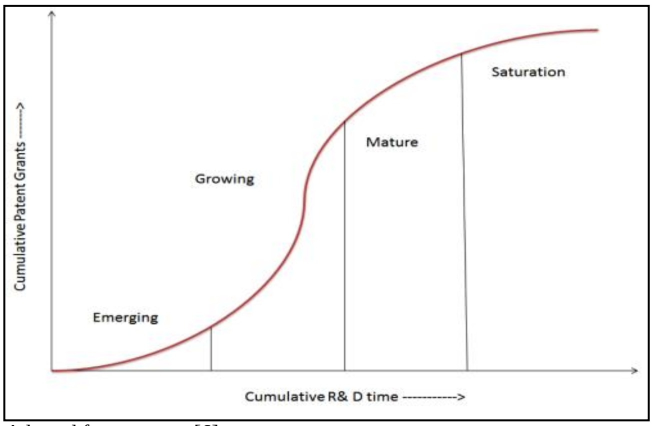
One form of nanotechnology is quantum dots. By definition, QDs (quantum dots) are nano meter (nm) semiconductor materials, usually between 3 and 25 nm. When compared with the distance between atoms in a crystal arrangement, which is 1-2 angstroms (or 0.1 - 0.2 nm), the quantum dot (QD) consists of only about 1000 atoms. According to existing literature, the electronic characteristics of QDs are determined by their size and shape, which means we can control their emission wavelengths by tuning their size. Their highly tunable optical properties based on their size are fascinating, leading to a variety of research and commercial applications including bioimaging, solar cells, LEDs, diode lasers, and transistors. The properties of quantum dots have led researchers to engage in various innovations. Increasing demand from various sectors has led to the growth of the quantum dots market which offers opportunities worth $ 2.76 billion in 2018, and the market value will balloon with a compound annual growth rate (CAGR) of 27.34% during the forecast period 2019-2025.

Patents are one of the Intellectual Property (IP) which contains comprehensive information about technological developments. Patent documents are important sources of information in science, technology, business, economics, law, etc. According to statistics from the World Intellectual Property Organization, 90-95% of world inventions can only be found in patent documents and 80% of these techniques do not appear in other professional. Patent analysis is a good tool for planning Research and Development (R & D), knowing new emerging technologies, analyzing technology trends, predicting technological developments, technology road maps, identifying technologies that are vacuum and which are in demand in industry and research, and identify technology competitors [4]. Many researchers believe that knowledge about the development and diffusion of technology can be obtained through analysis of patent information, because patent documents are an important source of information for analyzing innovation in the field of technology if the data is analyzed systematically.

Technological innovation is the prime source for economic development in a knowledge based economy. Research and development (R & D) is critical for technological innovation. R & D creates innovative technologies that can be diffused into markets. World-wide organizations are evolving new methodologies to understand innovative technologies and how to diffuse those technologies into markets. Experts are often relied on to suggest ways to market those technologies and also where to diffuse the technologies. Experts feel that the maturity is a term to reckon with. The method of relying on experts is known as the "Delphi Method" [5]. This method has limitations such as limitations on the knowledge of the experts themselves, the availability of experts, time, and money. A technology is said to be mature if it exhibits high competitive impact and is ready to integrate into i.e. products or processes at the pre-market entry stage. Greater the maturity of technology, the greater diffusion of technology into markets.

A. Technology Life Cycle

It is a challenge for technology management researchers to understand the technological maturity that will greatly help them understand the potential of technology to spread to the market. Forecasting such technology requires data, but data is barely available at the pre-market stage. One way to solve this problem is to study patent data [6]. Little, (1981) [6] presented the concept of the life cycle of technology to understand technological change and he gave a graph that illustrated the concept. The graph is shown in Figure 1.



Adapted from source: [6]

Fig. 1. S curve illustrates various stages of development technology

Figure 1, shows certain technologies at various stages of development. In the emerging stage, the competitive impact and integration of the new technology into products and processes can be ignored. When technology is in the stage of growing, the evolution of technology is fast and the competitive impact is high but the integration into products and processes has not been significant. In the adult stage (mature), a technology becomes an important technology with high competitive impact and great integration into products and processes. At the saturation stage, technology loses its competitive impact and becomes a general / base technology that can be easily integrated. Sometimes new technology can replace it [7].

Liu (2000) [8] notes that strategic planning for patent management must take the life cycle of technology into account. When technology is at the stage of recognition, companies must develop and implement related patent technology as a means to strengthen their position in the industry. If technology is in the stage of growth, the plan must include means to modify core technology and look for new applications. During the adult stage, technology developers must be clear in understanding intellectual property boundaries and evaluating the benefits of forming strategic alliances to trade IP. Finally, if the technology is in a saturated stage, new technology will be created to replace the old and signal new opportunities for research and development.

II. Objectives, Scope and Methodology

A. Objectives

The objective is to look at the conditions, trends and predictions of quantum dots technology in the world. Forecasting will use the technology growth curve and thus evaluate the technological maturity of these estimates.

Literature and research on technological maturity are very rare and the application of this type of research in industry is very large. Efforts to understand the maturity of quantum dots technology can act as a stimulus for further research in this domain. The maturity of quantum dots technology is analyzed at the world level and in several major countries.

B. Methodology

a) Samples

In this study, the patent data analysis was the quantum dots patent data from 1988 to 2016. The researchers did not include patents in 2017 until 2019 because generally it takes 18 months from the priority date until the patent is approved in the destination country. Priority date is the date of receipt of the patent in the area of origin patent office provided that both countries are members of the Paris Convention or WTO.

Quantum dots patent data is taken from the USPTO website using the web scraping technique. The USPTO website is a United States patent database website. Among national patents, USPTO patents are considered the most valuable because of the competitiveness of the US market. The US is a world leader in most technologies. As a technology indicator, US patents can be considered the most reliable because companies want to secure their intellectual property rights in this largest market.

b) Patent Map

Patents filed in most patent databases contain various information such as publication dates and applications, applicants, inventors, and international classification numbers. Analysis of patent map information utilizes that information to make general summaries. One such summary is the number of patents that can be expressed as the number of cumulative patents or as the number of annual patents. The cumulative patent count reflects the technology life cycle which in turn can be used to determine the stage of technological development. If the analyst knows the stage of technology development, it is possible to estimate future trends and predict market saturation. Knowledge of the maturity and future growth of the market from technological innovation helps researchers decide whether to continue to invest resources or move towards research.

Patent map is an important problem in the analysis of patent information. The most popular map patents are built by extracting bibliographic patent documents based on descriptive and visual statistics. The presentation of patent maps is widely visualized in visual form (eg tables, graphs, and charts).

c) Technology Life Cycle Forecasting

Growth curves are widely used in technology forecasting. The most common curve used by other studies is the S-curve which can describe the stage of the life cycle of a product. The simple logistic model itself is a widely used S-curve forecasting. In this study, the cumulative total patents per year are modeled in the S-curve and predictions using simple logistic regression. The model for a simple logistic curve is controlled by three coefficients, a, b, and L expressed as

$$y_t = \frac{L}{1+ae^{-bt}} \quad (1)$$

where y represents the cumulative total patent at time T, L is the maximum value yt, a describes the location of the curve, and b controls the shape of the curve. Parameters L, a, and b will be calculated using the least square nonlinear estimation method provided by the NLS function using R software. Using this model, observers can obtain an estimate of how many patents will be submitted in the future. If the maximum cumulative patent value (L) is obtained, the technological life cycle stage can be estimated and the time the technology is in the saturation stage can be predicted statistically.

For the simple logistic model, Trappey et al. [9] proposed 10%, 50%, and 90% as a cutoff point to classify the four stages of the technology life cycle. If y (T) represents the cumulative patent application at time T, L is the maximum value of y (T) then, y (T) / L <10%, y (T) / L ⩽ 50%, 50% ⩽ y (T) / L <90%, and 90% ⩽ y (T) / L indicates the interval at the stage of recognition, growth, maturity, and decline.

Technology prediction life cycle is done with the following procedure:

1. Calculate cumulative patents per year.
2. Predict parameters a, b, and L using the nls function. Nls function requires a preliminary or suspected value that must be assigned by researchers as priors to get the actual parameters.
3. After getting the parameters a, b, and L, predictions are made for the next few years.
4. The model formed is then evaluated by looking at the value of RMSE (root-mean-square deviation) and R squared.

III. RESULTS

A. Patent Map

a) The development of QDs patents in the world

In Figure 3, it can be seen that the growth of the quantum dots patent has a positive trend until 2015, then declined dramatically in 2016. Since the quantum dots partama patent was published in 1988 by the USPTO, quantum dots research and research experienced very slow output growth for 20 years forward. Until finally in 2001, there was a significant surge and became the beginning of the increasing number of findings produced in this field. Growth in 2001 alone amounted to 49.16% and the increase was the biggest increase throughout the year of observation in this study. The decline in the number of patents in 2016 signaled that new innovation activities for quntum dots began to decrease.

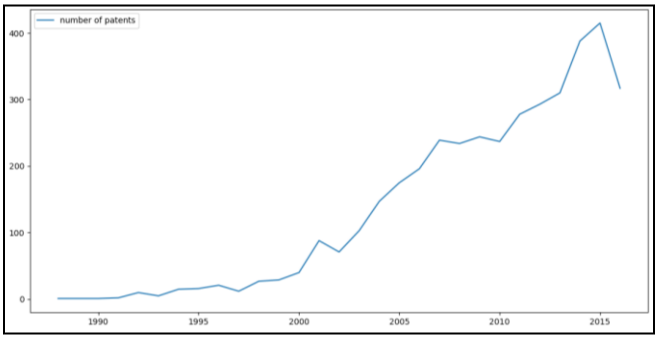


Fig. 2. Number of USPTO quantum dots patents from 1988 to 2016 in the world

b) The development of the number of patent QDs in the main countries

If observed from the five largest patent countries, namely the United States, South Korea, Japan, China, and Taiwan, the same trend conditions were also experienced, where there was a simultaneous decline in quantum dots patent applications in 2016. From Figure 3 it was seen that the source of the surge was large 2001 came from research and research activities in the United States. 2001 was the starting point for the United States to grow and leave other countries in research in the field of quantum dots technology.

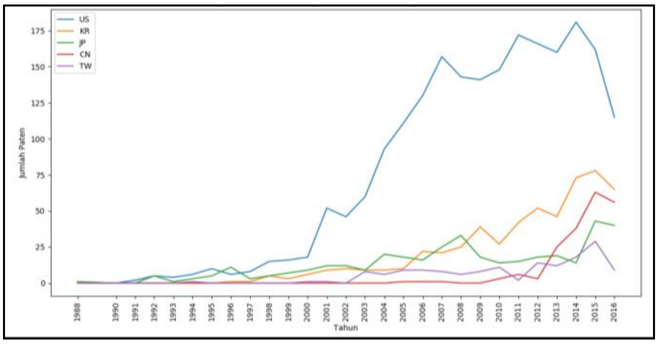


Fig. 3. The number of QDs patents from 1988 to 2016 in main countries

c) Assignee distribution of quantum dots

Through the analysis of patent data from 1988 to 2016 it was found that there were only 39 countries holding quantum dots patents from a total of 193 countries in the world. This gives the message that only a few countries have taken the opportunity to implement and develop quantum dot in the industry and in research.

The United States, with a percentage of 41.6% or as many as 2127 patents of all world patents, is the country that leads in mastering quantum dots patents. In fact, the aggregate of the main players of Asian countries (South Korea, Japan, China, Taiwan) is unable to keep up with the number of patents from the United States. That said, the United States is the dominant and invincible country in quantum dots technology. In Europe, Germany, England, the Netherlands and France play a role in quantum dots but they are far behind the Asian and American Continent.

Unlike countries on other continents, no country on the African continent holds a quantum dot patent. This condition can be seen clearly on the following map.

Fig. 4. Map of the assignee distribution of quantum dots patent

B. Technology Life Cycle Forecasting

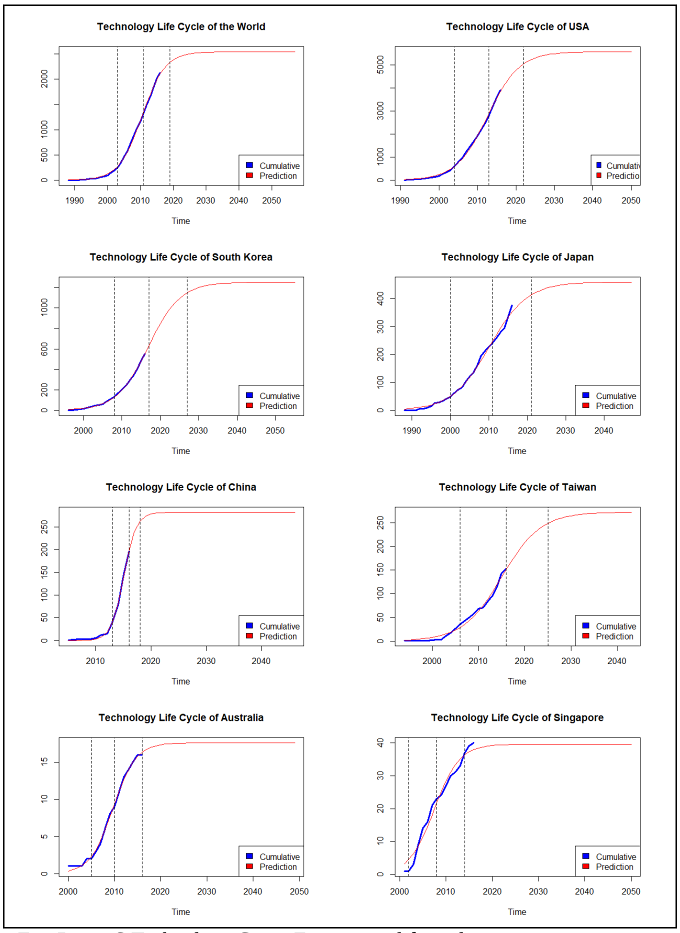


Fig. 5. S Technology Curve Forecasting life cycle

Technology life cycle forecasting is performed on top 5 countries holding patents and two neighboring countries of Indonesia, namely Singapore and Australia. Cumulative patents per year rom 1988 to 2016 form the basis of technology life cycle forecasting per observation country. Simple logistic regression models are used for this forecasting purpose. The modeling results curve can be seen in Figure 5. The obtained curve gives good results except in Australia and Singapore. This is because the cumulative curves of the two countries' patents are not too sloping in the early stages of the emergence of patent activities. This condition can make the model fit but not in accordance with reality. Because although logistic models are widely used for forecasting purposes, the model is not suitable for modeling technology adoption when the number of technologies grows rapidly instantly after technology first appears. The reason is because the logistic curve has the character 'hardly starts to grow up' [10]. Therefore, the results of technology life cycle forecasting for Australia and Singapore will not be discussed further.

From the table below it can be seen that in 2016 patent quantum dots at the world level, quantum dots patents in the United States, Japan, China and Taiwan have now entered the adult stage in the technology life cycle, seen from the share to the upper limit of more than 50%. The adult stage of the United States is the most mature stage compared to the other four countries and even the world. Taiwan seems to have just entered the adult stage because the percentage is still slightly above 50%. China that just started in 2005 showed a very fast life cycle because 2016 had entered the adult stage (11 years later). Another thing with South Korea. South Korea has the longest life cycle because it is still in the growth stage.

TABLE I. Estimation Results of F QDs

	Number of Patent (1988-2016)	**Estimated maximum patent**	**Year of upper limit**	**Share of upper limit (%)**	**Stage of technology life cycle**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
World	3914	5582	2049	70,12%	Mature
USA	2127	2545	2042	83,58%	Mature
South Korea	553	1252	2049	44,17%	Growth
Japan	376	458	2041	82,10%	Mature
China	197	282	2025	69,86%	Mature
Taiwan	152	272	2043	55,88%	Mature

TABLE II. Parameter Estimation Results and Logistical Model Compatibility

	K	**a**	**b**	**R^2**	**RMSE**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Wold	5582,84	525,93	0,24	0,99	46,65
USA	2545,43	331,65	0,28	0.99	22,40
South Korea	1252,56	200,44	0,24	0,99	4,94
Japan	458,95	112,19	0,20	0,99	8,62
China	282,10	17961,67	0,89	0,99	2,38
Taiwan	272,42	187,09	0,24	0,99	5,14

We observe that China shows a very different growth pattern compared to the pattern of the world and other countries, where their patent ownership shows a pulse of growth that is much faster than others. This can be seen from the speed with which China completed the adult stage in the technology life cycle. China emerged as the most productive economy because of its strong performance in the ownership of patents related to Quantum dots. This country was once behind other countries and the world average, in 2010 China was still in the introduction stage. China followed the world average in a short time and managed to close the gap in the mid-2010. The potential for patent growth for this country is very large (see the a coefficient in table iii).

If the S curve which is the result of simple logistic regression above is log-linear, it will produce a plot as shown in Figure 6. Figure 6 clearly shows that China is very productive in applying patents. China outperformed the world productivity level in 2014 and caught up with the United States in 2018.

In 2006, the Chinese government announced a Medium-Term and Long-Term Plan for Science and Technology Development (2006-2020), which identified nanotechnology as a very promising area that could give China the opportunity to develop with a big leap. The plan produced new policy guidelines, Chinese Science & Technology, which were then implemented by Ministry of Science and Technology (MOST) which operates Nanoscience Research as part of the State Key Science Research Plans. So far the Nanoscience Research program has invested around 1.0 billion RMB to support 28 nanotechnology projects. All of these efforts have led to a very rapid increase in nanotechnology in China as evidenced by publications, industry R & D and applications in the field and researchers also prove directly through this research

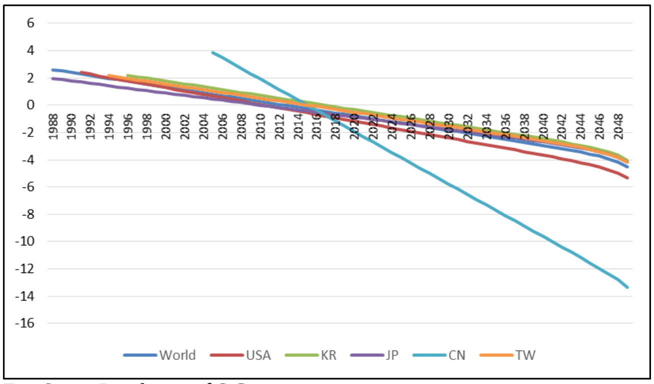


Fig. 6. Log-linear of S Curve

The rapid development of nanotechnology-based science and technology in China has caught the world's attention, including Demos, one of the most influential think tanks in the UK. Led by Wilsdon and Keeley, Demos completed 18 months of study. After completing the study project, Wilsdon and Keeley published their study findings in the book, "China: The next science of superpower?" [11]. In recent years, China has emerged not only as a mass producer, but also as one of the leading nanotechnology countries in the world. Many nanomaterial-based semiconductor products originating from China and the country dominate in the field of nanotechnology from the most cited academic articles: the top eighteen of twenty scholars come from China [12].

IV. Conclusion

Based on the research conducted, conclusions that can be obtained are as follows:

1. The growth trend of quantum dots technology is positive until 2015 which can be seen from the growth of patent documents registered with the USPTO database. However, in 2016 there has been a decrease in the number of patents which indicates that the output of innovation has begun to decrease. From the analysis, it is known that were 39 countries holding patents from 193 countries in the world. US is the country that has the most patent in the quantum dots field with the number of patents 41.6% of the total patents of the entire country. Five of the ten most patent holders come from the Asian continent, where Samsung is the top while the rest are universities and technology companies from the United States.
2. The life cycle of quantum dots technology in US, Japan, China and Taiwan has now entered the adult stage. The adult stage of the United States is the most mature stage compared to the other four countries and even the world. China who just started in 2005 showed a very fast life cycle because 2016 had entered the adult stage. Unlike South Korea, which has the longest life cycle, it is proven that it is still in the growth stage.

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