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COMPARING THE MARKET HISTORY OF MOBILE PHONES AND ELECTRIC CARS BY USING SIGMOID CURVES

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Abstract: The time curves of market history for mobile phones and for electric cars is compared by sigmoid curves. Creating the approximate sigmoid curves of the curves showing the real data of products sold in function of the time, it is possible to find similarities and differences of the time history of the market of mobile phones and electric cars. One of the most important decisions during this investigation is to decide, which curve describes better the product investigated: Logistic curve (Pearl-Reed curve) or Growth curve (Bertalanffy)? On the basis of many characteristics of these curves, in the second step of the study it is possible to characterise the market of the products, and the comparison can give important points of view for the understanding the present situation of the markets and to try to forecast their possible future.

Keywords: *market of mobile phones, market of electric cars, comparison, sigmoid curves*

1. INTRODUCTION

Sigmoid curves are very useful to describe several phenomena of our life. If we have the equation and the diagram of the sigmoid curve, it is possible to find very useful and interesting characteristics of the investigated phenomenon. Investigating as many cases as possible can give new points of view for the study of a concrete case: the sigmoid curve has all its characteristics in every case, but it is necessary to “translate” or reinvent or reconsider what could be the actual meaning of a given property of the curve. This reinvention can lead to a new conclusion on the investigated phenomenon, it can give a new point of view for the studies, which was not investigated before. In this way it is possible to “learn” new information from the investigation of several different phenomena.

The author of this paper until today performed the investigation of the following cases:

- Iteration history curve of optimisation algorithms (Szabó, 2018), (Szabó, 2023);
- 100 years history of sport world records (long jump, women and men, world and Hungarian, javelin throw, man and women, world and Hungarian) (Szabó, 2011);
- Comparison and characterisation of different student groups by using the EBSYQ system (Evolutionary Based System for Qualification of Group Achievement), writing the same test (Szabó, 2017);
- Forecasting the possible future of the plastic waste quantity of the world seas and oceans (Szabó, 2019);
- Investigating the wear curve of machining tools (Szabó, 2021);
- Application of sigmoid curves in product development (Szabó, 2022), (Szabó, 2021);
- Study of the market of electric cars (Szabó, 2023);
- Time history of the COVID-19 disease in Hungary from March 2020 until June 2023 (Szabó, 2020), (Szabó, 2022);
- Possibility for decreasing the time necessary for experiments (Szabó, 2024).

During the investigation these different phenomena it was possible to derive many useful conclusions which can be used for the forecasting and characterising some other or newer phenomena (Bihari & Sarka, 2018). The EBSYQ system can give the possibility to compare sigmoid curves of cases very accurately and detailly, giving numerical differences of several points of view of the comparison. This accurate comparison shows the existing differences between phenomena even in case when they are very similar to each another or the shape of the curves are very close to each another. This could help us during the qualification of the cases and to decide which one is “better” or “quicker”, etc.

2. TYPES OF SIGMOID CURVES

Two important forms of the sigmoid curves can be identified in the literature:

- Pearl-Reed (logistic) curve, they used it for the analysis of the population of the United States in 1920 (Pearl & Reed, 1920).
- Bertalanffy (growth) curve, he used this curve for measurements of agricultural products in 1960 (Von Bertalanffy, 1960).

The most important difference between these two curves is the derivative curve, which is monotone decreasing in case of Bertalanffy curve, but the derivative of the Pearl-Reed curve has an increasing part, too. Other important difference is that the Pearl-Reed curve in the beginning part has an exponential increasing shape and only after the inflexion point will have the saturation growth part. Table 1 shows the shape of the curves, the derivatives and the integrals. The equations of the curves:

Pearl and Reed (logistic) curve:

equation of the curve: $y(x) = \frac{K}{1+ce^{-rx}}$, first derivative: $\frac{dy(x)}{dx} = \frac{Kcre^{-rx}}{(1+ce^{-rx})^2}$, integral:

$$\int y(x)dx = -\frac{K}{r}\ln(e^{-rx}) + \frac{K}{r}\ln(1 + ce^{-rx}) \tag{1}$$

Bertalanffy (growth) curve:

equation of the curve: $y(x) = K(1 - ce^{-rx})$, first derivative: $\frac{dy(x)}{dx} = Krce^{-rx}$, integral:

$$\int y(x)dx = Kx + \frac{Kc}{r}e^{-rx} \tag{2}$$

For the approximation of the curves the least squares approximation technique (Szabó, 2022) is used, but before this approximation it will be always necessary to transform the exponential functions into linear function. For this step the Fisher-Pry transformation (Fisher & Pry, 1971) is applied.

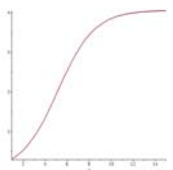
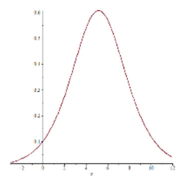
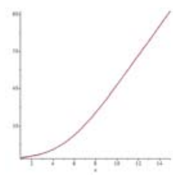
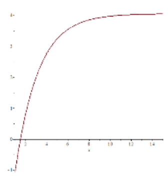
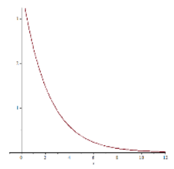
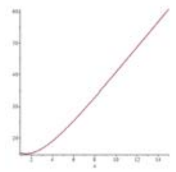
When using the method of least squares, it is necessary to approach the given discrete values $(xi, yi),\ i = 1, 2, 3, \ldots, n$, by a function $y^* = f(x)$, while the parameters of the curve should give the minimum possible value of the sum of the squares of the differences. This means that regarding the approximating function values $f(xi) = y_i^*$, we have to find:

$$H = \sum_{i=1}^{n}(y_i - y_i^*)^2 = min \tag{3}$$

Equation (3) describes an optimisation problem. For the numerical solution this optimisation problem Nelder-Mead (Nelder & Mead, 1965) optimisation algorithm is used, searching the minimum of the H function (3).

Table 1

Two important sigmoid curve types

Pearl- Reed (logistic curve)		
The curve	**Derivative**	**Integral**
		
Bertalanffy (Growth curve)		
The curve	**Derivative**	**Integral**
		

Calculating the regression coefficient of the linear regression R_{lin}, it is possible to decide, which type of the sigmoid function gives the best approximation to the investigated phenomenon: If the value of the regression coefficient is closer to 1, that type of curve is better for further approximation or forecasting.
The regression coefficient can be calculated as:

$$R_{lin} = \frac{A_{xy} - \frac{B_{xy}}{n}}{\sqrt{\left(C_x - \frac{D_x}{n}\right)\left(C_y - \frac{D_y}{n}\right)}} \tag{4}$$

where:
$A_{xy} = \sum_{i=1}^{n} x_i y_i$, $B_{xy} = \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i$, $C_x = \sum_{i=1}^{n} x_i^2$, $D_x = (\sum_{i=1}^{n} x_i)^2$,
$C_y = \sum_{i=1}^{n} y_i^2$, $D_y = (\sum_{i=1}^{n} y_i)^2$.

In equation (4) it is possible to calculate the linear regression coefficient of the y* transformed function determined in equation (3), but it is simpler return to the y notation.

3. MARKET OF MOBILE PHONES

It can be seen in Figure 1, that the number of smart phones sold to end users worldwide from 2007 until 2023 shows the classical Pearl-Reed curve (logistic curve) form. From the shape of the curve, it can be evidently decided, that the logistic curve will be the best to approximate it, because the Bertalanffy curve cannot follow its exponential growth part in the beginning of the curve. After 2020 it is possible to detect a little decrease of the market, but it is possible also to discover some effects of innovations or developments in 2021 and 2022. This means that the real shape of the curve could be a multi-logistic curve with two waves.

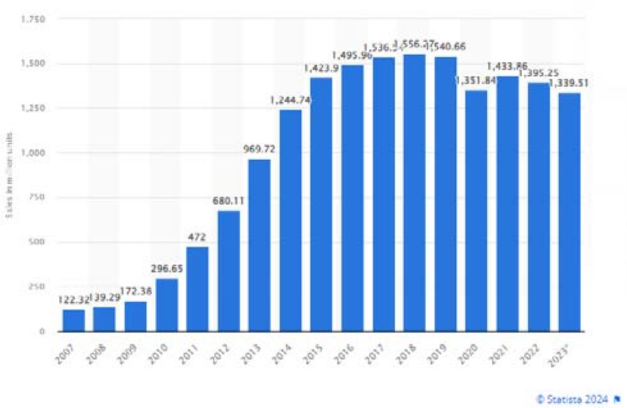


Figure 1. *Mobile phones sold from 2007 until 2023*
https://www.statista.com/statistics/271496/global-market-share-held-by-smartphone-vendors-since-4th-quarter-2009/

Figure 2 shows the number of mobile network subscriptions sold worldwide from 2016 and forecasted until 2028. The shape of this curve does not show in its beginning part the exponential growth shape, so in this case the Bertalanffy curve will be the best to approximate.
Comparison of the curves shown in Figure 1 and Figure 2 shows that the market of the mobile phones follows the classical form of product life curve. The market of the mobile network subscriptions follows the Bertalanffy growth curve. This means that the number of mobile networks sold is always growing monotone, not needing any development or innovation, but the number of mobile phones can show a saturation part, with decreasing market, so it will need in the future more intensive developments and innovations. If the market is already saturated, the efficiency of the developments and innovations will be slower and slower.

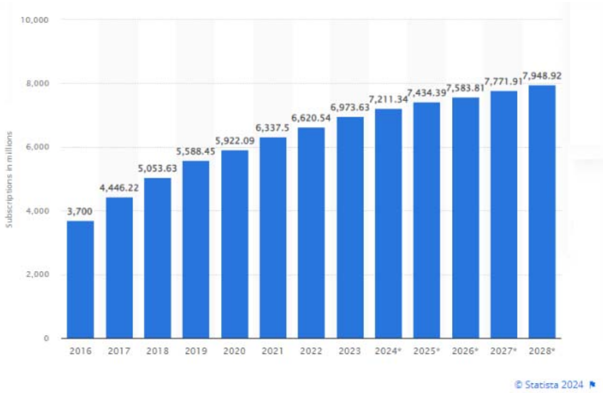


Figure 2. *Mobile network subscriptions from 2016 and forecasting until 2028.*
https://www.statista.com/statistics/271496/global-market-share-held-by-smartphone-vendors-since-4th-quarter-2009/

4. MARKET OF ELECTRIC CARS

The electric cars selling in percents of the total number of new cars sold is shown in Figure 3, for Europe, China and USA. The figure shows that all three curves are sigmoid curves, with several decreasing parts and renewal of the market, which means that this segment of the market can be described by multi wave logistic curves. The presence of the newer and newer increasing parts shows the effects of significant innovation works, developments and several forms of government grants.

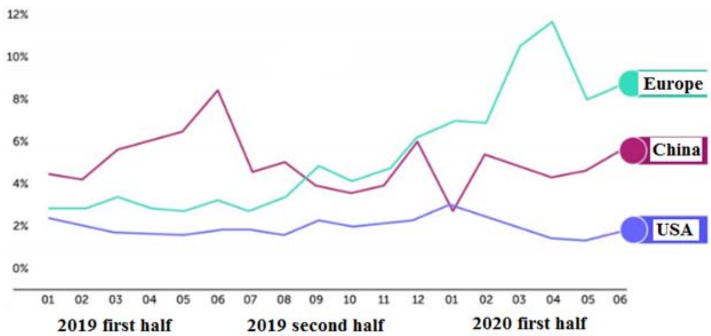


Figure 3. *Market of electric cars by the new cars selling in percents, regarding USA, China, Europe*
https://theicct.org/

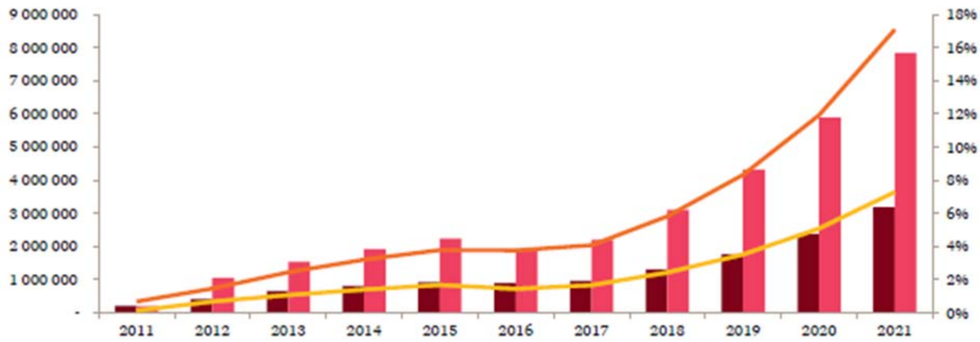


Figure 4. *Number of electric cars manufactured in the world and in Europe*
www.pwc.com/hu

Figure 4 shows the number of the manufactured electric cars in the world and in Europe from 2011 until 2021. Both these curves show that between 2016-2017 there was a saturation in the manufacturing of electric cars, but after this period it was renewed, and it is growing monotonous also in our time. This new part of increasing could be the result of several innovations and/or developments.
The number of electric cars in Hungary (Figure 5) shows a very similar shape, the only difference is that the saturation part of the curve is between 2019-2020, a little bit later than in the World or in Europe. The EU 90 g/100 km rule also has an effect to this curve.

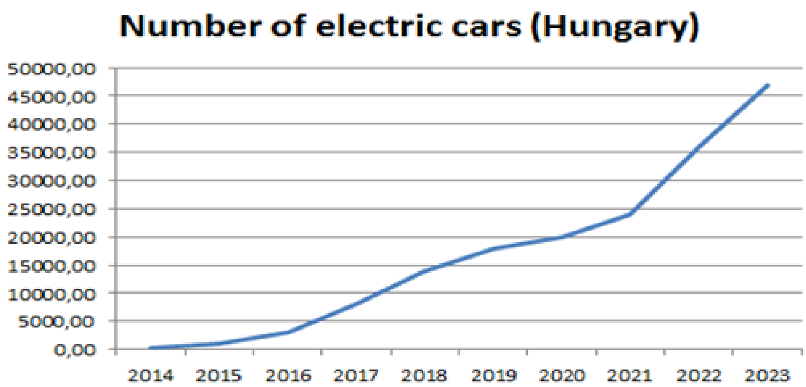


Figure 5. *The number of electric cars in Hungary, from 2014 until 2023*
www.pwc.com/hu

Figure 3, 4 and 5 show the situation of the manufacturing of electric cars. These curves are very optimistic regarding the possible future. However, in the end of 2024 latest news say that because of a worldwide decrease in the demand for electric cars, several electric car manufacturers and manufacturers of parts for electric cars close some parts of their factories, provoking the termination of employment of several thousands of workers, so possibly the increasing tendency of the electric car manufacturing will slack in the future. In this dim and equivocal situation, it would be hazardous to build any forecasts for the future, in particular long-term prognosis.

5. Summary

In this paper the market of the mobile phones is studied by the sigmoid curves of the number of mobile phones sold worldwide between 2007 and 2023 and by the sigmoid curve of the mobile network subscription sold from 2016 and forecasted until 2028. The analysis of the sigmoid curves shows that the mobile phones market shows the shape of the classical product life curve, even with decreasing market in 2020. In order to increase this market, the experts and managers will need to do important innovations or developments. The number of mobile network subscription describes a monotonous growth shape, so in this case no need to do innovations or developments, the growth will continue in the future without any problem. Comparison of the number of waves of the curves, it can be concluded that the market of electric cars regarding the percentage in new cars selling shows more waves than market of mobile phones. This means that the market of the electric cars needs high amount of innovations, developments and governmental grants in order to compete with other car types. Regarding the curve of the number of electric cars in Hungary, it is very similar to the curve of the World or of Europe, but the difference is that the saturation period of the Hungarian curve is later, than it is in case of the world or Europe. Comparing the sigmoid curves of mobile phones and electric cars, it is very interesting that from 2017 until 2020, a strong saturation period can be found in the curves. This shows a significant decrease of the market in case of mobile phones and in case of electric cars, too. In this kind of situations an innovation or some developments could be necessary to increase the market again. In case of the electric cars the experts and managements performed these innovations or developments and maybe there are government grants too; therefore, it can be seen a remarkable increase in the amount of the market. In case of the mobile phones this increase is smaller, which means that the innovations or developments are not enough to improve the market. In future work it would be very interesting to investigate the reasons of the saturation of the markets in 2017 and to find, what could be the reason for this saturation presents a little bit later in Hungarian electric car market.

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