THE DYNAMICS OF INTERNET AND GSM GROWTH, AND INHERENT MARKET FLUCTUATIONS

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ABSTRACT

The purpose of this paper is to explore whether recent insights into the "emerging properties" of complex social networks can help us to understand the development of GSM and Internet, and to open up possible new avenues for communications policy analysis. It is intended as a stimulus to further research, not a substitute for it.

A simple model of self-limiting hyperbolic growth, characteristic of a self-organising social network, matches the observed growth in use of the Internet and GSM mobile telephony. At the world level, both growth curves have the same critical time and the same time constant, but different levels of population saturation. We present this as indicative of the further progress needed in usability and affordability of technologies if we are to significantly reduce the global "digital divide".

Both growth curves also appear to have passed the inflection point to declining annual growth in 2000, and this paper explores the implications for telecommunications handset and PC market development, and for equity valuations, and highlights the importance of a rapid transition to GPRS and 3G capabilities for peer-to-peer multi-media communications, but also for a second track of development of simple and affordable interfaces for a more inclusion global knowledge society.

The views expressed in this article are those of the authors and do not necessarily reflect the official European Commission's view on the subject.

1. Background

The current phase of development of the networked knowledge society is characterized by the emergence of new communication technologies. The most significant being digital mobile telephony, notably on the GSM standard, and the Internet. These technologies, and the facilities they offer, strengthen and extend the patterns of communication and collaboration between people.

In recent years, there have also been major new insights into the nature and characteristics of complex social networks: The realization that they are part of a class of self-organizing networks with a scale-invariant power-law distribution of linkage, and a "small-world" characteristic[1]. This class of complex social network is best know in the networks of scientific collaboration, through co-authorship analyses - with the joint authors of scientific papers being considered as linked[2].

However, not only do these networks have these well defined "architectural features", they also have common dynamics - Their "emergent properties" are characteristic of networks that grow by progressive accretion of new participants, each of which links to existing participants in relation to their existing linkages (with the preference for attachment to an existing node proportional to the number of existing links it has). It is characteristic of social networks[3]; business networks; other research networks; the network of Internet routers and of web-pages[4]; and appears to be a common social characteristic of a complex networked society.

The dynamic properties of these networks have recently attracted considerable interest – principally in relation to the stability and resilience of the Internet, but also in relation to fluctuations and crises in economic and financial systems[5].

While the mathematics of such analyses can be complex, we have been concerned principally in this paper to explore whether a very simple model of self-organised and self-limiting growth can give possible new insights into the observed pattern of growth in GSM and Internet use; into possible future challenges of the "digital divide" – the division of world society into those connected to the knowledge society, and those not; and into the dramatic fluctuations in growth and equity valuations of the ICT sector in recent years.

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[1] Newman Santa Fe institute

[2] The structure of scientific collaboration networks : M.E.J. Newman, Santa Fe Institute, *Proc. Natl. Acad. Sci. USA* **98**, 404-409 (2001)

[3] Exploring complex networks. S.H.Strogatz, *Nature* **410**, 268-276 (2001)

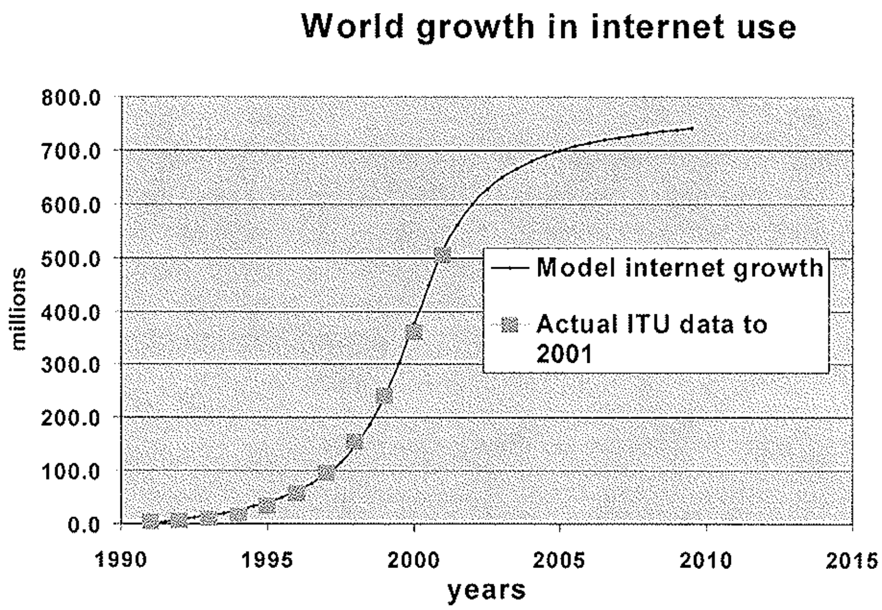
[4] Diameter of the world-wide web : R.Albert, H Jeong and A-L. Barabasi, *Nature* **401**, 130-131 (1999)

[5] Why stock markets crash : critical events in complex financial systems : Didier Sornette ; Princeton University Press, 2003

2. SELF-LIMITING GROWTH IN KNOWLEDGE NETWORK USE

Both GSM and the Internet are networking technologies that should exhibit well known "externalities". These should initially manifest themselves in growth that reflects Metcalf's law[6] : That the total value[7] of a network increases as the square of the number of people connected. Initial growth should therefore be hyperbolic – the incremental growth proportional to the square of the number of existing users. However, this cannot persist. Unconstrained hyperbolic growth inevitably explodes to a singularity at a critical time.

However, while new networking facilities first attract more prosperous and skilled people, continued expansion beyond a certain proportion of the population has **diminishing value, usability and affordability.** For these exploratory analyses, we have chose to use a very simple formulation for of self-limiting hyperbolic growth proposed by Sergey Kapitza[8,9] in the context of analysis of human demographics. This is the simplest form that might be expected to reflect an initial growth proportional to the square of the number of users, and saturation at the fraction of the population for which a new technology is attractive and affordable. In this, it generates a typical"S"-curve of accelerating, then stagnating growth (which has been observed for the take-up of many innovations in society), but with a rigorous form determined by only three parameters.



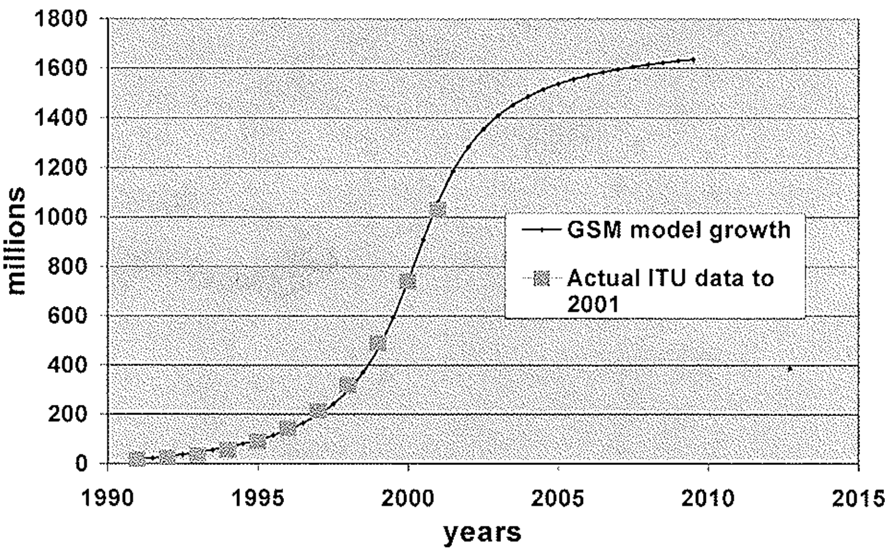
[6] Bob Metcalf was the inventor of Ethernet. For further discussion see « Information rules », Carl Shapiro and Hal R Varian, Harvard Business School Press, 1999.

[7] The **"total value"** is associated with the ability to communicate with any (or all) of the other connected people – value associated with each individual or business being a creator **and** user of knowledge.

[8] Information Society and the demographic revolution : the non-linear theory of growth of Humankind, Sergey P. Kapitza, Institute for Physical problems, RAS, Moscow, 2000

[9] $dN/dT=tK^2/((T_1-T)^2+t^2)$ where N is the number of users, T is historic time in years; t is a "time constant" of 6.4 years; K is a scaling factor, and T_1 is the "transition time" =2000. The mathematical form of the growth dynamic is summarised in Annex 1.

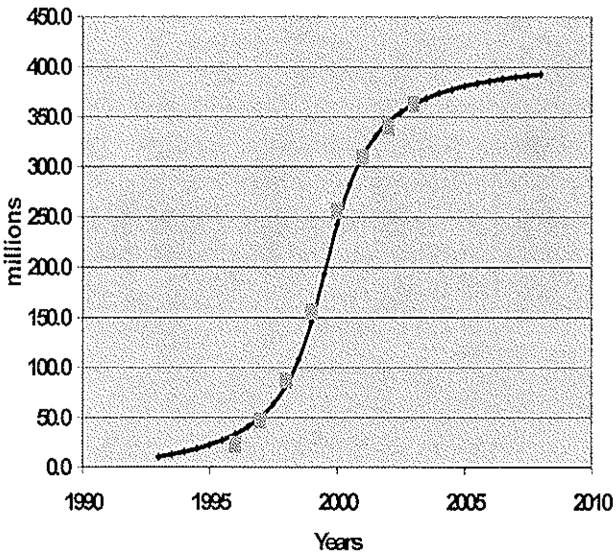
World growth in GSM users



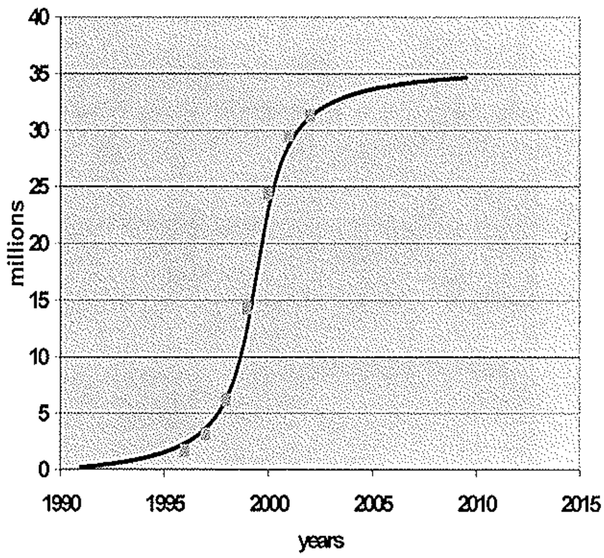
As shown above, it matches well the observed growth of users of the Internet and of GSM mobile telephony at the world level, from 1991 to the latest actual data in 2001. We must be careful not to read to much into the apparent match between this very simple model and observed growth : No data on the actual numbers of GSM subscribers or PC-Internet users is very accurate. The data on initial growth do not allow us to distinguish definitively between and hyperbolic and exponential growth, and actual data are not yet available sufficiently beyond the inflection point to reliably pin down the saturation level.

Fortunately GSM growth in Europe has been earlier than in the rest of the world, and the similar comparison with European data[10] shows the same form of self-limiting growth, but with actual data further beyond the inflection point. Similarly Spanish GSM growth was even faster, and the same form is again observed.

European GSM growth



Growth in Spanish GSM users



[10] European IT Observatory data from the EITO reports of 1998-2002.

At the Spanish and European level, saturation is to about 80-85% of the population – essentially all adults – with this saturation population emerging from the growth curve, not an imposed constraint in the model-based pojections.

At the world-level, the comparison with the actual data[11] on Internet users and GSM users is interesting in three ways:

- Firstly, actual data from 1991 to 2001 can be matched with this simple model – with only three free parameters – essentially the critical time; the maximum rate of growth, and the saturation level - both for GSM and Internet : This indicates that the growth dynamics for GSM and Internet use are similar and are consistent with Metcalf's law in the early years, but with a self-limiting character intrinsic to the match between the technology and social needs;

- Secondly, the self-limitation is to a total population of users much smaller that the total world population - for GSM to about 1700 million, and for PC-based internet use, to about 800 million. This reflects the different "utility values" and affordability of these technologies to people. The difference shows that GSM is useful and affordable for about twice as many people as PC-based internet access, but that neither technology is likely to be used by more than about 25% of the world population with the current wealth inequities and the technology's usability and affordability.

- Thirdly, the two growth curves differ only by a scaling factor. The "critical time" (at which half the limit is reached) is the same (about March 2000), and the "time constant" of growth (the time over which usage increases from about 10% to 90% of the limit is the same (6.4 years) both for the Internet and GSM. While GSM and the Internet are different technologies- having emerged independently in the early 1990s : GSM from the European telecommunications industry, and the Internet from the US IT sector, this identity in growth dynamics must tell us something about their similarity - perhaps that they address the same social networking need that has emerged in the 1990s as the world population reached a critical point in its own growth dynamic as a knowledge society; perhaps the tight linkage comes through their common dependence on progress in micro-electronics.

The similarities and difference between GSM and PC-based access to the internet shows clearly that the most important parameter for the extent of the "Digital Divide" at the world level is the attractiveness, affordability and usability of the technology. It is intrinsic to the technology itself. This suggests that perhaps the only, and possibly the most cost effective way to address the "Digital Divide" will therefore be to invest in more attractive, affordable and useable communication and networking interfaces.

[11] ITU data to 2002 http://www.itu.int/ITU-D/ict/statistics/at_glance/KeyTelecom99.html

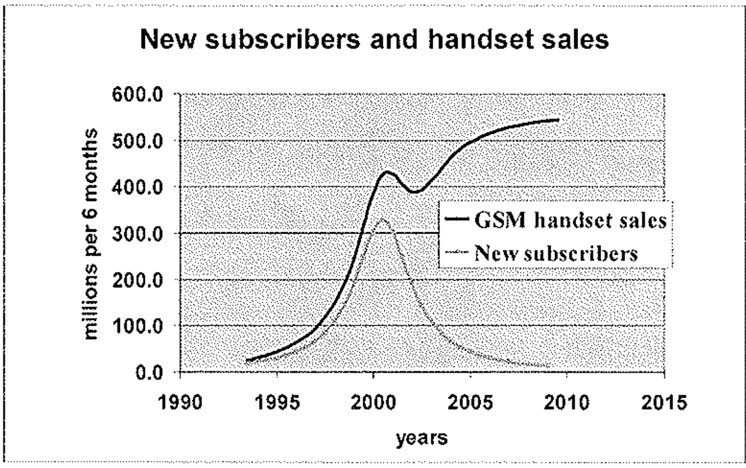
The future evolution will not necessarily follow the same growth dynamic as in the recent past – technology is not static : GSM is already evolving to data-capable networking, able to support e-mail with the 2.5G GPRS technologies, and with use emerging from the already widespread use of SMS on the GSM platform. The introduction of 3rdgeneration technologies and networks, capable of supporting image and video-communications between people will benefit from the same "network growth dynamics" as for GSM, but will cannibalize the market for GSM hand-set sales as most 3G subscribers will upgrade from GSM.

In addition, social and economic inequity at the world level is not static; The saturation of the world GSM market at less than 2 billion subscribers[12] is associated with 2 billion people living in poverty, and many others on the margins of economic activity. This polarization has worsened in recent decades, but could be reduced by the new commitments at Doha, Monterey and the recent WSSD, and the Millenium commitments to reduce poverty.

3. Implications for Key Market Developments

Whether or not future evolution of GSM and Internet use continues to follow the same growth dynamic, the simple model of self-limiting hyperbolic growth is at least a fair reflection of the recent past. It may therefore allows us to better understand the reasons for the sharp downturn in the fortunes of the IT and telecommunications sector, worldwide.

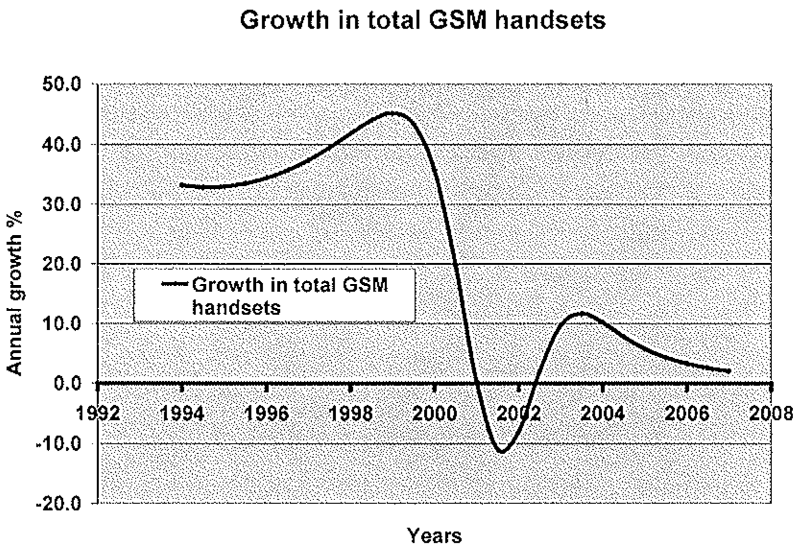
The diagram below shows the evolution in **GSM handset sales** that would be expected from the self-limiting growth dynamic in the number of subscribers. The only additional assumption here is that all new subscribers buy a new handset, and that existing subscribers replace their handset with a more up-to-date model every few years. The lower curve shows the expected evolution in handset sales to new subscribers, and the upper curve, that expected for total handset sales, including a replacement of their handsets by each subscriber after 2.5 years.



[12] The number of users may be greater than the number of subscribers : studies in the UK indicate that a GSM handset and subscription is often shared between family members, and enterpreneurial innovations in developing countries such as service provision to a whole community by a single GSM subscriber can also substantially extend usage beyond subscribers.

The sharp downturn in the world market growth for GSM handset and PC sales is similar to that observed in late 2000 to 2002. At the world level, GSM handset sales rapidly stagnated at about 400 million per year in 2000 – 2002, after a period of fast growth[13]. It reflects the observation that growth in subscribers passed its inflection point in 2000, which was also the peak in new subscriber handset sales. Because the subscriber-market is already saturated in the EU, further subscriber growth will be mainly in the developing world, and the handset-market will increasingly be for replacement handsets.

The close match of actual growth to that of a self-limiting network also suggests that the slowdown in growth of Internet and GSM use in 2002 may not be the **result** of a world economic slowdown or an unusually large random fluctuation, but was intrinsic to the growth dynamic for the use of these technologies. The same projections, presented in terms of the evolution in the annual growth-rate for the GSM handset market, well illustrates why this sector hit a wall in late 2000 – not because of external changes in the economic climate, but because the downturn was internal to the dynamics of self-limiting network growth.



The abrupt drop from an apparently sustained growth of over 30% per year to an actual contraction in the market for GSM handsets within about 12 months would challenge the business planning skills of any sector, and naturally damaged confidence in the investment community.

The super-exponential growth (faster than exponential) immediately prior to the sharp downturn has recently been identified[14] as a sign of imminent "corrections" in financial markets. In this case the super-exponential growth is simply the remnant of the hyperbolic growth and Metcalf's law.

In the immediate future, and if GSM and PC-based access to the Internet remain the lead technologies with similar affordability; and if world distributions of wealth and skills remain constant, these projections suggest that the GSM handset and PC

[13] The curves give the expected continuation of annualised sales.
[14] Why stock markets crash : critical events in complex financial systems : Didier Sornette ; Princeton University Press, 2003

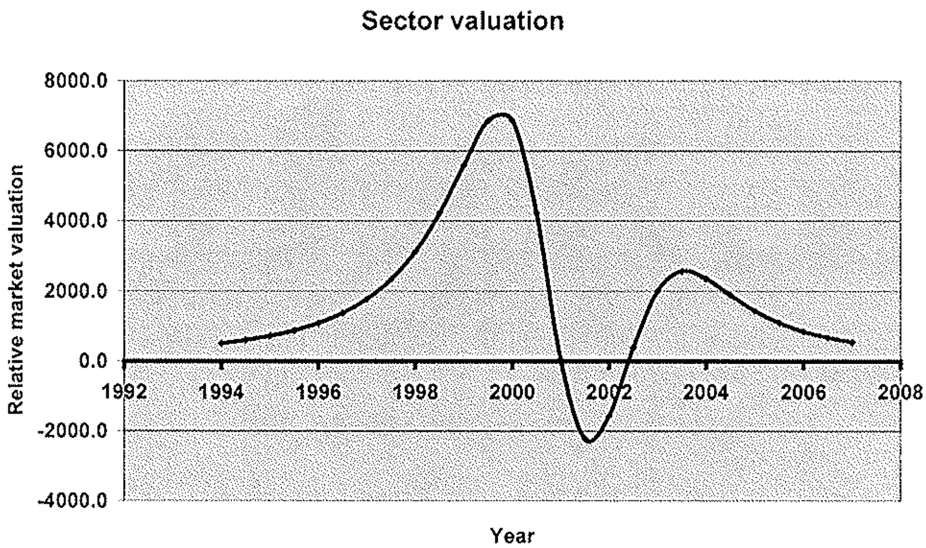
markets should recover to about 10% annual growth in 2003 to 2004. However, sustained growth beyond 2004 will depend on the timely introduction of new technologies, with more attractive features, or much wider affordability.

4. Rational Exuberance?

Business expectations, investment enthusiasm and equity valuations are closely linked to annual growth rates in leading markets and product lines. The evolution of growth rates in the GSM handset and PC markets have been critical to the perceived health of the mobile telecommunications and IT equipment suppliers.

Investment valuations reflect expectations of growth as well as current turnover and profitability[15]. Expectations of continued high growth clearly contributed to the exuberance of investors for IT and telecommunications companies in the late 1990s, and a "herd instinct" in a highly connected investment community clearly contributed to over-valuations.

The dramatic correction to equity valuations in May 2000 to end 2002 is outside the range of normal equity market fluctuations. Recent research[16] has shown that the prolonged correction is characteristic of critical point in an unstable complex system. Without trying to over-rationalize investor valuations, a simple combination of GSM handset or PC sales revenues and the growth rate shows the same form of valuation evolution as has been observed for this sector in equity markets in the last few years.



The dramatic fall in relative valuations in late 2000 until today, following a period of "exuberance" from 1996 to mid-2000, may again be intrinsic to the growth dynamic for human communications technologies. The probable recovery to valuation levels

[15] « Annual sales multiplied by the growth rate is not the best way of valuing a business if profits ultimately fail to materialise.... Markets get saturated, as they always have done. The new technologies are not immune » Charles Handy ; « The elephant and the flea » : Arrow, 2002

[16] See « why stock markets crash » cited earlier

of 1997-1998 is to be welcomed, but would not be sustained beyond 2005 without the new revenues and growth that will come from 3rd generation systems.

The present analysis is too simplistic to be a reliable guide to future equity market developments, and we have therefore deliberately not compared these projections with equity market data. Nevertheless, the broad similarity of this form of fluctuation to the observed market evolution in recent years, and in previous crises associated with utility and network developments may deserve further study.

5. THE 3RD GENERATION SYSTEMS AND THE GLOBAL DIGITAL DIVIDE

By enabling an entirely new inter-personal communication capability – that of image and video communications – the 3rd generation of mobile communications could again benefit from and follow a dynamic of network growth – with an initial n-squared growth.

However, if usage is significantly more expensive and complicated than that of GSM, growth will be self-limiting to a total population smaller than that for GSM – probably intermediate between those for GSM and PC-based Internet access. Nevertheless, 3rd generation systems, if they can be widely introduced in 2003-2005 could rescue the mobile telecom equipment suppliers from a second decline in market growth, and a second decline in market valuations, and their investment capability.

It is unlikely that this transition to a 3rd generation of systems, as currently conceived will help to address the global "digital divide" and significantly increase the potentially "connected" population in the global knowledge society beyond 2 billion. For this, a second track of technology development is likely to be needed, with the emphasis on usability and affordability for both voice- and data-communications from simple terminals with Internet capabilities.

6. CONCLUSIONS AND FURTHER ASSESSMENTS

The new insights into self-organizing complex systems are of enormous importance and relevance to the emergence of a networked knowledge society. This simple analysis, together with parallel analyses of the emergence of self-organizing knowledge networks in the European Research Area, is a first step – to stimulate wider interest and further research.

Substantial resources are available in the EU 6th Framework Programme for research and technology development to support further research in this area : Resources are available in the IST Priority in the Area of "Future and emerging technologies" for innovative research on "Complex systems". For the first time, resources are also available in the 6th FP for research in direct support of EU policy development. A first Call for Proposals was published in December 2002, and full information about the workprogrammes, the support instruments and future Calls for Proposals is available on the web : www.cordis.lu/IST

Annex 1

The Mathematics of Self-Limiting Hyperbolic Growth

In hyperbolic growth, the growth rate at any time is proportional to the square of the population : $dn/dt = n^2$: $nt = -K$, and $dn/dt = K^2/t^2$

In network applications, it is commonly known as Metcalf's law - the value of a network is proportional to the square of the number of people connected.

If hyperbolic growth is expressed in the form $dN/dT=K^2/(T_1-T)^2$, the number of connected people, N, explodes to a singularity at a critical time T_1: Inevitably, other effects intervene to moderate and eventually to limit growth to a maximum level: Populations are inhomogeneous – being connected in a network is less valuable to some people; some people can't afford the technology or the services, some people don't have the skills to use the technology, and inclusion in a network can never exceed 100% of the population.

In these assessments, we have chosen to use the simplest possible modification to hyperbolic growth, drawing on the initiative of Serge Kapitza in his analyses of self-limitation to hyperbolic population growth[17]. This involves the transformation to: $dN/dT=t_xK^2/((T_1-T)^2+t_x^2)$ where N is the number of users, T is historic time in years; t_x is a "time constant"; K is a scaling factor, and T_1 is the "critical time". This differential form is relatively simple, and its general characteristics are readily identified:

- When T is much less than T_1 such that (T_1-T) is much greater than t_x, well before the self-limiting effects are apparent, it reduces to the simple hyperbolic form : $dN/dT = t_xK^2/(T^2)$;

- The growth is progressively reduced below the hyperbolic rate, but still increases to a maximum at the critical time, $T= T_1$, when it is $dN/dT= K^2/t_x$;

- Beyond the critical time, when (T_1-T) is again much greater than t_x, the growth rate continues to decline, and the population approaches a stable maximum value as $N=N_{max} - t_xK^2/(T^2)$;

For an exact solution, the differential equation of growth can be converted to a dimensionless form by re-defining the time variable $t=(T_1-T)/t_x$, and the population variable as $n=N/K$; then $dn/dt = K^2/(t^2+1)$, and $n = -K^2 \tan^{-1}(t)+C$, (when $y = \tan^{-1}(x)$, this means $\tan(y) = x$, not $y = 1/\tan(x)$). C is a constant of integration determined by initial conditions – we have assumed N=0 at $T<< T_1$, therefore $C= K^2 \pi/2$.

[17] Information Society and the demographic revolution : the non-linear theory of growth of Humankind, Sergey P. Kapitza, Institute for Physical problems, RAS, Moscow, 2000

The differential and integral growth equations

$dN/dT = t_x K^2/((T_1 - T)^2 + t_x^2)$ where t_x , K and T_1 are constants.

Let $T_1 - T = t_x \tan O$, then $-dT/dO = t_x \sec^2 O$,

Then $dN/dT = dN/dO \times dO/dT = t_x K^2/(t_x^2 \tan^2 O + t_x^2) = t_x K^2/(t_x^2(\tan^2 O + 1))$,

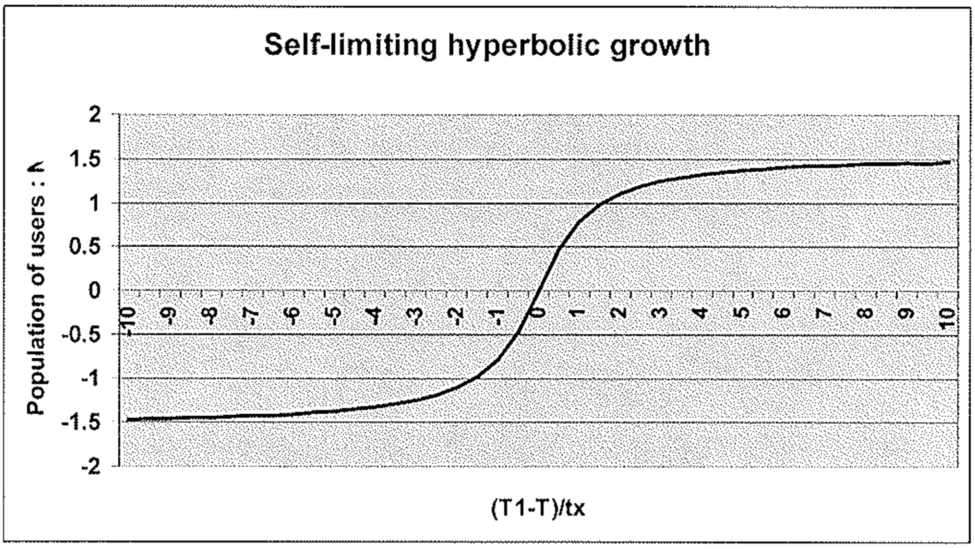
But, $\tan^2 O + 1 = \sec^2 O$,

So $dN/dT = t_x K^2/(t_x^2 \sec^2 O) \times (-t_x \sec^2 O)$,

Therefore $dN/dO = -K^2$ so $N = -K^2 O + C$ where C is a constant of integration depending on initial conditions;

Therefore $N = -K^2 \tan^{-1}((T_1 - T)/t_x) + C$

The graphical form of this formula is shown below



Or, one can use the substitution $T_1 - T = t_x \cot O$, then $-dT/dO = t_x \operatorname{cosec}^2 O$

And since $\operatorname{cosec}^2 O = 1 + \cot^2 O$, $dN/dO = +K^2$

$N = +K^2 \cot^{-1}((T_1 - T)/t_x) + C_1$ where C_1 is a different constant of integration. The graphical form is the same, but with $C_1 = C - \pi/2$.

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Technology Management and Economics

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Publications

A number of publications have resulted from CITISEN's research efforts so far. Below, we list published and forthcoming articles, books and reports. In addition to publications that have resulted from the program's work, relevant papers written by researchers associated with CITISEN and published before the program was established in 2002 are included in the list. Several of the publications can be downloaded (PDF-format); if an article is not available electronically, please contact Erik Bohlin (erbo@mot.chalmers.se) for requesting a copy.

Presented papers

1989

Bohlin, E., Granstrand, O., (1989), Strategic Options for National Monopolies in Transition: The Case of Swedish Telecom, paper presented at the European Regional Meeting of the International Telecommunications Society (ITS), Budapest, Hungary, August 30- September 1, 1989.

1990

Bohlin, E., Granstrand, O., (1990), Investment Appraisals and Diffusion of New Communications Technology: The Case of Swedish Telecom, paper presented at the Eighth Biennial International Conference of the International Telecommunications Society (ITS) in Venice, March 18-21, 1990, and in slightly revised form at the 18th Annual Telecommunications Policy Research Conference (TPRC), Airlie House, Airlie, Virginia, September 30-October 2, 1990.

Bohlin, E., (1990), Techno-Economic Management of Investments in Telecommunications Networks, Licentiate Dissertation, Chalmers University of Technology, CIM-Report 1990:08.

1991

Bohlin, E., Granstrand, O., (1991), Strategic Options for National Monopolies in Transition: The Case of Swedish Telecom, Telecommunications Policy, Vol. 15, No. 6, pp. 453-476, 1991.

1992

Bohlin, E., (1992), Appraising Investments in New Telecom Technologies: The Case of Swedish Telecom, Prometheus, Vol. 10, No. 1, pp. 30-52, 1992.

Bohlin, E., de Fontenay, A., (1992), Investment Management and the Role of Information Asymmetries: Theory and the Case of Swedish Telecom, paper presented at the Ninth Biennial International Conference of the International Telecommunications Society (ITS), Sophia Antipolis, June 15-17, 1992.