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The Use of S Curves in Technology Forecasting and its Application On 3D TV Technology

Gizem Intepe, and Tufan Koc

***Abstract*—**S-Curves are commonly used in technology forecasting. They show the paths of product performance in relation to time or investment in R&D. It is a useful tool to describe the inflection points and the limit of improvement of a technology. Companies use this information to base their innovation strategies. However inadequate use and some limitations of this technique lead to problems in decision making. In this paper first technology forecasting and its importance for company level strategies will be discussed. Secondly the S-Curve and its place among other forecasting techniques will be introduced. Thirdly its use in technology forecasting will be discussed based on its advantages, disadvantages and limitations. Finally an application of S-curve on 3D TV technology using patent data will also be presented and the results will be discussed.

***Keywords*—**Patent analysis, Technological forecasting. S curves, 3D TV.

I. Introduction

SCIENCE and technology are increasingly recognized as influences in the transformation of society and governments must therefore strive to foresee the impacts which technological developments are likely to have on future society and to guide the application of new knowledge in the attainment of national goals. Technology forecasting (TF) is the process of predicting the future characteristics and timing of technology. It is important to foresee as clearly as probable impact of a rapidly growing technology. When possible, the prediction will be quantified, made through a specific logic, and will estimate the timing and degree of change in technological parameters, attributes and capabilities [16].

Recognition of the possibility of planning for future options by guiding technological development along alternative paths in an economic, social and political context presents both a stimulus and a challenge to the policy-maker [12].In literature there is a number of forecasting techniques and some of which are most widely used for policy making. Some are numerical data based, some are judgment based. In general, numeric data-based forecasting extrapolates history by generating statistical fits to historical data. A few numeric methods deal with complex interdependencies. Judgmental forecasting may also be based on projections of the past, but information sources in such models rely on the subjective judgments of experts. Table I offers one listing of forecasting techniques as categorized by Vanston[19].

Each category has its supporters and detractors. Although there are no hard-and-fast rules, it seems that most engineers are basically extrapolators, most pure scientists are primarily pattern analysts, and most marketing people are goal analysts. The majority of executives appear to be intuitors, although, interestingly, many characterize themselves as counter punchers [19].A good choice of a forecasting method in a particular situation could affect the accuracy of the forecast and conceivably, the ability of a firm or government to complete in today’s global economy [15].

II. Literature Review

During the past several decades, there has been growth in the number of growth curve methods for examining the development of technology, and the substitution of technology. Growth curve method involves fitting a growth curve to a set of data on technological performance, then extrapolating the growth curve beyond the range of the data to obtain an estimate of future performance [2].

Growth Analysis is highly quantitative and requires numerical data and uses S-shaped curves. Most used S-shaped curve is logistic curve, is helpful for estimating the level of technological growth (or decline) at each stage in the life cycle and for predicting when a specific technology will reach a particular stage.

S curve model has been studied extensively in recent years. The popularity of the subject is based on the Foster’s book [6]. According to S curve model a technology usually has a life cycle composed of initial adoption, growth, maturity and decline stages. Specifically S curves are based on the parameter estimation of a technology’s life cycle curve. Because of this feature they come into prominence and most widely used. The upper limits of technological growth and decline at each stage of the life cycle are estimated. And the results produced by this technique are highly quantitative.

The S-Curve emerged as a mathematical model and afterwards applied to a variety of fields including physics, biology and economics. It is used in different fields such as; the development of the embryo, the diffusion of viruses, the utility gained by people as the number of consumption choices increases. S shaped curves have three main stages. The logistic law of growth assumes that systems grow exponentially until an upper limit or carrying capacity inherent in the system is

G. Intepe is with the Istanbul Technical University, Mathematics Department, 34469 Maslak Istanbul Turkey (phone: 0090 212 285 3311; e-mail: karakang@ itu.edu.tr).

T. Koc., was with Istanbul Technical University, Industrial Engineering Department, Macka, Istanbul, Turkey (e-mail: koctu@itu.edu.tr).

TABLE I
FORECASTING TECHNIQUES

Extrapolation	**Pattern Analysis**	**Goal Analysis**	**Counter Punching**	**Intuitive**
Technology trend analysis	Analogy	Impact Analysis	Scanning, monitoring and tracking	Delphi survey
Fisher-Pry analysis	Precursor Trend Analysis	Content analysis	Alternative scenarios	Nominal group conferencing
Gompertz analysis	Morphological Matrices	Stakeholder analysis	Monte Carlo models	Interviews
Growth limit analysis	Feedback models	Patent analysis		Technology advanced management
Learning Curve				

approached, at which point the growth rate slows and eventually saturates, producing the characteristic S-shape curve [17]. S-Curves are performed by using a regression model that tests for non-linearity between the dependent variable (to be forecasted) and time.

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The most commonly used formulation of the logistic growth curve is described by (1).

$$Y_t = \frac{L}{1+ae^{-bt}} \tag{1}$$

The coefficients a and b describe, respectively, the location and shape of the curve, whereas L is the asymptotic maximum value of Y_t [1].Models based on initial data for a growth curve are quite valid if the correct curve and upper limit have been identified.

In literature there is a number of S-curve applications in different fields. [2] forecasted new clean energy development using three kinds of fuel cells with patent data. [4] investigated technology development in the field of wind power technology by using three different segments of wind power technology. [3] used growth curves for forecasting fuel cell, food safety and optical storage technologies. [18] also analyzed the real technology level by using a new model application and review the relevance of this method.

Researchers use different variables for the model. Usually a technology performance parameter is plotted against time [6].However some researchers used patent data instead of performance parameter for the vertical axis to form S-curves [4], [5], [9], 13]. Some others such as Bengisuve Nekhili [1] used both patent and bibliometric data for generating technology S-curve and also examined the correlation between them. For the horizontal axis, instead of time amount of R&D investment for technology evolution are also used by some authors[6].

According to the literature forecasting technology using S-curves is a meaningful choice as properly established logistic growth reflects the action of a natural law. Independently from scale it can be applied for systems where the growth mechanisms are understood. It is relatively easy to apply, has clear concept and working mechanism [7], [14].On the other hand this method has some weaknesses. It is not evident what can be selected to measure the growth of system evolution. Defining and measuring growing parameter is a challenging problem, also there is lack of formal procedure to define growing variable [14]. Fitting technique errors and uncertainties mostly depends on applied data and algorithm which have certain accuracy and precision.

III. RESEARCH FRAMEWORK

As can be seen from the literature in spite of the wide use of S curve to analyze a particular technology the model itself poses various difficulties. The difficulty of selection of the most adequate performance parameter for evaluating a specific technology and estimating the value of this parameter depending on time or R&D investment create problem in model building process. Fosterclaims thatthat the parameter must reflect technical characteristics which are easily measurable and, at the same time, recognizable by the clients [6]. In this way, any increment in the physical/technical performance of a technology will also reflect an improvement in the contributions of the products that incorporate it. Therefore the definition of this parameter poses some problems and if an incorrect definition is made the results of the analysis might become invalid. Even if it is defined well obtaining reliable information about the investment for technology evolution is nearly impossible.

In this paper these problems are attempted to be solved in different ways:

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Firstly cumulative patent numbers are used in this research instead of technology performance parameter. The underlying assumption for this is increments in the number of patent for a specific technology reflect increments in the level of knowledge accumulation and in turn creating an understanding of that technology. This knowledge base normally is expected to be converted into improvements in the products that incorporate it. The significant role of learning process and knowledge is widely studied in literature [8], [20]. The second problem is about the strategic use of S curve model. According to model the evolution of a particular technology follows an S curve. However if the current technology might be supplanted by others and potentially lead to decay. This possibility prevents the current technology to follow the whole pattern and in turn lead to erroneous and irrelevant conclusions. Although this can be a case for any technology developed; in this paper mature technology namely HD, LCD and LED TV from same product family are examined. The objectives of these analyses are to understand if these technologies follow the full pattern of S curve and can be predicted accurately.

In addition to this, the amount of data is also important for the accuracy of results. The limited data from the earlier period of a technology might provide misleading S curve. Therefore for the accuracy of the results further analyses for the mature technologies from same product family will also be analyzed by early lifetime patent data to observe the accuracy of predictability.

IV. The Application of 3D TV Technology

3D TV technology is analyzed by S curve model. This technology is becoming increasingly popular with each passing day. Due to the rise of popular 3D feature films major television manufacturers began developing three dimensional home television technologies in 2009.Today, the 3D TV is slowly becoming a household essential and soon we would not be able to imagine our lives without it anymore. Employing technology first discovered in the early 1800s, the leading TV manufacturers are using ground-breaking technological skills to give us improved access to stunning 3D imaging - also known as stereoscopy - which basically tricks the brain into creating an illusion of visual depth by displaying two different images. This is known as a parallax view - the two slightly different perspectives of a visual object that each eye sees naturally because they are spaced physically apart. Brains resolve these two different object views and this is what gives us the perception of depth and three dimensions [11].

The dataset for this study is constructed from Espacenet. Espacenet contains full collection of published patent applications worldwide [10]. '3D TV' is used as keyword term and patents are found for the period between 1969 – 2011. For 3D TV only current data is used since the 3D TV technology is still an emerging technology and at its early lifetime. For the technologies HD, LCD and LED TV the full data and early lifetime data are collected from the same data base. Early lifetime data S Curves are drawn based on the first half of the current data for each technology that are 1994 for HD; 2001 for LCD and 2003 for LED TV. Loglet Lab software is used to fit growth processes to S-curve for all technologies.

V. Results and Discussion

The results of S curves for 3D TV with current data, HD, LED and LCD TV with early lifetime data and current data are shown and discussed as follows.

A. 3D TV S Curve

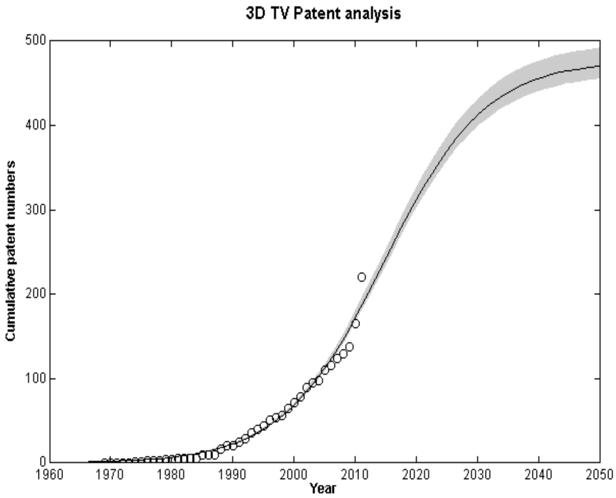

Fig. 1 3D TV S Curve with cumulative patent numbers

According to Fig. 1 the fast growth in cumulative patent numbers is achieved around between year 2000 and 2020. Then the growth slows down and reaches to finally saturation point. The saturation point of 3D TV S curve is 477, meaning that 3D TV technology is expected to reach its limit in 2050.

B. HD TV S Curve with Current and Early Lifetime Patent Data

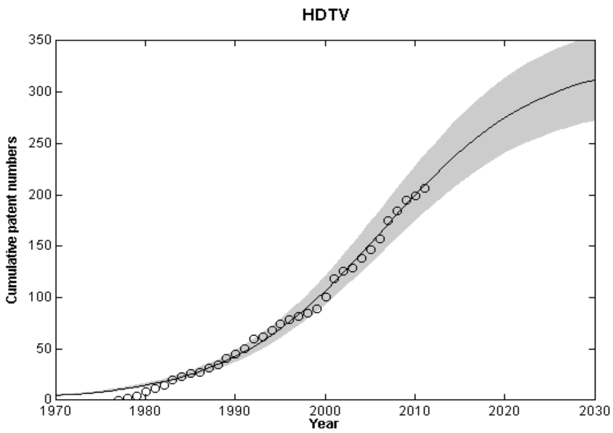

Fig. 2 HD TV S Curve with current cumulative patent numbers

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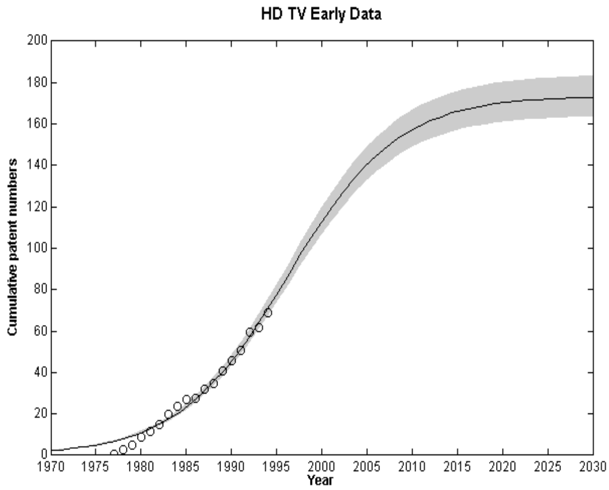

Fig. 3 HD TV S Curve with earlier data set until 1994

According to the S Curves the inflection points are around between 1995 and 2010 with current data and between 1985 and 2005 with early lifetime data. The saturation point with current data at Fig. 2 is 332 at year 2030 and with early lifetime data at Fig. 3 is 173 at year 2030.

C. LCD TV S Curve with Current and Early Lifetime Patent Data

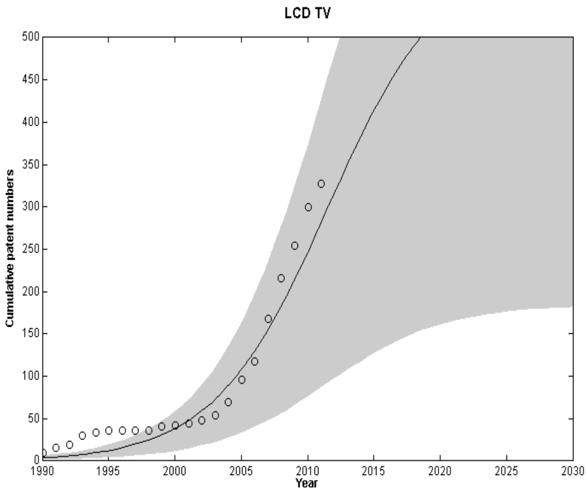

Fig. 4 LCD TV S Curve with current cumulative patent numbers

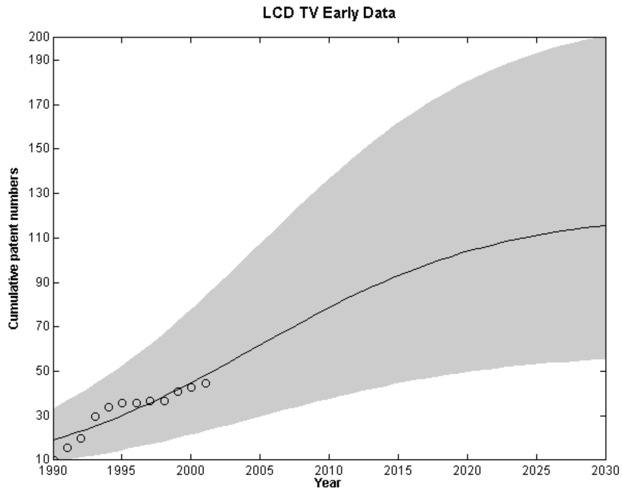

Fig. 5 LCD TV S Curve with earlier data set until 2001

For LCD TV S Curve with current data set the inflection points are between 2007 and 2015; with early lifetime data set between 1995 and 2010. The saturation points are 600 at year 2030with current data in Fig. 4 and 122 at year 2030 with early lifetime data at Fig. 5.

D. LED TV S Curve with Current and Early Lifetime Patent Data

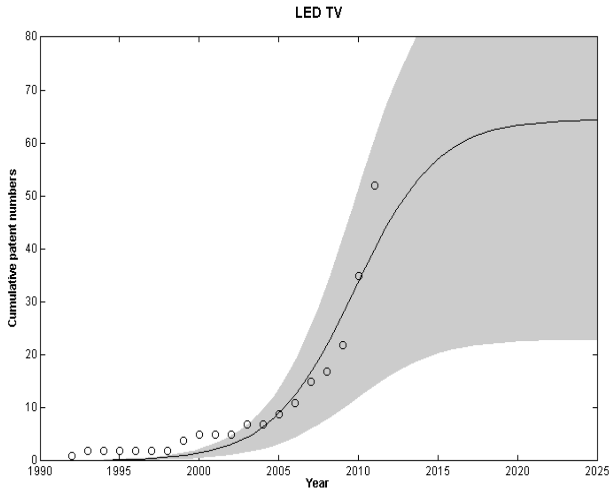

Fig. 6 LED TV S Curve with current cumulative patent numbers

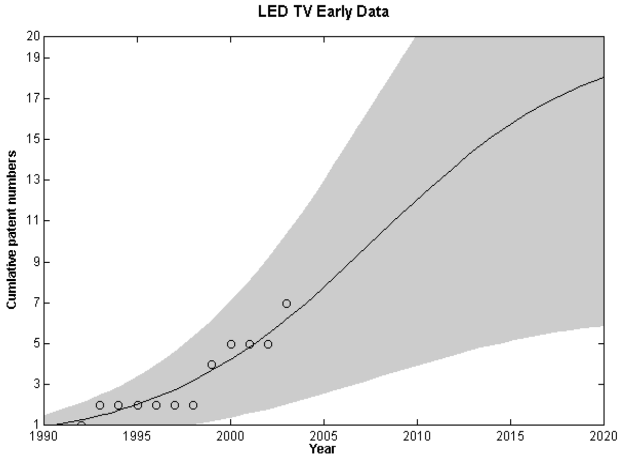

Fig. 7 HD TV S Curve with earlier data set until 2003

According to the S Curves the inflection points for LED TV technology evolution are between 2004 and 2012 for current data at Fig. 6; 1998 and 2010 for early lifetime data at Fig. 7.. The saturation points are 65 at year 2025 with current data set and 20 at year 2020 with early lifetime data set.

VI. Conclusion

In this paper the usability of S Curve and the trajectory of the evolution of 3D TV technology are investigated. The S Curve studied extensively and used commonly by academic circle and companies. Despite it is easy to use and easy to understand it has some disadvantages such as the difficulty in parameter selection and measurement. In addition the assumption that a technology evolution is continuous and reach eventually its natural limit might lead policy makers to mistakes in strategy preparation. Therefore great care should be exercised during decision making based on S curves.

In Fig. 1 the S curve for 3D TV appears to fit patent data properly. Currently the technology is in the pattern of fast growth since it has passed the first inflection point. The evolution of the technology seems to slow down around 2020 and reach to its limit in the year 2050.

Another result of this research is that as can be seen from the S Curves of all technologies the trajectories appear to fit S curve better with full patent data than early lifetime patent data. Companies usually consider inflection points and saturation as reference for their strategies. Therefore deviations because of the curves are based on early lifetime data possibly lead to mistakes in decisions. These results reveal that validity of results is very sensitive to the amount of data.

Although the results of S Curve models provide important information care should be exercised for decision makers because an unpredictable event from alternative technologies might stop technology to reach its natural limit. In the case of 3D TV technology, an evolution trend is expected to continue until year 2050 through the pattern defined in Figure 1. However it is always possible that an unexpected technology that satisfies the mass market outperform this technology. In this case, decision can still be made according to the probability of unexpected event or additional forecasting techniques such as scenario analysis can be applied to provide additional information to increase the quality of decision.

For future works, other technological forecasting techniques could be performed to forecast 3D TV technology and compared with the one studied in this research and evaluated accordingly. Also different performance variables could be used to compose growth curves.

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