Forecasting technology trends based on separation of product inventions and process inventions: The technology S-curve

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Abstract. This study examines a method of categorising inventions into product inventions and process inventions. Corporate research and development (R&D) projects must be set up to create innovation so that companies can grow sustainably. The visualisation of market and technology trends can help companies develop competitive strategies. To investigate technology trends, the projector is selected as a product for analysis. The technology S-curve is drawn from the perspectives of ‘Product’ and ‘Process’. There is a gap in the rise time and an observable difference in shape between the curves of product inventions and process inventions.

Keywords: S-curve, A-U model, patent analysis, technology trend

1. Introduction
Companies must grow sustainably to fulfil their roles as members of a society. To do so, innovation is needed. To enable innovation, corporate research and development (R&D) must set up research projects in the YES area of the ‘Consideration of use?’ axis as defined by Stokes’ quadrants [1]. Today’s world is known as volatility, uncertainty, complexity, and ambiguity (VUCA), with diverse customer needs, fast-paced changes, and high uncertainty. In addition, products have matured, and some markets are already saturated. Companies must set up research projects to innovate and meet the needs of potential customers under these circumstances. However, a major concern is directing the growth strategy to new markets and new products, as shown in Ansoff’s growth matrix [2], while expanding the current business areas that companies are already competing with each other, for example through globalisation.

A more accurate understanding of the situation is essential for addressing this issue. Customers, markets, and technologies must be understood. Strategies must be developed and implemented to stay competitive. In other words, it is necessary to clarify market and technology
trends. If these trends can be visualised, first, it will be possible to set up research projects ahead of other companies, advance R&D, and develop products effectively and efficiently. Second, companies will be able to provide products that reliably meet customer requirements in a timely manner. Thus, companies can grow sustainably through innovation.

**Figure 1** shows the relationship between the keywords ‘customer value-product-process’, ‘core technology’, and ‘invention’, which are discussed in this paper. ‘Customer value’ is the market's requirement and includes the variety of values, including fundamental values, that customers experience and are satisfied with. ‘Product’ is a product that achieves customer value. ‘Process’ is a process for manufacturing a product. ‘Core technology’ is a distinctive technology that differentiates products from each other and is included in the products or in the manufacturing processes. Regarding ‘patent’, according to Article 2(3) of the Japanese Patent Act, ‘invention’ is classified into ‘an invention of a product’ or ‘an invention of a process’. Furthermore, an invention of a process is categorised into ‘an invention of a process for producing a product’ and ‘an invention of any other process’ [3].

![Figure 1. Relationship between the keywords](image)

One may argue that the future of markets and technologies can be forecasted using patent analysis. This is because a patent is filed for an invention, while the product is manufactured and marketed using the technology contained in the invention to satisfy customer needs. Of course, the results of the analysis using patent filings are faster than what really occurs in the market. Therefore, patent analysis is useful to visualise technology trends [4,5].

This study focuses on two major factors, the technology S-curve and the Abernathy-Utterback (A-U) model, to investigate the technology trends. For the technology S-curve, where technology evolution has a limit and follows an S-shape, the vertical axis of the graph was initially a qualitative indicator of technological achievement [6]. Later, the quantitative S-curve was drawn using the number of patents on the vertical axis [7]. Here, analysis is applied to various products, and the S-shape is evaluated using the logistic growth curves that may be eventually saturated
[8][9]. In addition, the state of technology evolution is analysed using several indicators included in the patent information [10]. However, in all cases, the entire patent population is analysed from a single perspective. As shown in Figure 1, there is a possibility of gaining new insights into the technology S-curve by viewing technology from the two perspectives of product and process.

The A-U model has been refined and perfected through three studies and has had a significant impact on innovation research [11-14] The A-U model distinguishes between types of innovation. This model argues for a shift from product innovation to process innovation after the emergence of the dominant product design. It is suggested that efficient management methods of technology and organisations at each stage of innovation can increase the probability of success of innovation. There are few studies that discuss, quantitatively, the status of product innovation and process innovation using the A-U model. The reason for this is that a major issue is what quantitative indicators should be used to categorise the innovation that has occurred in the market into product innovation and process innovation. It seems reasonable to use a quantitative indicator of the number of patents as well as the technology S-curve, utilising patent analysis which can possibly forecast the future [15]. From Figure 1, it can be inferred that the product innovation and the process innovation in the A-U model can be discussed by dividing them into two areas from the two perspectives of product and process.

To clarify the technology trends, the purpose of this study is to verify the following. By classifying patent information from the perspective of product and process based on Figure 1, it is possible to visualise the S-curve of technology and the A-U model with a good prospect, considering the technology layer. The projector is selected as a product for the analysis, because it fits the following three points and thus is considered to fit the scope of this study.

- Through technology development and product development, the product market has been formed, the technology S-curve can be drawn, and a dominant design has emerged.
- Although the Japanese domestic market has already begun to be saturated, there is still room for expansion in its business area (e.g. the global market).
- A growth strategy for new markets and new products is required.

2. Research methodology

The patent information used here are Japanese published patent applications filed since 1980. To extract published patent applications related to the projector, a theme code is used in the patent search. The theme code is one of Japan's original patent classifications, as opposed to the IPC, which is a universal patent classification. In Japanese patent classification, a FI (File Index) subdivides the IPC. The IPC consists of approximately 70,000 items, whereas the FI consists of approximately 190,000 items. All the technology categories defined in the FI are divided into a certain technical area. Each technical area is referred to as the theme and is assigned a 5-digit alphanumeric theme code. In other words, the theme code and the IPC are indirectly related. Currently, there are approximately 2,600 themes.

Figure 2 shows the analysis flow of the patent information in this study. First, a population of published patent applications related to projectors is extracted. Next, pre-processing is performed to improve the prospects of the analysis. Then, for the sub-populations created by pre-processing, the main processing is executed. The technology S-curves are drawn for the representative FIs, grouped by the leading FI for each sub-population.

As a pre-processing step, we propose a method to segregate inventions into product inventions and process inventions. As mentioned above, invention is classified into an invention of a product, an invention of a process for producing a product, or an invention of any other process. In this paper, an invention of a process for producing a product, which is directly related to its manufacturing, and an invention of any other process, which indirectly contributes to the
The manufacturing of a product and improves its quality, cost, and delivery (QCD), are collectively referred to as process inventions. An invention of a product and an invention of any other process other than the above, which is mainly a method of operation related to the function of a product, are referred to as product inventions.

![Flowchart](https://via.placeholder.com/150)

**Figure 2.** Analysis flow

![Flowchart](https://via.placeholder.com/150)

**Figure 3.** Pre-processing flow
Figure 3 shows the pre-processing flow. The title of the invention is extracted from the published patent applications. Each invention is conditionally judged by whether a desired keyword is included by text mining and is then separated into product inventions and process inventions. In the case of text mining on Japanese text, such as Japanese patents, the text cannot be treated as ‘without word segmentation’ consisting of a series of words and phrases, unlike in the case of Western languages. In addition to the word segmentation process, which divides the word into element units, morphological analysis is needed to decompose it into element units corresponding to morphemes, which are the smallest linguistic units that have meaning, and to identify grammatical attributes (parts of speech, conjugation, etc.) [16]. The Japanese morphological analysis software MeCab [17] is used, and the frequency of words and phrases are counted. First, morphological analysis is performed on the title of the invention, and a conditional judgment (a) is made on whether the noun ‘process’ is included. Next, when ‘process’ is included, conditional judgment (b) is made on whether a noun phrase (e.g. ‘manufacturing process’, ‘assembly process’) is included. A noun phrase consists of a combination of keywords related to production, manufacturing, and QCD improvement (e.g. ‘manufacturing’, ‘assembly’, ‘adjustment’, ‘inspection’, ‘correction’ etc.) and process. If both (a) and (b) are YES, it is regarded as a process invention. If either (a) or (b) is NO, it is regarded as a product invention.

3. Technology S-curve
The theme code for the projector is 2K203, and the population of published patent applications in this analysis is approximately 31,700. Figure 4 shows the cumulative number of the published patent applications for the projectors. The horizontal axis is the filing date (FY). Figure 4 depicts the so-called S-curve. Comparing this curve to the S-curve of a technological life cycle [8], one observes that the projector is now in the third stage (maturity). This is a conventional S-curve analysis.

Figure 4. Cumulative number of patent applications for projectors
Using the pre-processing shown in Figure 3, the inventions are separated into product inventions and process inventions. Figure 5 shows the cumulative number of published patent applications for each sub-population. For the projector, the separation of the technology S-curve for product and the technology S-curve for process is observed. In terms of product inventions and process inventions, a gap in the rise time and a difference in the shape of the S-curve are observed. First, the rise time of product inventions is around 1988 and that of process inventions is around 2001. This gap in rise time between product and process is estimated to be equivalent to the time between the emergence of a product and the demand for manufacturing of the product that occurs after market recognition. Next, each shape in the S-curve is examined in detail. Product inventions are increasing monotonically, and the slope has increased by approximately three times since 2001. Process inventions are also increasing since 2001. The slope between 2002 and 2009, when both are increasing rapidly, is almost the same. Specifically, when the cumulative number of patent applications in 2018 is set at 1, the average increase rate of product inventions is 5.5%, and that of process inventions is 5.1%. The slope of product inventions is decreasing since 2010. While the average rate of increase for product inventions has roughly halved to 3.1% between 2011 and 2018, the average rate of increase for process inventions has increased by 30% over the same period to 6.5%. This is estimated to be due to the continuous and efficient supply of products to the market. Thus, it is assumed that products take some time to become popular in the market and enter the growth stage after market recognition, while the manufacturing process is required especially during and after the growth stage. Therefore, the difference in the shape of the S-curve is thought to represent the difference in the characteristics of the technology evolution between product and process. In addition, it may be possible to forecast the growth rate of the market based on the rise time and slope of process inventions compared to product inventions.

To examine the gap in the rise time and the differences in shape of the technology evolution between product and process in detail, each is discussed in separate technology categories. Each published patent application has one or more of the above-mentioned FIs as well as the IPC. If two or more are given, the leading FI that is the subject of the patents is designated. The leading FIs are ranked for each of the product inventions and process inventions, and the top four are shown in Table 1. Figure 6 and Figure 7 show the cumulative number of published patent applications for each group by the leading FI for product inventions and process inventions, respectively.
Table 1. Top 4 of the leading FIs

|            | Product inventions | Process inventions |
|------------|--------------------|--------------------|
| 1          | G02F1/13,505       | G03B21/00,D        |
| 2          | G03B21/14,A        | H04N5/74,Z         |
| 3          | G03B21/00,D        | H04N5/74,D         |
| 4          | G03B21/14,Z        | G03B21/14,Z        |

Figure 6. Cumulative number of patent applications by each leading FI of product inventions

Figure 7. Cumulative number of patent applications by each leading FI of process inventions
Figure 6 shows the four technology categories in the product inventions. For example, G02F1/13, 505 and G03B21/14, A are product technologies related to liquid crystal applications and light source devices, respectively. First, in terms of the rise time, the top three FIs are around 1986-1991 and the 4th FI, G03B21/14, Z, is in 2000, which represents a 10-year gap. Next, in terms of the shape of the S-curve, the slope of the S-curve has increased after a certain year between 2000 and 2002 for each of the top three FIs. Specifically, when compared before and after the five-year average rate of increase for a certain year, G02F1/13, 505 has increased by approximately three times since 2000, G03B21/14, A has increased by approximately seven times since 2002, and G03B21/00, D has increased by approximately six times since 2002. This leads to the results derived from Figure 5, which indicate that the slope of product inventions has increased by approximately three times since 2001. For the top two FIs, the curves are saturated in 2010, while the slope of the 4th FI, G03B21/14, Z, has increased by approximately five times since 2009. The required technologies have been transferred from the upper two FIs to the lower two FIs from 2009-2010. This also leads to the results obtained from Figure 5, which indicate that the slope of product inventions has been decreasing since 2010. In Figure 5, there is a gap in the rise time by approximately 10 years, and the slope of the S-curve has increased by a factor of 3 to 7 after a certain year for each FI.

Figure 7 shows the four technology categories in process inventions. For example, G03B21/00, D, which has a fast rise time, is a process technology related to projectors. Others are more detailed process technologies, such as those related to projection equipment for image reproduction (e.g. signal processing circuits for image quality improvement) and details of the projector. First, in terms of the rise time, the first FI, G03B21/00, D, is in 1996, and the remaining three FIs are around 2005-2007, a gap of approximately 10 years. Next, in terms of the shape of the S-curve, the slope of the S-curve has increased since 2001 for the 1st FI, G02B21/00, D. G03B21/00, D has increased by approximately twenty four times, comparing the four-year average rate of increase before and after 2001, and the average rate of increase between 2002 and 2005 is 15.3%. Subsequently, the four-year average rate of increase before and after 2006 has decreased by one-third, and the curve is nearly saturated by 2011. On the contrary, the slope has increased since 2011 for all three remaining FIs. Specifically, comparing the four-year average rate of increase before and after 2001, there is a three time increase in H04N5/74, Z, a one and a half time increase in H04N5,74, D, and a three time increase in G03B21/14, Z. The required technology has been transferred from G03B21/00, D to the other three FIs in 2011. This leads to the results obtained from Figure 5, which indicate that the slope of process inventions has been increasing since 2010. This figure indicates that the slope of the S-curve has increased by a factor of 1.5 to 24 after a certain year, with an approximate 10-year gap in rise time.

The following two points are found for the projector. There is a gap between 1986 and 2007 in the rise time of the major technology categories, and the technology categories of products are earlier than that of processes. The year in which the slope changes, and the average rate of increase over several years before and after the year, vary by technology category. Moreover, and this is particularly important, the period between the rise time and the year in which the slope increases are shorter in the process technology categories than in the product. In other words, the slopes of the individual graphs in Figure 7 tend to appear greater than in Figure 6. This means that process technology is more rapidly evolving than product technology in the case of projectors. It is generally accepted that while a product enters the market, gets recognition, and enters the growth stage, the manufacturing process needs to move rapidly from the growth stage to the maturity stage and beyond. Similar tendencies are estimated to be observed for products other than the projector, although there are quantitative differences in the rise time and the shape of the S-curve.
4. A-U model

Figure 8 shows the normalised number of published patent applications for each sub-population, with the number of product inventions peaking around 2005, while the number of process inventions is peaking around 2013. One observes that the product inventions preceded the process inventions. In the case of projectors, this indicates that the content of the invention has shifted from product related inventions to those related to the process. Since the number of published patent applications is plotted in this paper, the technologies that have been applied for patents are evaluated, and the discussion is in the layer of technology. At the least, this is not an evaluation limited to marketed products (i.e. the market layer). Therefore, it cannot be said that Figure 8 is equivalent to the status of product innovation and process innovation shown by the A-U model. Nevertheless, the figures are similar. Thus, a transfer from product innovation to process innovation is occurring.

![Figure 8. Normalised number of patent applications of product/process inventions](image)

For the projectors, in terms of the technology trends shown by the technology S-curve, the process technology continues to grow while the product technology is becoming saturated. It can be inferred from the A-U model, that a shift from product innovation to process innovation has occurred, and the projector is about to enter a specific pattern. This indicates that companies are in the product design phase rather than the R&D phase. These analyses will suggest whether the product perspective or the process perspective is more important when considering the setting of research projects in corporate R&D, based on the consideration of use. Specifically, the following two types of projects can be considered. The first is to set up research projects that are closer to process, which will lead to process innovation through growth of process technology. The second is to set up a research project that is closer to product, which will lead to product innovation through new product technology that will launch the next generation of the technology S-curve. Applying this situation to Ansoff's growth matrix, one of the growth strategies for projectors will be market development with low-cost products that promote process efficiency.

5. Conclusion

The technology S-curve and the A-U model are shown in the layer of technology by separating inventions from the two perspectives of product and process using pre-processing for the patent analysis in the projector where the product market has been formed. In the technology S-curve,
there is a gap in the rise time and a difference in shape for technology evolution between product and process. Considering the generalised change from the product to manufacturing process, it is assumed that similar tendencies, although with quantitative differences, can be observed for other products for which a market has been formed. This approach will provide a clearer perspective on forecasting technology trends. These forecasts can make significant contributions to the setting up of research projects in corporate R&D. The analysis of the A-U model, which focuses on the distinctive technology (i.e. core technology) that differentiates products in the market layer, will be investigated in detail in later studies.

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