

Application of the Technology Life Cycle and S-Curves to the “Brain Drain” Area of Knowledge

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Abstract

Objective: The purpose of this paper is to apply an S-curve methodology to the area of knowledge of brain drain. **Methods and Analysis:** Thirteen non-linear models were applied through the statistical software SigmaPlot (online version) in an accumulated data series of articles obtained in the online data base SCOPUS. Afterwards, the inflection point was calculated and such was validated through “p” and “t” values. In addition, the Durbin Watson and adjusted R square values were also calculated. **Findings:** After the application of the thirteen non-linear models: sigmoidal 3, 4 and 5 parameters, logistic 3 and 4 parameters, Weibull 4 and 5 parameters, Gompertz 3 and 4 parameters, Hill 3 and 4 parameters and Chapman 4 and 5 parameters, the models with the best fit were sigmoidal and logistic, which gave an inflection point in the year 2023. These models were validated through the following ranges: T value greater than 2 or less than -2, P value less than 0.005. Given that the inflection point occurs in the future, this presents a great opportunity for academics and researchers who focus the topic of brain drain to publish given the high dynamism in online databases like SCOPUS. **Novelty:** The S-curve methodology and technology life cycle (usually executed in subjects related to technology) was implemented in this article with the innovative approach to apply it to a specific area of knowledge.

Keywords: Brain Drain, Curves, S Inflection Points, Technology Life Cycle

1. Introduction

This article comprehends the study of S curves regarding the brain drain phenomenon. The methodology used provides an element of added value for decision making related to the dynamism of publications on the subject based on what has been researched by other authors regarding the technology life cycle^{1,2}. This is important since academics and researchers related to the study of brain drain can find a tool for decision making related to the possibility of validating their interest in the generation of projects, publication of papers and new lines of research, amongst other aspects.

The main objectives of the study presented in the paper are: to search for articles on the Scopus database

regarding the topic of brain drain to apply “S” curves in the selected topic and calculate the inflection point.

1.1 Theoretical Framework

The “brain drain” phenomenon has a long history dating back to 1963, when the Royal Society defined the “brain drain” of the exodus of British scientists to the United States, seriously endangering the British economy, and it was from this situation that this term came to be commonly used to describe the emigration of scholars and professionals from third world countries or former colonies³.

Recently, keeping in mind the epistemological essence of the phenomenon, brain drain migration has been mutating to the point where, according to experts like

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Grubel⁴ “it is the process of abandonment of a country in favor of another by professionals or people with a high level of education, generally following an offer of better pay or living conditions), as well as improved conditions for conducting one’s professional activities”.

Understanding that both definitions talk about the movement of human capital and a potential loss of specialized knowledge, the complexity of the singularity has been a topic of research and study by several institutions of higher education, companies, and governments, who now have determined that such adjusts daily to the high dynamism of globalization⁵.

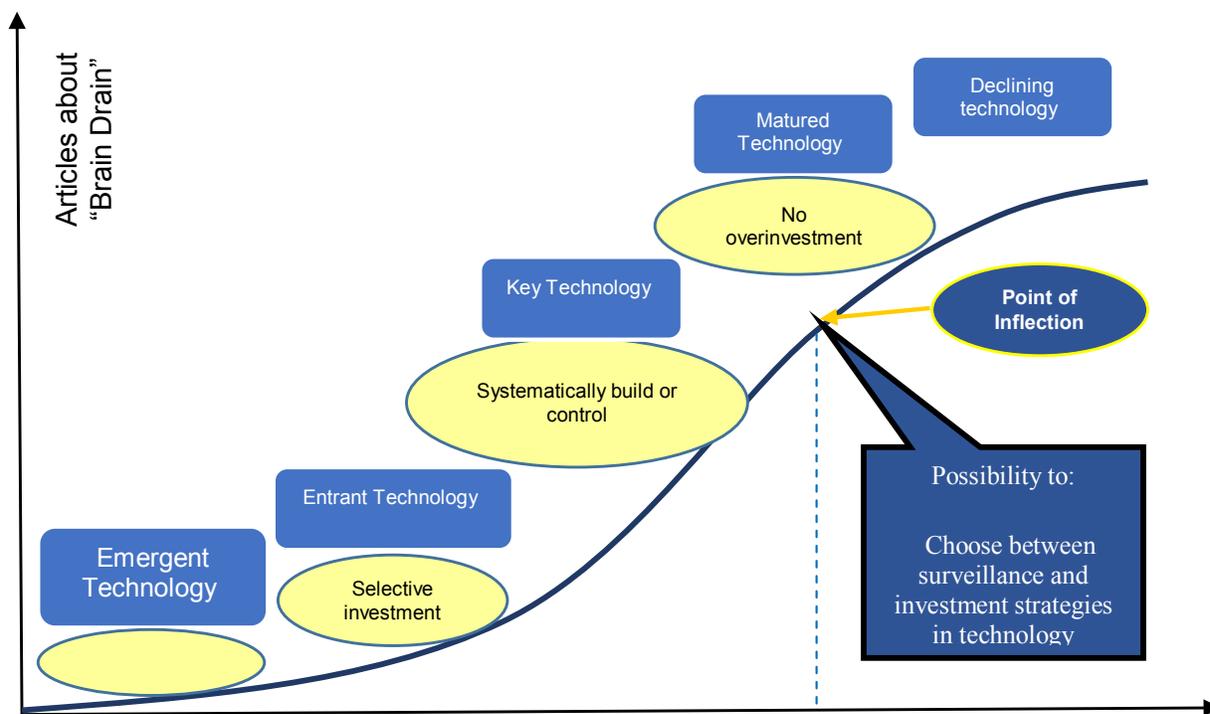
When such migration is under the umbrella of a macro phenomenon such as globalization, its impact and measurement become a difficult task, even for institutions that count with the appropriate resources (financial and human)⁵ obtained information from both the OECD and the UNESCO stating that:

“(…) testing the brain exchange hypothesis becomes difficult since there are no systematic statistics of inward and outward flows for many countries. In addition, countries use different criteria to classify migrants and do not always collect data on specializations. The strong iteration

is therefore still impossible to verify at a systematic and global level” (Milo et al, 2012 pg.16).

As any measurable phenomenon or area knowledge, the application of S-curves, in the last years, has been extended to understand the behavior and the strategies that can be implemented in each one of the phases of technology, innovation or life cycle of a specific are of knowledge. This is evidenced by the studies of^{2,6} who have deepened in analysis of the state of technology: emergent, incoming, key, and mature or in decline; and the possible strategies to follow: monitoring, selective investment or overinvestment. The research on the behavior of technology in each phase: initial, early growth, late growth and maturity are added to these studies¹. The aforementioned can be observed graphically in Figure 1⁷⁻⁹ present specific cases on the technology life cycle, curves for diffusing technological innovations and adopting them through S curves¹⁰.

On the applications of S curves in innovations, these have associated a series of market, trade and technological uncertainties, which are increased with the need for information or knowledge about the variables involved in the process of launching a new product or improvement



Source: Adapted from Ortiz & Pedroza², Perez^{1,3}

Figure 1. Phases of the technology life cycle and possible monitoring and investment strategies.

of an existing one¹¹⁻¹⁴. Likewise, technological uncertainty refers to the need for additional knowledge about the components and how the methods and techniques are related for the new product to work properly¹⁰. According to¹⁰: “These uncertainties can be reduced through the study of technological regularities, market regularities and the use of appropriate innovation strategies. The most appropriate way to analyze technological regularities is through S-curves, so the company can analyze the performance of innovation over time. Similarly, market regularities can be studied by means of S-curves”.

It is relevant to highlight that S curve models serve as a possibility to comprehend dynamics of change, to expose trends, causes, probabilities and possibilities in social, political, economic and technological surveillance.

Regarding bibliographical application (such as the one intended in this article¹⁵, states that the practice of citation analysis has become a fundamental part of the construction of scientific knowledge. In the early invention stage of cite indexation, that was initially oriented to the recovery of information, proposed the use of databases to reconstruct the history of scientific ideas.

Finally, Price¹⁶ exposes that progress regarding S-curve stages tends to be slow at the beginning, and then through a trial and error process, the field starts to become systemized. In the growth stage, the increase is fast and sustained. Finally, when the technology (in this case an academic field or an area of knowledge), an upper limit is reached and development becomes slow again. When technology is understood to be “matured”, such begins to decline and a new one that offers users benefits that are more attractive substitutes it. In relevance with the aforementioned, it is possible to guide bibliometric analysis with the objective of understanding future areas of importance for research and academic knowledge¹⁷.

2. Methodology

The methodology was developed in the following phases:

2.1 Phase 1. Selection of Accumulated Data

An equation or search strategy was established for articles in the database SCOPUS. From the documents obtained, a time series was organized with the accumulated articles.

2.2 Phase 2. Application of S-curve Models

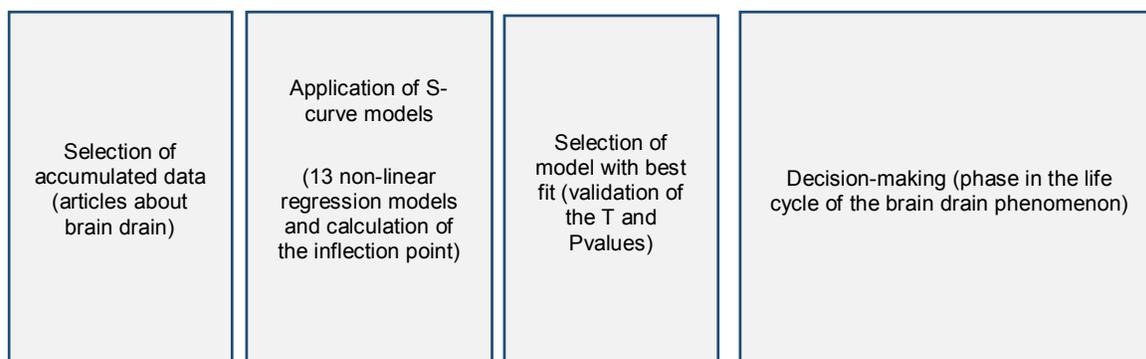
The accumulated data obtained in the articles was entered in Sigma plot software (online version) and the 13 pre-loaded models in the program were applied: sigmoidal 3, 4 and 5 parameters, logistic 3 and 4 parameters, Weibull 4 and 5 parameters, Gompertz 3 and 4 parameters, Hill 3 and 4 parameters and Chapman 4 and 5 parameters. In each of these models, the inflection point was calculated through non-linear regression.

2.3 Phase 3. Selection of Model with the Best Fit

With the results obtained in each of the thirteen models of the software, the inflection point and all the parameters of each model were validated with the T and P values. Those models (with all their parameters) with values of $-2 < T > 2$ and $P < 0.005$ were taken as valid, that is, models with greater fit. Other indicators such as adjusted R² value and Durbin Watson were also taken into account.

2.4 Phase 4. Decision-Making

Based on the results of the calculation of the inflection point in the models with the best fit, contributions were



Source: Self-elaborated

Figure 2. Phases of the methodology.

made according to the current phase in the life cycle of the brain drain phenomenon. The summary of methodology is explained in Figure 2.

Table 1. Time series of accumulated articles of brain drain

Years	Number Of Articles Per Year	Accumulated Series
1964	2	2
1965	2	4
1966	6	10
1967	23	33
1968	9	42
1969	5	47
1970	10	57
1971	12	69
1972	8	77
1973	7	84
1974	12	96
1975	12	108
1976	2	110
1977	7	117
1978	5	122
1979	5	127
1980	11	138
1981	7	145
1982	2	147
1983	6	153
1984	8	161
1985	9	170
1986	12	182
1987	13	195
1988	15	210
1989	8	218
1990	16	234
1991	10	244
1992	30	274

1993	19	293
1994	13	306
1995	11	317
1996	7	324
1997	17	341
1998	13	354
1999	9	363
2000	21	384
2001	32	416
2002	28	444
2003	38	482
2004	59	541
2005	71	612
2006	81	693
2007	92	785
2008	100	885
2009	110	995
2010	92	1087
2011	119	1206
2012	107	1313
2013	121	1434
2014	120	1554
2015	115	1669
2016	88	1757
2017	28	1785

3. Results

For the analysis of the life cycle through S-curves based on scientific articles, the following search equation was used:

3.1 Title-ABS-Key (“Brain Drain”)

The equation yielded the time series shown below:

The results regarding the accumulated articles are represented in Table 1.

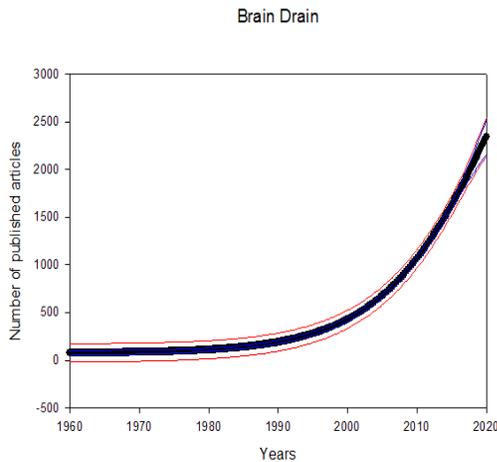
The accumulated data series was uploaded to the Sigma plot software, where the 13 non-linear regression models were applied and their respective inflection points

Table 2. Results on the application of the 13 non-linear regression models in accumulated articles about brain drain

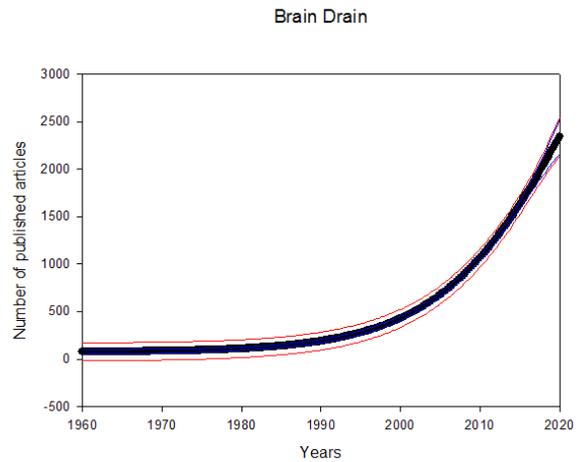
Articles	Brain Drain					
	Validity	Model	Inflexion Point	Adjusted R2	t Value	p Value
No	Sigmoidal 3	2166	0.9886	Doesn't meet the value	Doesn't meet the value	0.1847
Yes	Sigmoidal 4	2023	0.9914	Meets the value	Meets the value	0.1949
No	Sigmoidal 5	2015	0.9943	Doesn't meet the value	Doesn't meet the value	0.0827
No	Logístico 3	2158	0.9885	Doesn't meet the value	Doesn't meet the value	0.1801
Yes	Logístico 4	2023	0.9913	Meets the value	Meets the value	0.195
No	Weibull 4	2124	0.9884	Doesn't meet the value	Doesn't meet the value	0.1843
No	Weibull 5	2014	0.9915	Doesn't meet the value	Doesn't meet the value	0.1685
No	Gompertz 3	The model did not adjust given that it needed more interactions				
No	Gompertz 4	The model did not adjust given that it needed more interactions				
No	Hill 3	2080	0.8324	Doesn't meet the value	Doesn't meet the value	0.022
No	Hill 4	2071	0.9202	Doesn't meet the value	Doesn't meet the value	0.0331
No	Cahpman 3		0.9871	Doesn't meet the value	Doesn't meet the value	0.1486
No	Cahpman 4		0.9906	Doesn't meet the value	Doesn't meet the value	0.2455

where calculated. The results are shown in the following Table 2.

According to the data obtained in the non-linear regression from the Sigma plot software, the models that met the requirements to be valid (T value greater than 2 or less than -2, P value less than 0.005) were the sigmoidal 4 and Logistic 4. This coincides with other studies made¹⁸ where the sigmoidal models obtained a better fit (for three technologies in fish by-products); logistic 4 parameters (financial and telecommunications sector) and sigmoidal 4 parameters (financial sector, product housing credit).



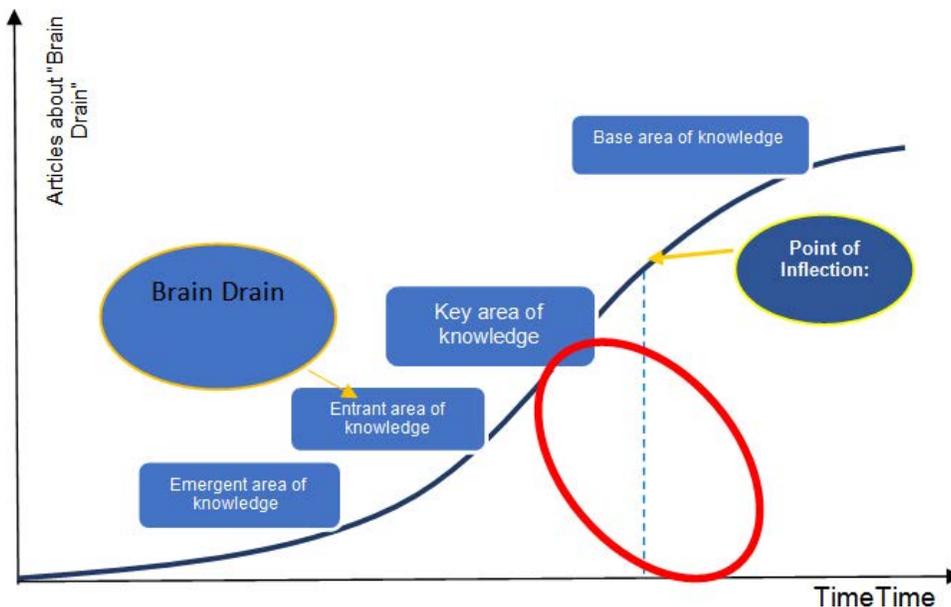
Source: Self-Elaborated
Figure 3. (Logistics 4 Parameters).



Source: Self-Elaborated
Figure 4. (Sigmoidal 4 Parameters).

In other studies on tourism-related issues¹⁹, the business diagnostic tool in this article's data series also obtained sigmoidal and logistic winning models. In addition, in the product lifecycle subject, four models had a better fit; amongst them were the sigmoidal and logistic models, which also coincide with the results obtained in this research.

According to the value of the inflection point, year 2023, it can be established that the rhythm of scientific production of articles presents a high degree of dynamism, which has allowed it not to occur at an inflection



Source: Self-elaborated
Figure 5. Position of the brain drain area of knowledge in the S-curve.

point before the year 2017. This presents a great opportunity for academics and researchers who focus the topic of brain drain since The rate of magazine publication in Scopus is still high. Figures 3 and 4 show the results obtained in accumulated articles through the application of the non-linear models Logistics and Sigmoidal.

Based on the different classifications of a technology according to Ortiz & Pedroza², understanding the existent correlation between technology and knowledge and that it is possible to guide a bibliometric analysis comprehending future areas of importance for research and academic knowledge¹⁸, Figure 5 aims to demonstrate that a respective area of knowledge, in this case brain drain, can be found in the initial phases before the inflection point of the life cycle (emergent, entrant and key). After the inflection point, we propose that an area of knowledge is not categorized as matured or declined but rather as a base area of knowledge.

For the brain drain phenomenon, it can be observed that, in terms of the number of articles published per year, it was identified that the highest number of publications was presented during the year 2011, with 131 documents and then in 2013, with a total of 130 Documents. This shows a growing trend in terms of the magnitude of publications per year.

The authors who have published most articles on brain drain have been Docquier, Frederick, Rapoport, H. Hugo, G. Kapur and D. Lien, D.

Finally, Table 3 shows the countries that present the most publications regarding brain drain.

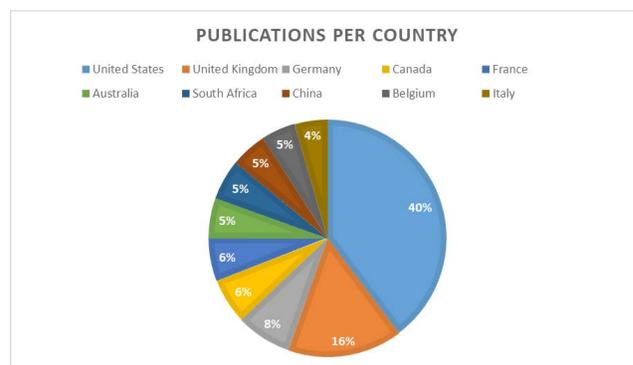
Table 3. Number of publication per country

United States	479
United Kingdom	188
Germany	91
Canada	75
France	71
Australia	66
South Africa	66
China	59
Belgium	56
Italy	54

Source: Self-elaborated

At a graphic level, Figure 6 shows the percentages of publications per country.

The point of inflection obtained in the topic of brain drain was the year 2023, which reflects a high dynamism regarding the production of articles and represents a great opportunity for academics and researchers related to this area of knowledge, with a possible research opportunity for courses taught in undergraduate and graduate programs dealing with this topic (business, economic, political science and sociology, amongst others).



Source: Self-elaborated

Figure 6. Percentage of publications per country.

Within the thirteen nonlinear regression models applied, the models with the best fit for the brain drain theme were Sigmoidal and logistic. This coincides with results obtained in other subjects in the financial sector, telecommunications, product-housing credit and in subjects of agro-industry. New applications of these models are necessary with search equations on the same subject or related areas of knowledge in order to generate definitive information on the best-fit models on the topic studied in this paper.

The countries with the highest production of articles in brain drain are The United States, The United Kingdom, Germany, Canada, France, Australia, and South Africa, all with a production rate above 60 articles in the past five years. The years with the highest percentage of publication were 2011 and 2013. Not one Latin American country was present in the ranking within the 10 countries with highest publication rates, meaning that in this region article publication is low, representing an opportunity for academics that wish to research and publish on this topic.

S-curves have had multiple uses in technology and innovation both qualitatively and quantitatively, given the close relationship between these two phenomena with fields or areas of knowledge. It is possible to use the mod-

els that represent the S-curves to understand the state or phase in terms of its life cycle or current and future phase in a field of knowledge of research. This becomes an opportunity to apply the methodology of S-curves presented in this paper in other areas of knowledge of interest to research groups, academic programs, doctoral and master's theses in the component of systematic literature review, surveillance and competitive intelligence studies, amongst others.

4. Limitations and Future Projects

Cites can be used to evaluate the quality of scientific work, whilst citations have the purpose to measure the obsolescence of a field, in this case, brain drain.

The struggle is in the process of decision making with just one performance parameter. It is suggested that in the subject of brain drain, citations and articles are analyzed simultaneously.

The analysis acquired from the software at the time the inflection point had not occurred, yet estimated in the future (in this case inflection point in 2023) are estimates are shown that should be read carefully now that the software does not have the capacity to allow or read pre-installed limits, threats (legal, political or social). Nonetheless, the fact that the inflection point is in the future shows promise to those interested in publishing topics related to brain drain.

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