Predictive Analysis of New Energy Vehicle Life Cycle Based On Logistic Model

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Abstract. This article uses (new energy vehicle or electric vehicle or hybrid vehicle or fuel cell vehicle or hydrogen energy powered vehicle or solar vehicle) as the search key. Based on the new energy vehicle invention patent data retrieved in the SooPAT patent search engine, The logistic model is used to analyze the life cycle of China's new energy vehicle technology, to predict and analyze the technology, and to summarize the development stage of China's new energy vehicle technology. Research shows that China's new energy vehicle technology has begun to sprout from the early 1990s. After a 23-year technology introduction period, it entered the growth stage in 2014, entered a mature period in 2020, and is expected to enter a recession in 2026. Finally reveal the current status and future development trends of technology in this field in China.

Keywords: New Energy Vehicles, Technology Life Cycle, Logistic Model, Patent Analysis

1. Introduction
Since the 21st century, with the continuous increase of car ownership, the global petrochemical resources have become increasingly tense, and the ecological environment has deteriorated, new energy vehicles have gradually become the focus of national strategic development. More and more domestic and foreign researchers have joined this field of research. In recent years, with the development of Internet technology and data analysis technology, the bibliometrics and patent analysis based on the data of journal articles and patents are objective, quantitative, systematic and intuitive, they can discover the phase characteristics of industrial innovation, and help to better grasp and understand the development law and trend of technological innovation, so as to provide references for the in-depth development of technology in the field of new energy automobile industry[1].

In this paper, China's new energy vehicles as the object of analysis, through the sorting and analysis of patent data, logistic model in s-curve method is used to judge the stage of technology life cycle, and the development law of China's new energy vehicle technology is studied to provide reference for the development of China's new energy vehicle industry.

2. Technology life cycle analysis theory
Technology life cycle analysis is one of the most commonly used effective research methods in patent quantitative analysis, because the number of patent applications represents the research and development of a certain technology, it can also objectively reflect the context and trends of technology development. The methods of using patents to study the technology life cycle include technology life cycle diagram method, relative growth rate method, patent index method, S curve method and TCT calculation method. In practical applications, the above 5 methods need to be selected according to the actual situation. If you need to calculate the actual value to study the technology life cycle, you can use the S curve method and TCT calculation method. Among them, the S-curve method is based on actual measured data using technology development trend charts generated by software such as matlab, Excel, and then based on the technology development trend chart to calculate the cut-off point and critical value at each stage. The implementation of the TCT calculation method is tedious, and the TCT needs to be calculated item by item during use, and then the average value is calculated. However, because the TCT can predict the technical life cycle of a single patent, it still has certain research significance. If a combination of quantitative analysis and qualitative analysis is required to predict the technology life cycle, it is easy to use the patent index method and the relative growth rate method. The patent index method is easy to collect, but the disadvantage is that each index must be calculated year by year.

Qualitative analysis method—technical life cycle diagram method, through the two-dimensional coordinate chart, the vertical axis unit is the number of patents, and the horizontal axis unit is the number of patents. According to the annual order (the year from small to large), the position of the number of patents and the number of patentees in the year is plotted on the graph, then the points are connected in the order of the year, use the ratio of the number of patents and the number of patentees to judge the cyclical stages of technology development.

According to the above analysis, based on the number of patents applied for new energy vehicles in SooPAT patent database every year, this paper adopts logistic model in s-curve method to predict and analyze the technical life cycle of new energy vehicles in China.

3. New energy vehicle data source and retrieval strategy

The patent data in this article comes from the patent database of the State Intellectual Property Office of China. Using SooPAT patent search engine, by searching Chinese keywords for new energy vehicles or electric vehicles or hybrid vehicles or fuel cell vehicles or hydrogen energy powered vehicles or solar vehicles, 41,375 invention patents were retrieved from 1985 to 2019, the number of annual patent applications retrieved is shown in Figure 1.

![Figure1. Annual application of new energy vehicle related patents in China](image)

According to the number of patent applications in each year, the cumulative number of patents from 1990 to 2019 can be sorted out, as shown in Table 1, which is used to analyze the sample data of the patent technology cycle and predict the technology life cycle.

| years | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|-------|------|------|------|------|------|------|------|------|------|------|
| cumulative patent | 6    | 10   | 14   | 17   | 22   | 26   | 34   | 50   | 69   | 85   |
applications

| years | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|-------|------|------|------|------|------|------|------|------|------|------|
| cumulative patent applications | 102  | 131  | 187  | 260  | 356  | 526  | 772  | 1119 | 1556 | 2116 |
| years | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| cumulative patent applications | 312  | 4501 | 6098 | 7978 | 1038 | 1365 | 19345| 27231| 36626| 41364|

The patent technical index used in this paper is the cumulative number of patent applications in the patent database. Based on the data and the theory of technology life cycle, the development stage and future development trend of new energy vehicle technology in China are defined[4,5].

4. Life cycle analysis of new energy vehicle technology

4.1. Theoretical model

An s-shaped curve is a model for making long-term predictions about the growth curve, the predicted data changes with time in accordance with the law of the growth curve, that is, things always go through four stages: occurrence, development, maturity and saturation. According to the principle of growth curve, the change process of a certain technology can be predicted. Based on this growth curve, the future can be estimated and the stage of technology can be predicted, so as to seize the opportunity in the future competition[6].

S curve mainly includes two types: one is symmetric S curve, called Logistic curve; One is an asymmetric s-curve, called the gomper-tz curve. Logistic curve was used when the development of the research object was affected by both the growth rate and the waiting growth rate[2]. The research on new energy vehicle technology in this paper is more suitable to use Logistic curve, whose curve equation is:

\[
y = \frac{k}{1 + ae^{-bx}}
\]  \hspace{1cm} (1)

Among them: y—Cumulative number of patents;
ap—S-curve slope, also means the growth rate of the S-curve;
b—the point in time at which an inflection point in a growth curve occurs;
k—Saturation point.

In this paper, Matlab is used as the calculation tool, and Logistic curve is used to calculate the technical life cycle, the calculation results include three parameters: ① Saturation point: the maximum available value generated during the use of a technology, that is, the highest estimated cumulative number of patents; ② the growth of time: the time spent from 10% of the maximum utility value produced by a technology to 90% of the maximum utility value produced by the technology is the time spent in the growth and maturity period; ③ the turning point: the inverse point of the S curve, that is, the point at which the quadratic derivative changes from positive to negative 0, these three parameters can be calculated automatically by the system, or can be determined by itself[3].

Differentiate Equation (1) to get a differential
\[
\frac{dy}{dt} = -k \times (-b) \times ae^{-bt} = \frac{kb(\frac{k}{y} - 1)}{(1 + ae^{-bt})^2} = b(1 - \frac{y}{k})
\]  

(2)

According to mathematics we known,equation (2) is not 0 for all y values except y = 0 and y = k. So there is no maximum or minimum between these two limits, that is, the curve changes monotonically.

Take the derivative of equation (2) again, and you get the second derivative

\[
\frac{d^2y}{dt^2} = b \times \frac{dy}{dt} - \frac{2by}{k} \times \frac{dy}{dt} = b(1 - \frac{y}{k})b(1 - \frac{y}{k}) = b^2(1 - \frac{2y}{k})(1 - \frac{y}{k})
\]

(3)

According to equation (3), when y= 0,y=k or y=k/2, \(\frac{d^2y}{dt^2} = 0\). Therefore, the curve has a unique inflection point at y=k/2 in the monotone interval. At this inflection point, the quadratic derivative of the curve function changes from positive to negative, the curve changes from convex to convex, and the growth rate begins to decrease. If given a certain meaning, the technical performance changes from rapid growth to slow growth and from rapid growth to maturity, this point can be regarded as the dividing point between growth and maturity.

y value at the inflection point is denoted as \(y_{gd}\), then

\[y_{gd} = \frac{k}{2}\]

(4)

Substituting equation (4) into equation (1), the time point \(t_{gd}\) corresponding to the inflection point can be obtained

\[t_{gd} = \frac{lna}{b}\]

(5)

Therefore, the dividing point between growth and maturity is \(\left(\frac{lna}{b}, \frac{k}{2}\right)\). The s-curve can be fitted with matlab, and saturation point \(y_b\), inverse curve point \(t_f\) and growth time \(t_c\) can be calculated automatically. Growth time is between 10% and 90% of technology performance, the time it takes for a technology to develop from growth to maturity. So we can solve for all the constants.

\[k = y_b\]

\[t_{gd} = \frac{lna}{b} = t_f\]

The technical performance reaches 10%. The technology enters the growth period from the guidance period, and this time cut-off point is set as \(t_{dc}\); the technology performance reaches 90%, and the technology enters the decline period from the mature period, the cut-off point of this period is set as \(t_{ms}\), growth time \(t_c\) is actually the length of growth to maturity. Substitute \(\left(\frac{t_{dc}}{10}, \frac{k}{10}\right)\) and \(\left(\frac{t_{ms}}{10}, \frac{9k}{10}\right)\) into equation (1) respectively.

\[
k \left(1 + ae^{-bt_{dc}}\right) = \frac{ln a}{b} - \frac{ln 9}{b}
\]

(6)

\[
9k \left(1 + ae^{-bt_{ms}}\right) = \frac{ln a}{b} + \frac{ln 9}{b}
\]

(7)
while \( t_{ms} - t_{dc} = t_c \) \hspace{1cm} (8)

Substituting equations (6) and (7) into equations (8), we get
\[
\frac{\ln 81}{b} = t_c, \quad \text{while} \quad \frac{\ln 81}{b} = t_r, \quad \text{so} \quad a = e^{\frac{t_r \ln 81}{t_c}}.
\]
So far, all constants \( k, a \) and \( b \) have been solved. But we’re more interested in the representation of the cut-off point. The time cut-off points are as follows:
\[
t_c = \frac{\ln 81}{b} \quad \Rightarrow \quad \ln 9 = \frac{t_c}{2}, \quad \text{while} \quad \frac{\ln 81}{b} = t_r, \quad \text{so}
\]
\[
t_{dc} = t_r - \frac{t_c}{2}, \quad t_{ms} = t_r + \frac{t_c}{2} \hspace{1cm} (9) \quad \text{and} \quad (10)
\]

It can be seen that the growth period and maturity period have the same time, both of which are half of the growth time \( t_c \), that is \( \frac{t_c}{2} \). At this point, the time boundary points of each stage are all solved as follows:

Introduction period, growth period time cut-off point \( t_{dc} = t_r - \frac{t_c}{2} \); Growth and maturity time boundary point \( t_{ed} = t_r \); Maturity and decline time boundary point \( t_{ms} = t_r + \frac{t_c}{2} \).

### 4.2. Technology life cycle prediction analysis

By sorting out the patent retrieval data, using matlab software, the cumulative number of patent applications for new energy vehicles in each year was used as Logistic model regression, and three unknown parameters (see table 2) and the corresponding S curve (see figure 3) were obtained. By using the patent analysis method, parameters such as technology start time, technology turning point time, technology limit time and limit value can be obtained on the growth curve, which can be used to calculate the time points of germination, growth, maturity and decline. Use matlab to calculate the above model to get the time of each stage of new energy vehicle technology, \( t_r = 30.21 \), corresponding year is 2019, \( t_{dc} = 24.39 \), corresponding year is 2013, \( t_{ms} = 36.03 \), corresponding year is 2025, and \( t_c = 11.64 \). Therefore, the cut-off point of each stage is known, as shown in table 3.

**Table 2.** Values of regression model parameters

| Parameter     | the values | Parameter     | the values |
|---------------|------------|---------------|------------|
| \( k \)       | 88673      | \( a \)       | 89798      |
| \( b \)       | 0.3775     | Saturation /number | 88673     |
|               |            | Midpoint /year | 2019       |
|               |            | Growth Time /year | 11.64     |
According to the above data analysis and logistic model prediction calculation, it is known that the annual growth of patents before 2013 is slow, and this period is the bud period; since then, the patent process has experienced a spurt of growth from 2014 to 2019, with an annual increase of tens of thousands, indicating that the technology has entered the growth stage; 2019 is also a turning point, from the S curve, it can be predicted that from 2020 to 2025, patented technologies of new energy vehicles show a trend of decelerating growth, but the total amount is still increasing. This stage is the maturity stage, and the cumulative number of patent applications in the mature stage is about 88,673; after 2026, the number of patent applications is in a saturation state and the growth rate is close to zero, indicating that the number of patent applications is in a declining period in the life cycle of patent technology.

The analysis results of technology life cycle show that China's new energy vehicle technology has just entered the mature stage. This is related to the guidance and support of government policies and the development law of the whole automobile industry. At present, China has entered the mature period, and the number of patents has been increasing rapidly, which is consistent with the overall atmosphere and market environment of China's new energy automobile industry. With the substantial increase in the number of patents, patent quality will become the main factor influencing the change of industrial technology competition pattern and the leapfrog development of technology in the future, attention to patent quality should be the focus of the entire industry and research institutions. From the perspective of technology development trend, China's new energy vehicle technology has a huge potential, and the key problem is to solve the driving range of power batteries and supporting infrastructure construction under the conditions of gradually mature market environment. At the same time, lightweight, intelligent, low-carbon will become the main direction of the future development of new energy vehicles, really improve energy efficiency and car use experience [6-7].

5. Conclusion

This paper is based on the patent data in the patent technology database of the intellectual property office of the People's Republic of China, according to the principle of technology life cycle, the overall development status of China's new energy vehicle technology is empirically studied, through the application research of the Logistic growth model, combined with the measured data analysis and
prediction of the development stage of China's new energy vehicle technology, and forecasts the future development trend of new energy vehicle technology, at the same time from the perspective of patents for the development of the market and the layout of enterprises to provide a basis.

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