Study on Broadband Penetration

Prof. Ryszard Struzak, NIT PL

Studies

- Poland
  - Rozwój szerokopasmowego internetu w Polsce – trendy i granice wzrostu; TiTI Nr. 1-2/ 2009, pp. 38-48
- EU
  - Broadband Internet in EU Countries: Limits to Growth; IEEE Communications Magazine, April 2010, pp. 53-57
  - Diffusion of Broadband Services: An Empirical Study; IEEE Communications Magazine, August 2012, pp. 129-134
- OECD
  - Perspectives of Household Internet in 35 Countries; Proc. of XXVIII National Symposium on Telecommunications and Tele Informatics, Warsaw 12-14 September 2012 (KSTiT 2012)

- Beware of misprints! These materials are preliminary notes intended for my lectures only and may contain misprints.
- Feedback is welcome: if you notice faults, or you have improvement suggestions, please let me know.
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- If you cite these materials, please credit the author and ICTP.
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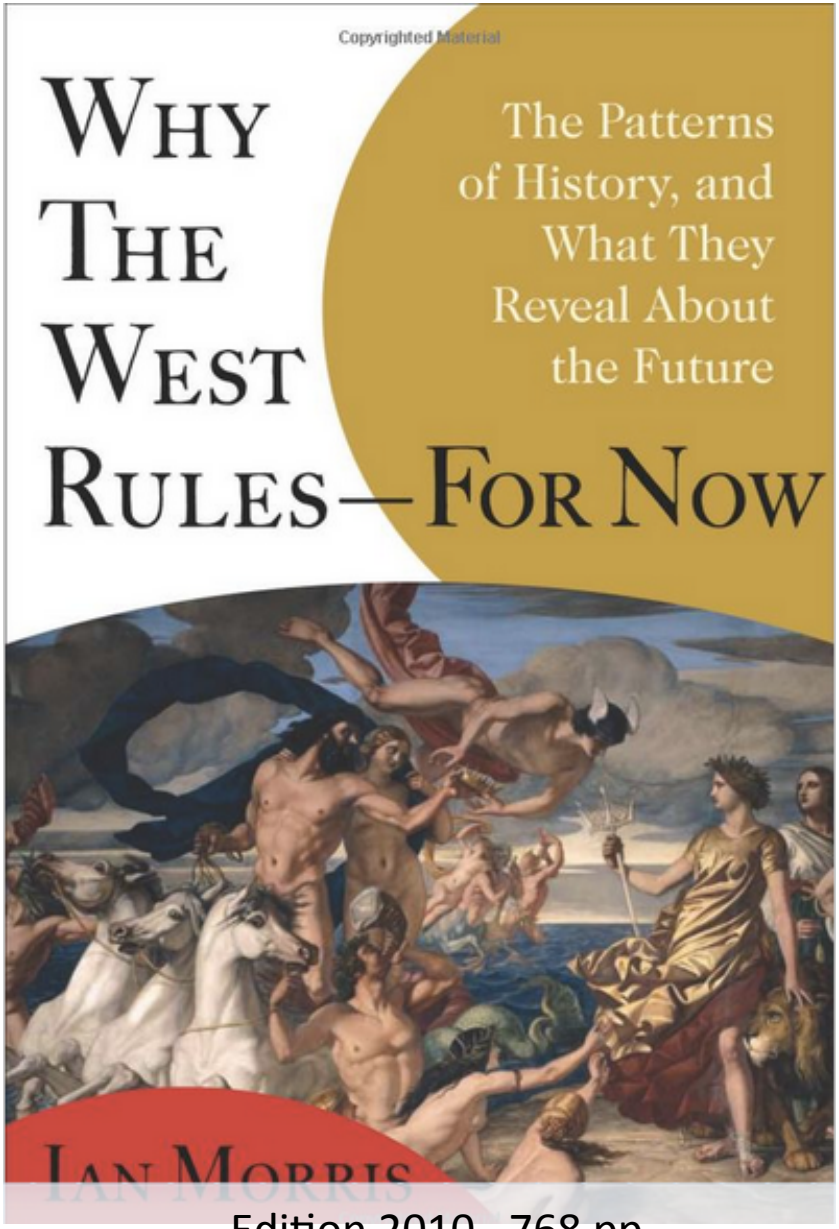
Outline

- Introduction
- Models
- Application examples
- Summary



Edition 2010, 768 pp.

Ian M. Morris (1960 -)

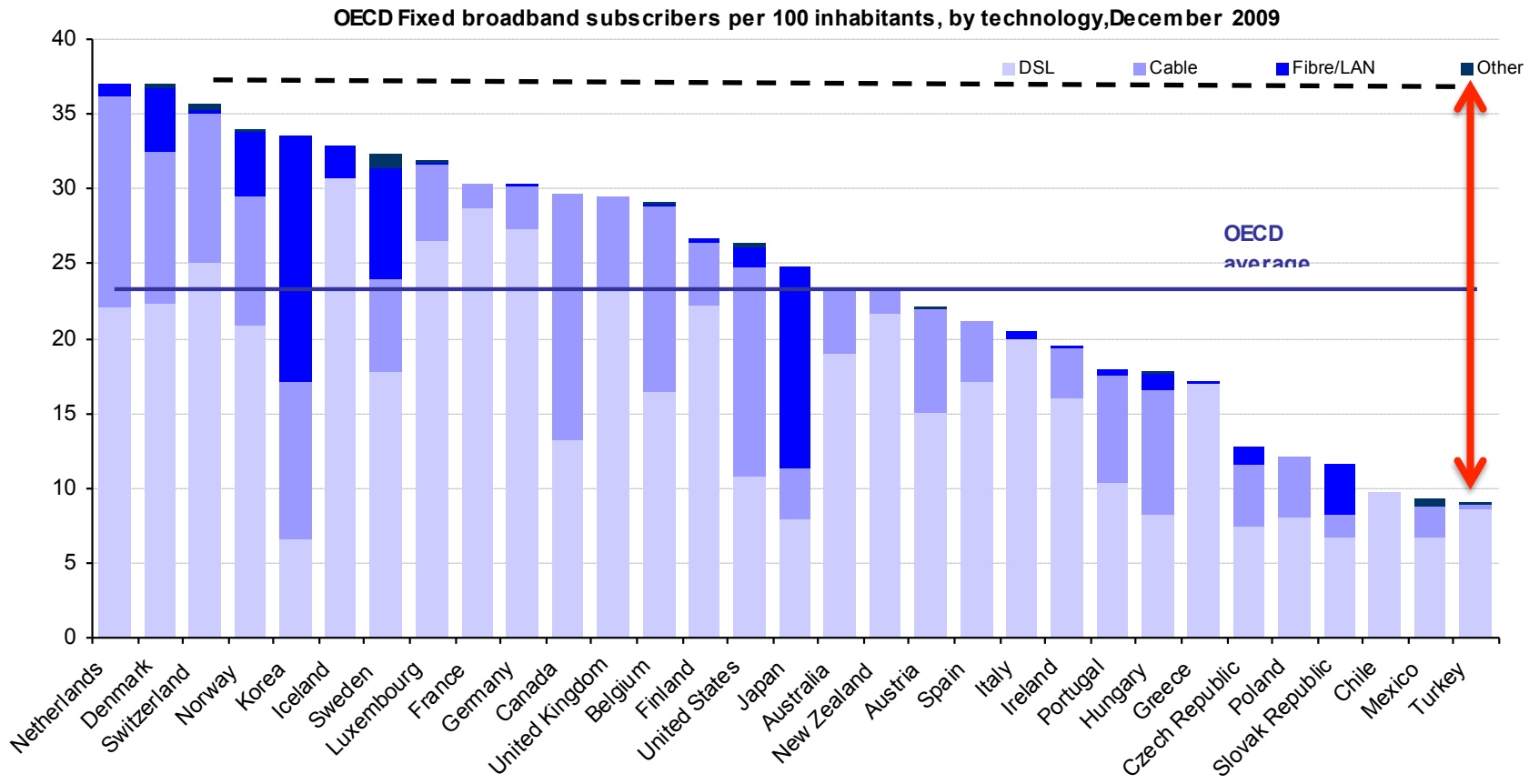
- … during the next 50 years the socio-technological development of humanity will be 2 times greater than during the previous 15 000 years …

- … in the next 50 years it will double again …
- … the XXI century will assure immediate access to all information and knowledge gathered on the Earth till now …

- … their brains will be interconnected
  with a gigantic computer
  and their capacity will be billions times greater
  than the total computing power
  of all brains and computers today …

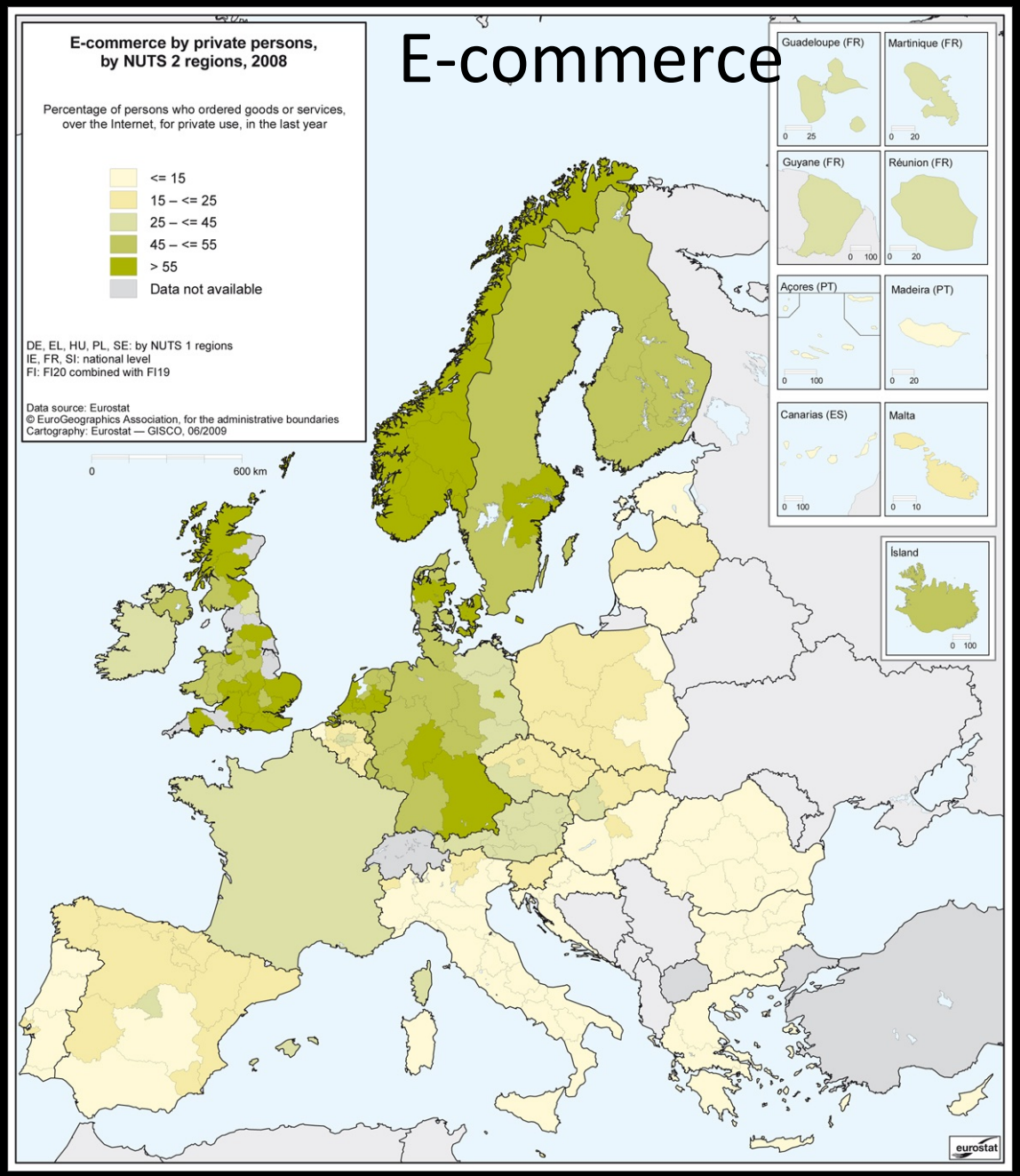
Geography

Bb. penetration rate in OECD (2010)



Source: OECD (Jan 2010)

E-commerce



Popularity of broadband services varies among the lowest administrative units

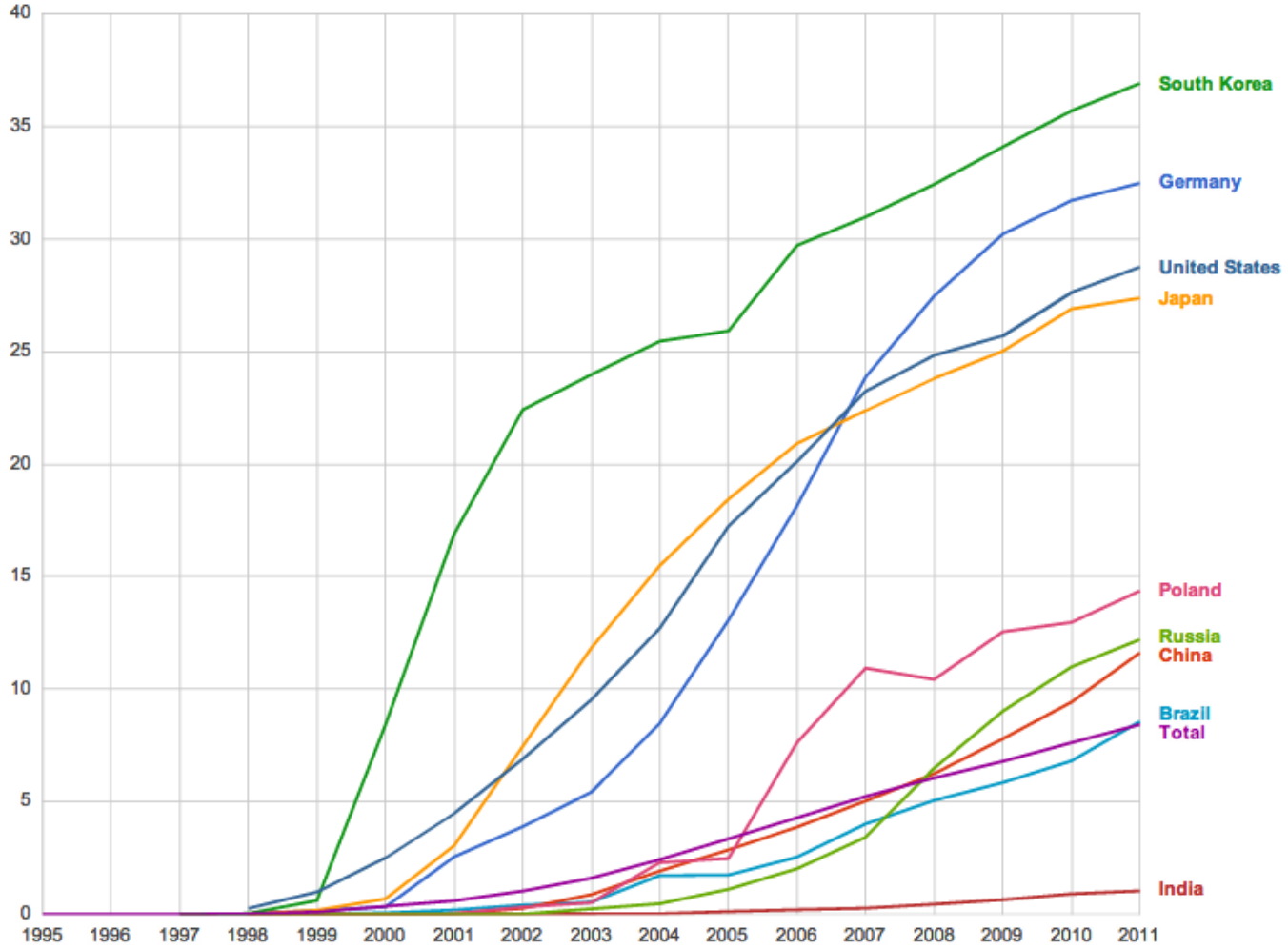
The aid is not distributed following reasonable and transparent rules

Models could help

Time

Fixed (wired)-broadband subscriptions per 100 inhabitants

(Source: http://www.itu.int/ITU-D/ict/, statistics/explorer/index.html; accessed 1 September 2012)



Broadband services are relatively new

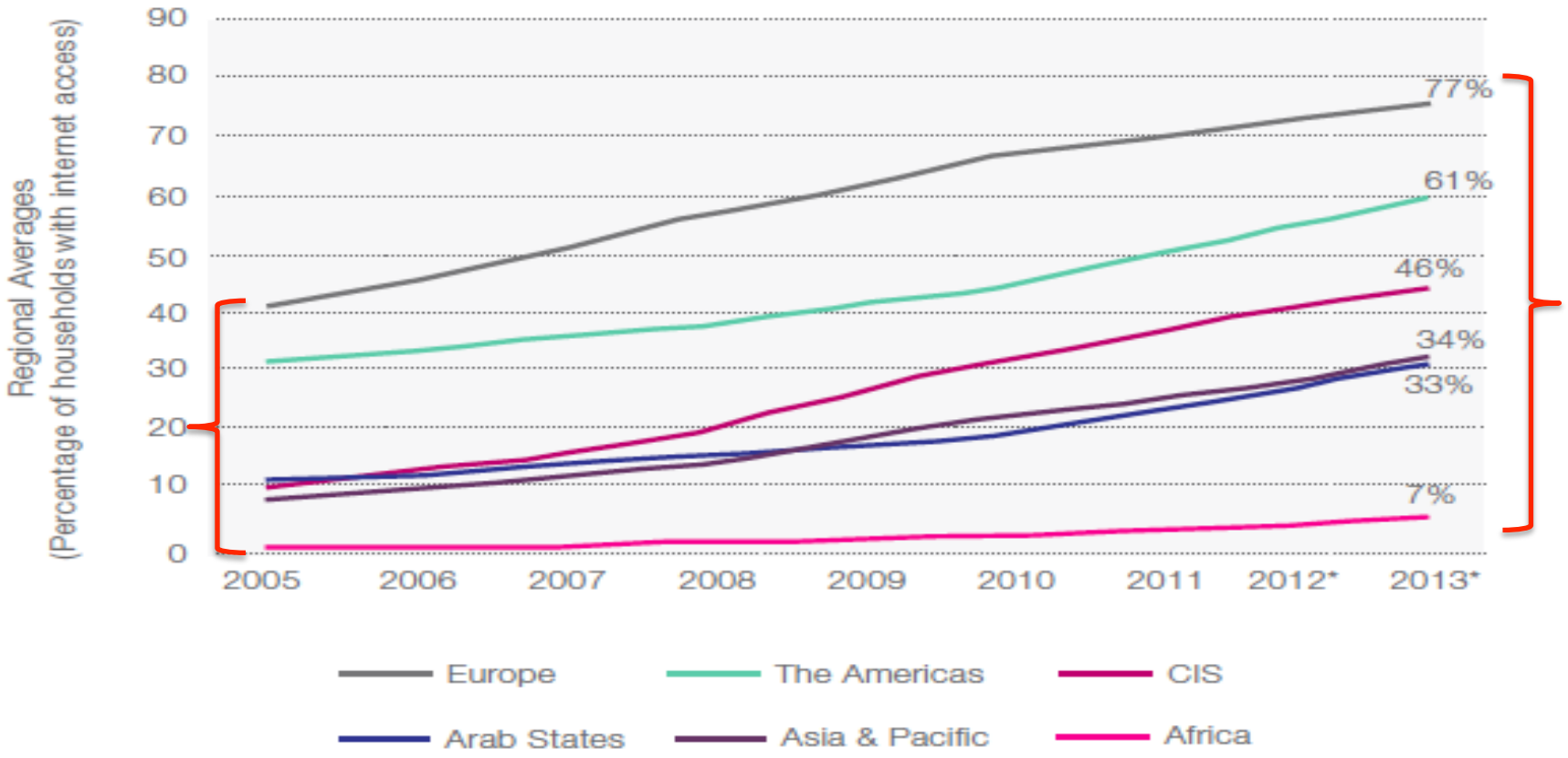
Free-market produces diversity

How long the "digital gaps" will continue?

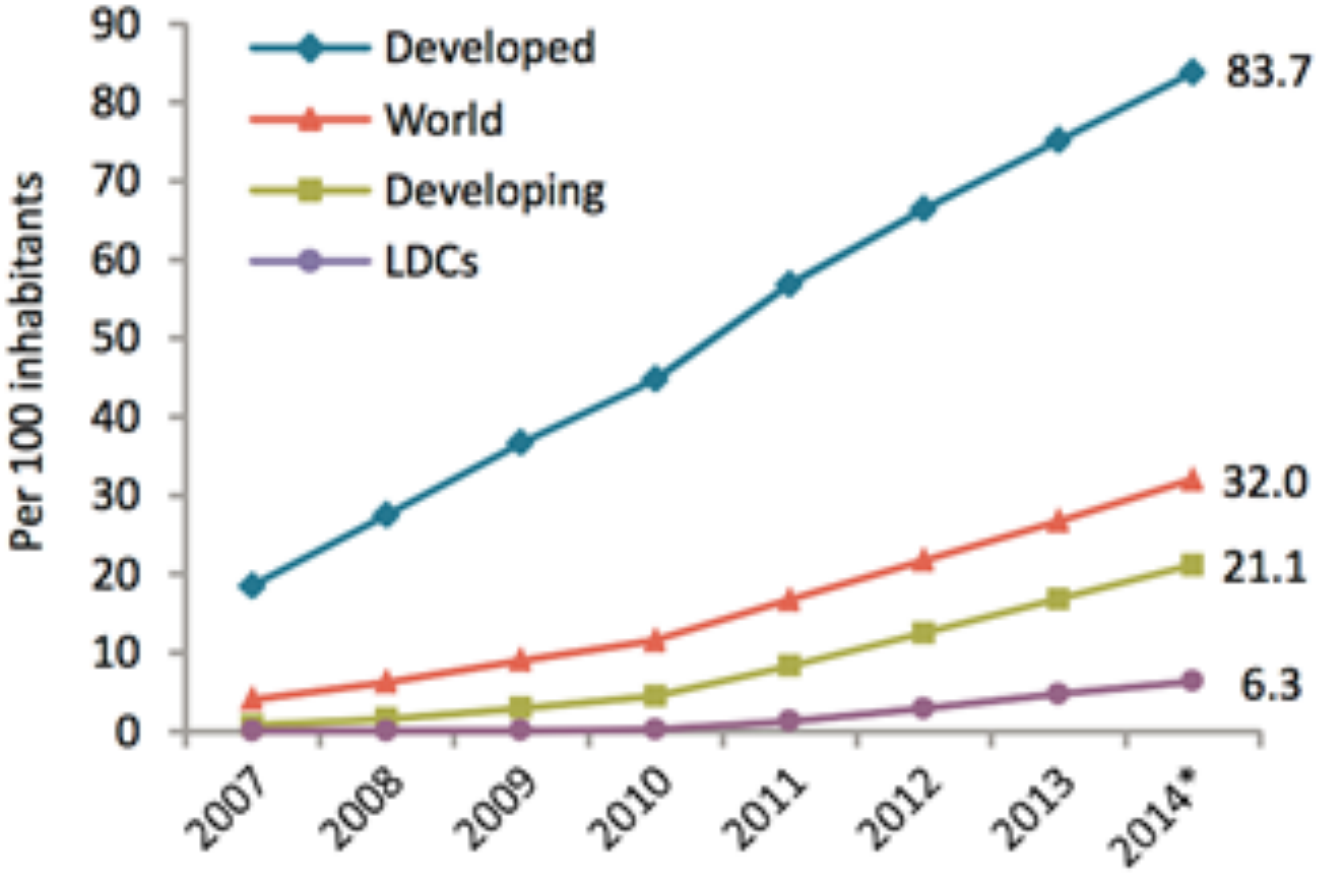
Are they reducible?

Households with Internet Access (2005-2013)

Regional Averages



Source: The State of Broadband 2013: Universalizing Broadband. A report by the Broadband Commission, ITU & UNESCO Sept. 2013 (T.3)


Per 100 inhabitants
90
80
70
60
50
40
30
20
10
0
Developed
World
Developing
LDCs
83.7
32.0
21.1
6.3
2007
2008
2009
2010
2011
2012
2013
2014*

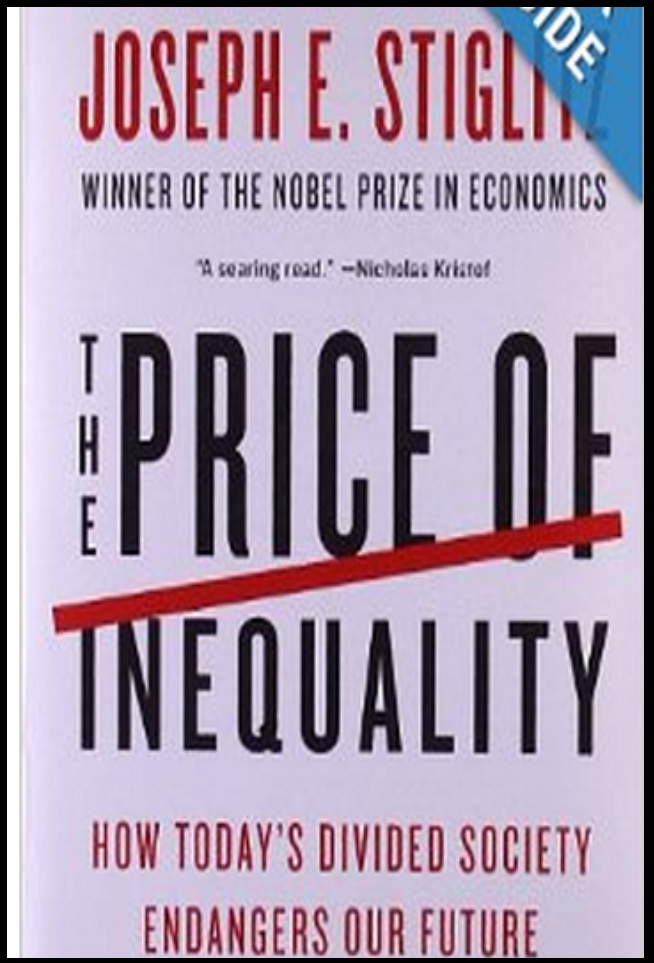
- Will the gaps ever vanish?
- As the raw statistical data do not directly answer this intriguing question, I proposed a simple approach that leads to a reasonable answer – via a mathematical model

- The growth of the Information Society and Internet diffusion can be compared to a course of virtual illness, where infected people become Internet users.
- In case of real diseases we would like to be all 100 percent immune; hence vaccinations and other preventive measures.

- With Internet diffusion the aim of governmental policies is o have 100 % of the population “infected”.
- In studying diseases differential equations have been successfully used, but such an approach cannot be applied to Internet because of the lack of necessary data.
    - M. Keeling: “The Mathematics of Diseases” Plus Mag., Mar. 2001, p. 3–8.

- "Everyone, everywhere should have the opportunity to participate

- … no one should be excluded from the benefits of the Information Society offers."
  - The WSIS Declaration of Principles, 2003, item #4

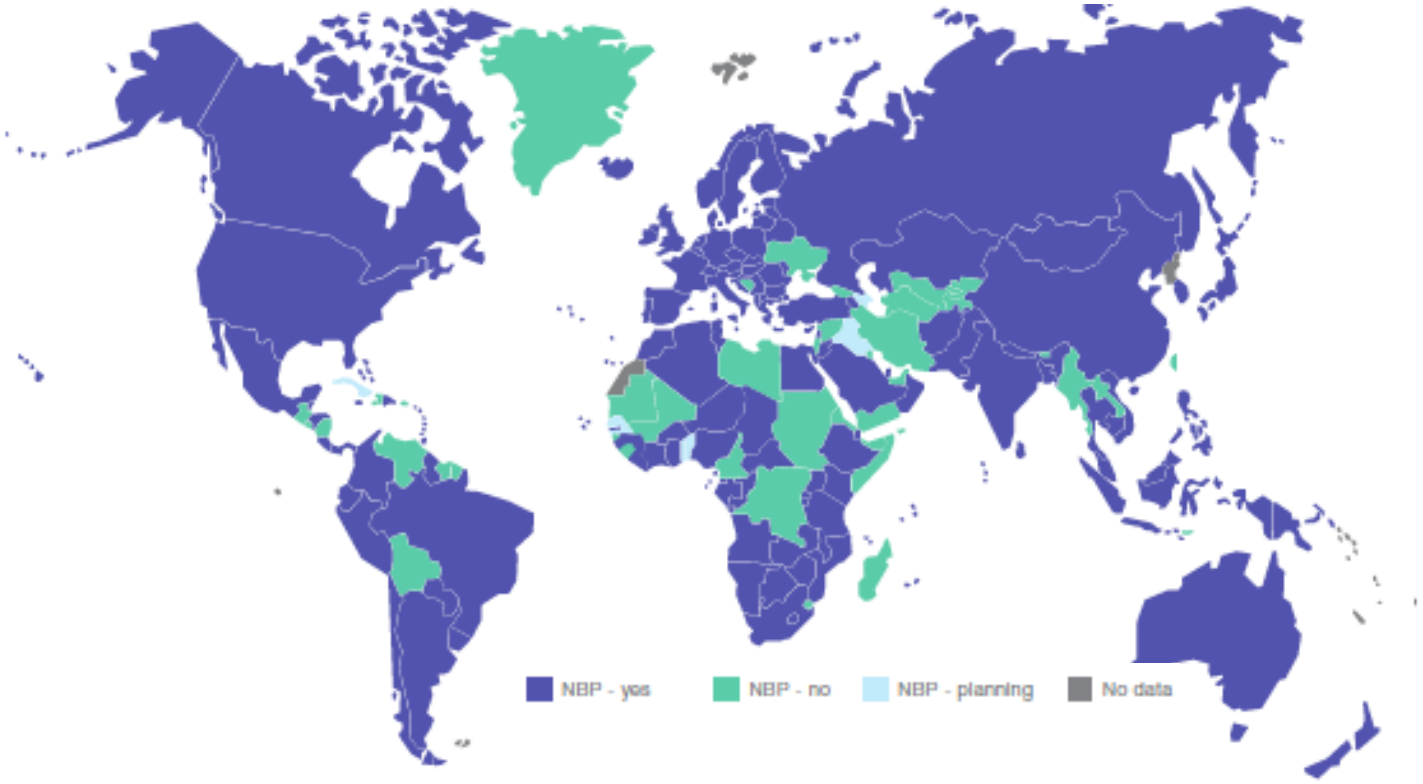


OECD Council recommends:

- *"Governments should focus […] on improving […] analysis to better understand new usage trends, their impacts on the economy and society as well as policy."* OECD Publications (2008); ISBN 978-92-64-04668-9-No. 56221

- National Broadband Plans are under discussions
  - Plans ignore the inherent limits to growth

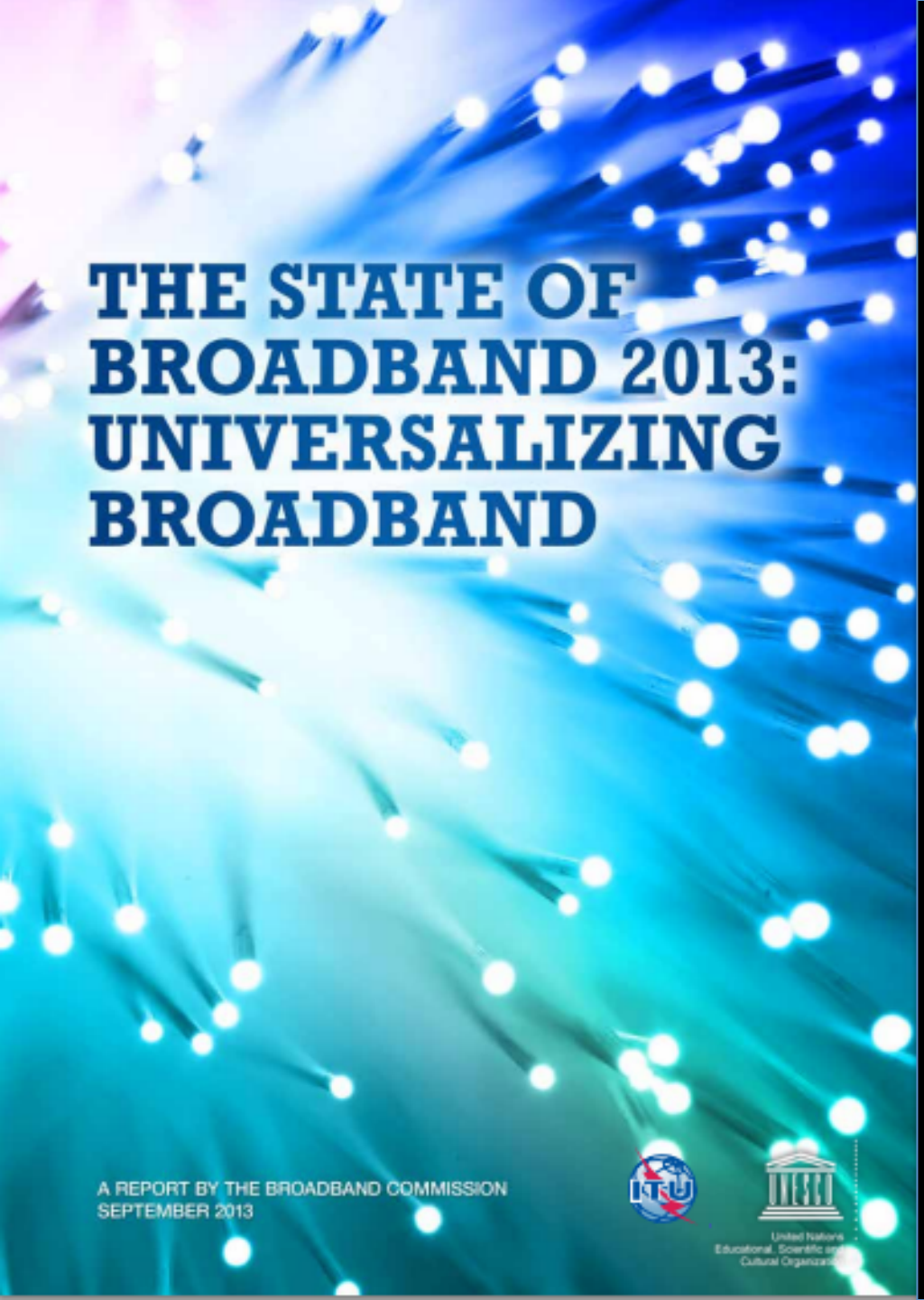
National Broadband Plans (2013)



Source: The State of Broadband 2013: Universalizing Broadband - A report by the Broadband Commission, September 2013

Broadband Commission: by 2015, Internet user penetration should reach 60%worldwide, 50% in developing countries and 15% in LDCs.

http://en.wikipedia.org/wiki/National_broadband_plans_from_around_the_world



UNESCO & ITU 2013

… broadband connectivity, services and applications are essential to modern society, offering widely recognized social and economic benefits.

… the Commission views broadband as a cluster of concepts: always on, high-capacity connectivity enabling combined provision of multiple services …

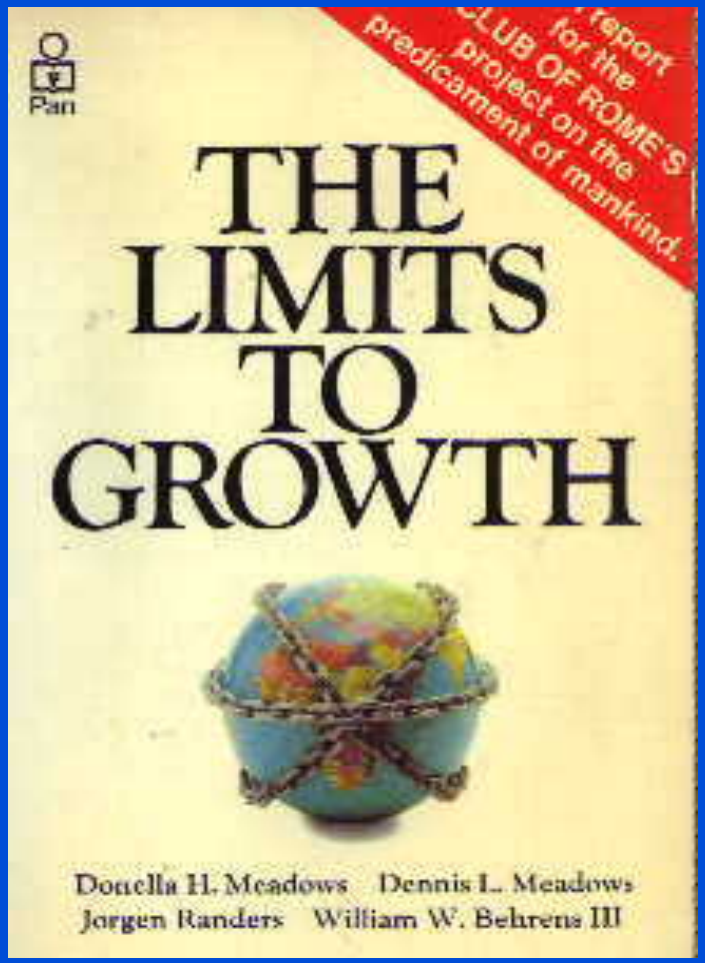
www.broadbandcommission.org/Reports

http://en.wikipedia.org/wiki/National_broadband_plans_from_around_the_world

Limits to growth

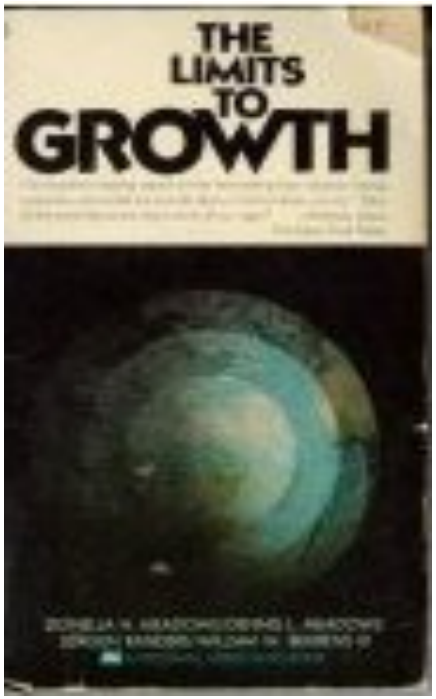
- Countries develop, but the digital divide increases faster

- Is there any natural limit?

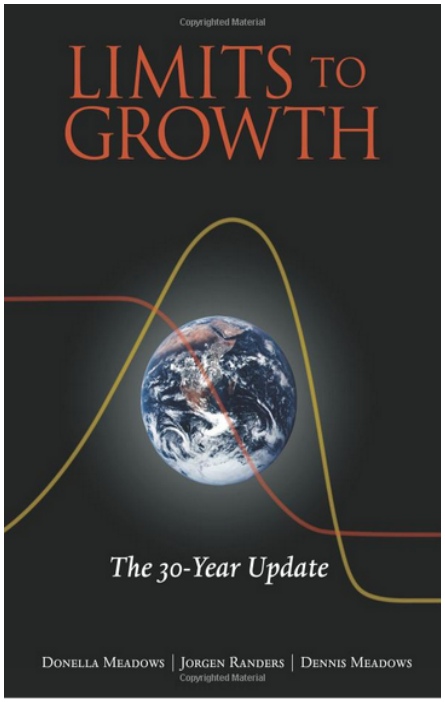


Inherent limits to growth

Discussions on limits to growth have started in the 18th century (T. Malthus). Apparently the most popular publications are those of the "Club of Rome"



1972



2004

"Once the limits to growth were far in the future.

Now they are widely in evidence …"

Consequences of ignoring the limits:

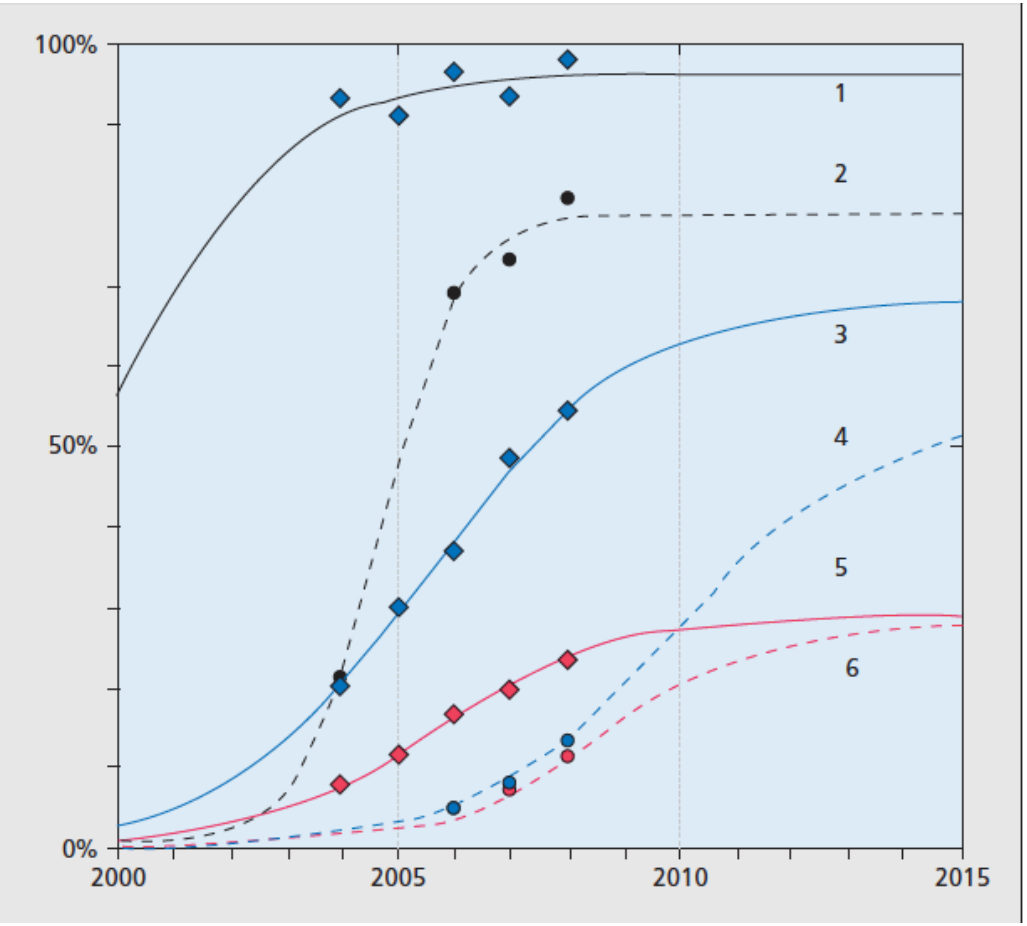
- Wrong targets
- Unrealizable projects
- Increased costs
    - due to delays and necessary corrections
- Frustrations
- Eroding confidence
  - in the competence of experts & politicians that propose (or endorse) such unrealizable projects

- Mathematically, Internet growth can be compared to
  - colonization of a host organism by a parasite
  - epidemic development of infectious disease, where pathogenes are transmitted from one person to another
  - growth of human population
    - Thomas Malthus (1776 – 1834)
    - Pierre François Verhulst (1804–1849) → Logistic Model

Country data ingested

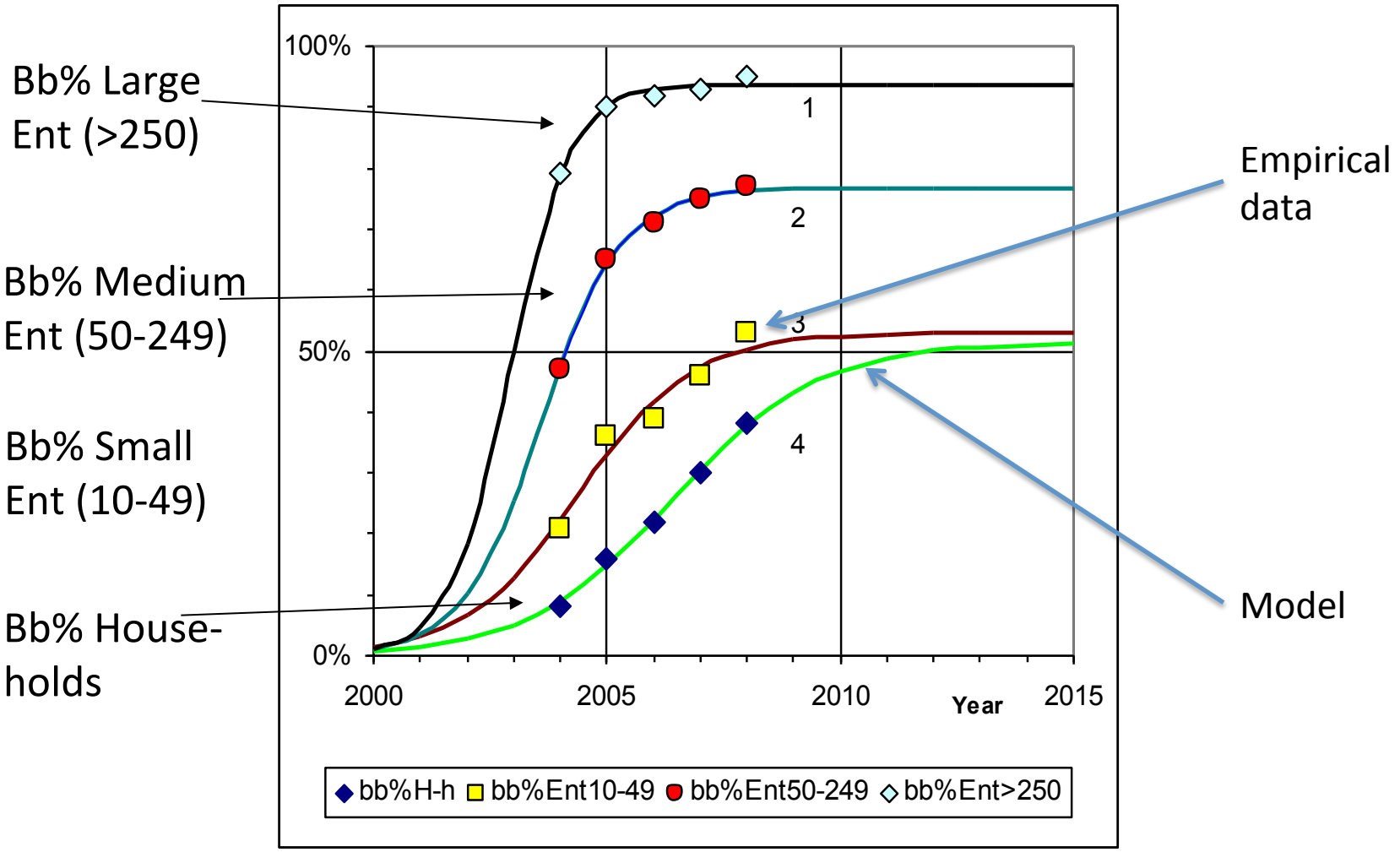
Australia
Austria
Belgium
Bulgaria
Canada
Cyprus
Czech Rep.
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Japan
Latvia
Lithuania
Luxemburg
Malta
Mexico
Netherlands
Norway
Poland
Portugal
Rep. of Korea
Romania
Slovakia
Slovenia
Spain
Sweden
U. Kingdom
United States

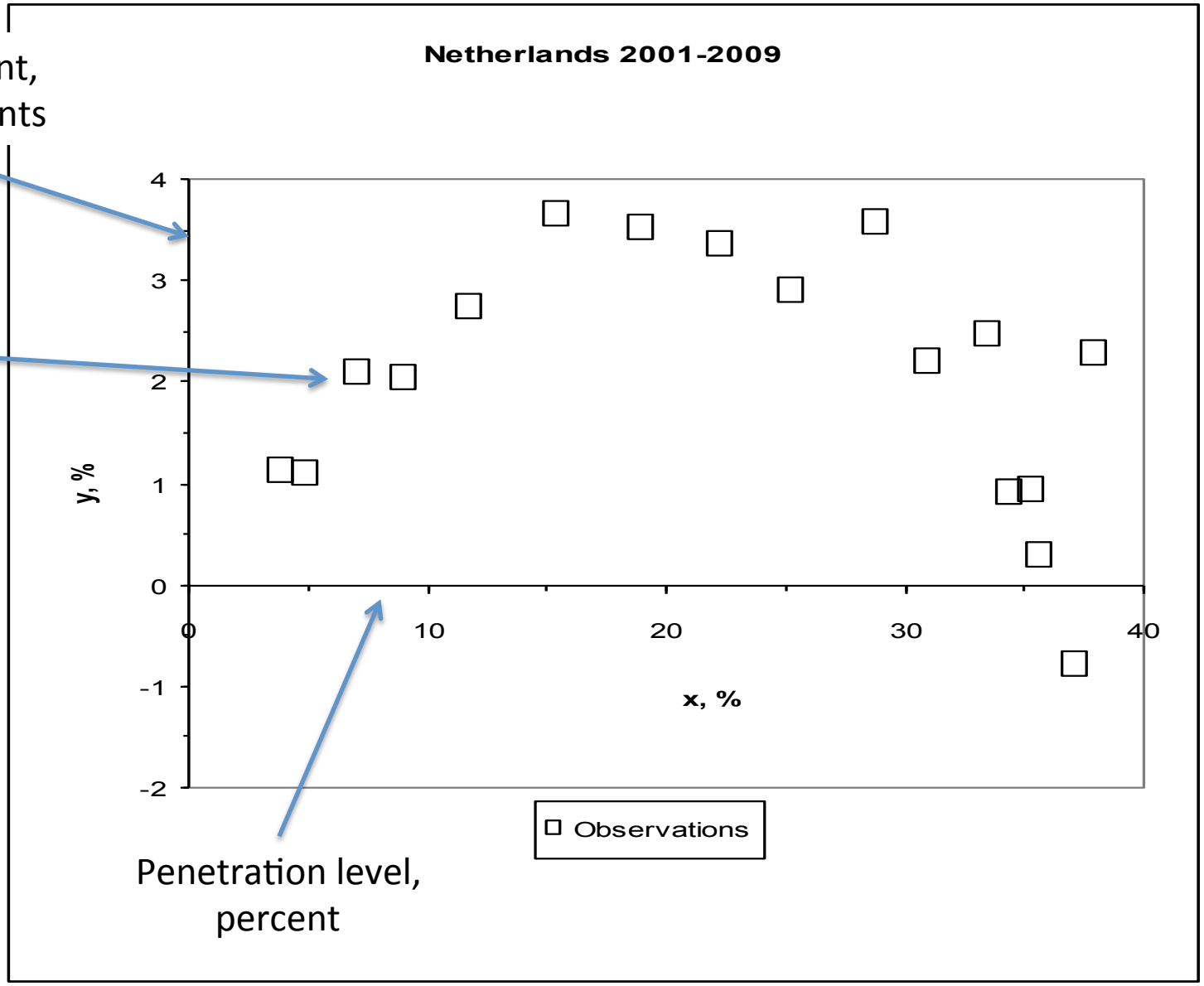
Bb Internet diffusion: Estonia vs. Romania



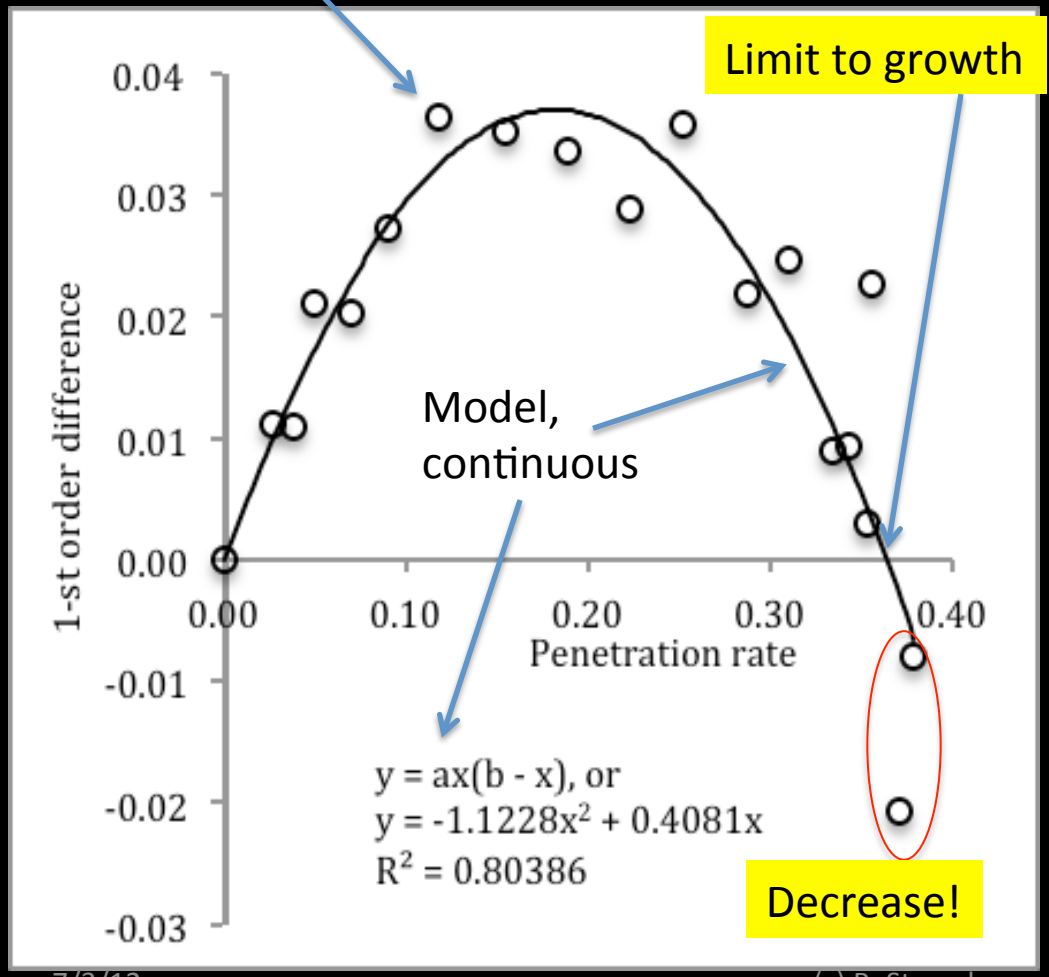
Estonia - continuous lines
Romania –
1 and 2: percentage of large enterprises connected to a broadband network;
3 and 4: percentage of households connected to a broadband network;
5 and 6: the penetration rate of broadband.
Source: R. Struzak, IEEE Comm. Mag. April 2010, pp. 53-57

Inherent limits (PL 2000 – 2015)




Netherlands 2001-2009
Yearly increment, percentage points
Emirical data points
Penetration level, percent
y, %
x, %
4
3
2
1
0
-1
-2
0
10
20
30
40
Observations

Penetration rate analysis (Netherlands 2000-2010)



R^2 (coeff. of determination) is a standard measure of the match between the model and observations

$R^2 = 1$: the model perfectly matches the data and explains fully their variability.

$R^2 = 0$: model and observation are completely unrelated.

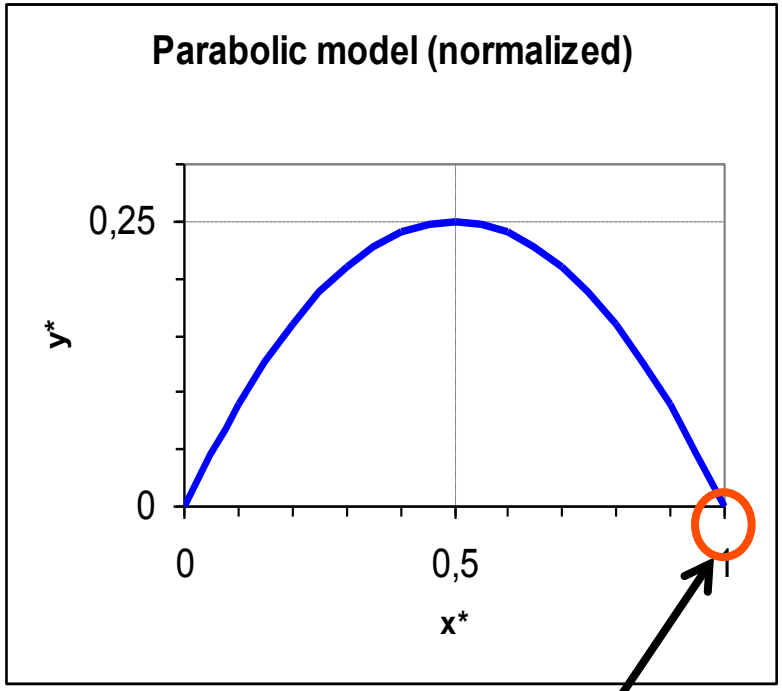
$0 < R^2 < 1$: some observations do not fit the model.

1-st order differential & difference equations

$$\left.\begin{aligned}\frac{\Delta x}{\Delta t} &\approx \\ \frac{dx}{dt} &\approx\end{aligned}\right\} = ax(b - ax)$$

After nomalization:

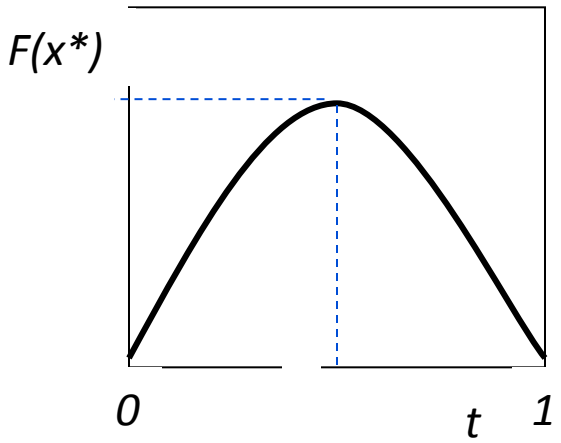
$$\left.\begin{aligned}\frac{\Delta x^*}{\Delta t} &\approx \\ \frac{dx^*}{dt} &\approx\end{aligned}\right\} = x^*(1 - x^*)$$



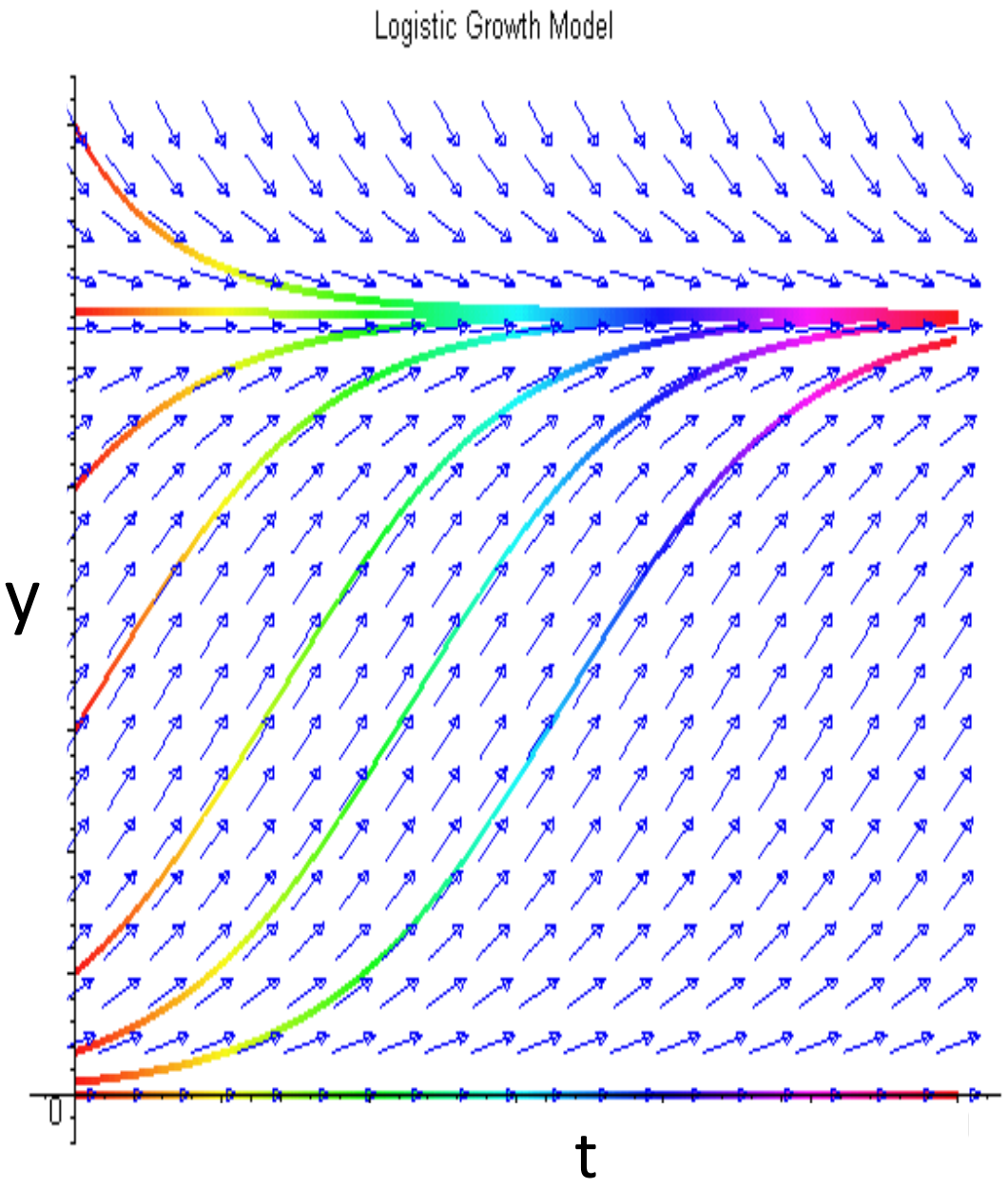
Limit to growth

$$\frac{dx^*}{dt} = f(x^*)$$

$$f(x^*) = y(1-y)$$



$$y(t) = a\frac{1}{1+\exp(-t)}$$



Continuous model (normalized)

Differential equation:

$$\frac{dx}{dt} = x(1-x)$$

Continuous logistic model:

$$x(t) = \frac{1}{1+\exp(-t)}$$

Difference equation:

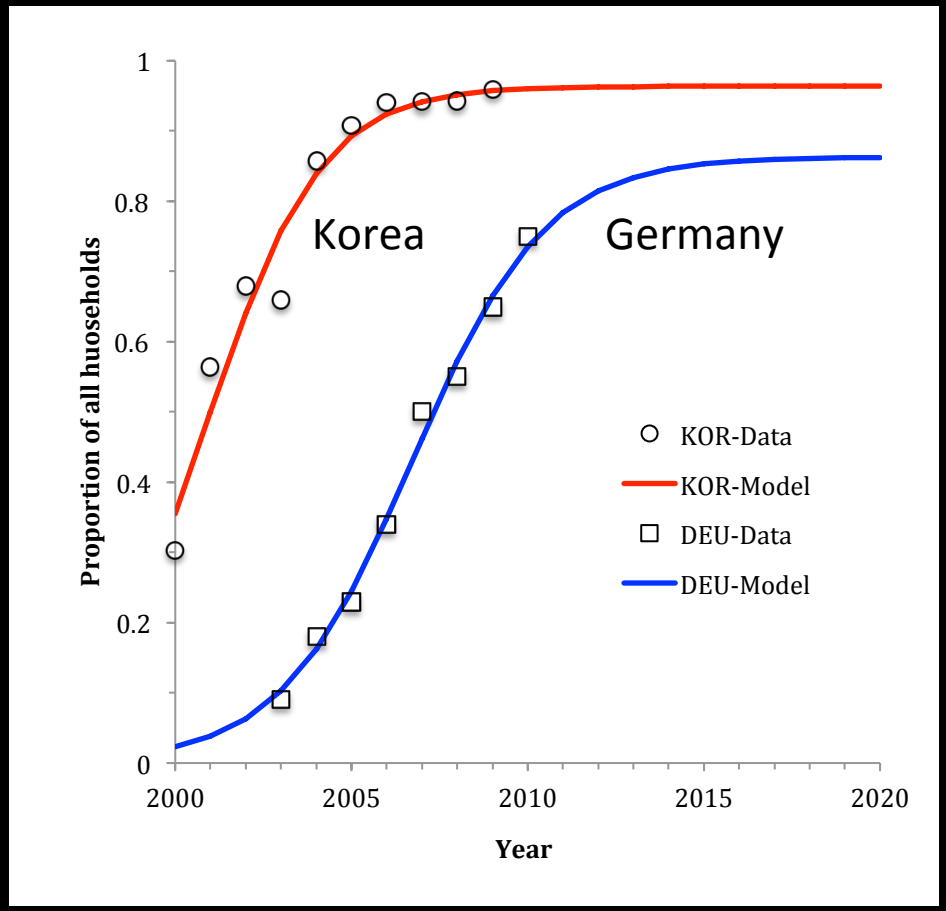
$$\frac{\Delta x}{\Delta t} = x(1-x)$$

Discrete logistic model:

$$x(t+\Delta t) = rx(t)[1-x(t)]$$

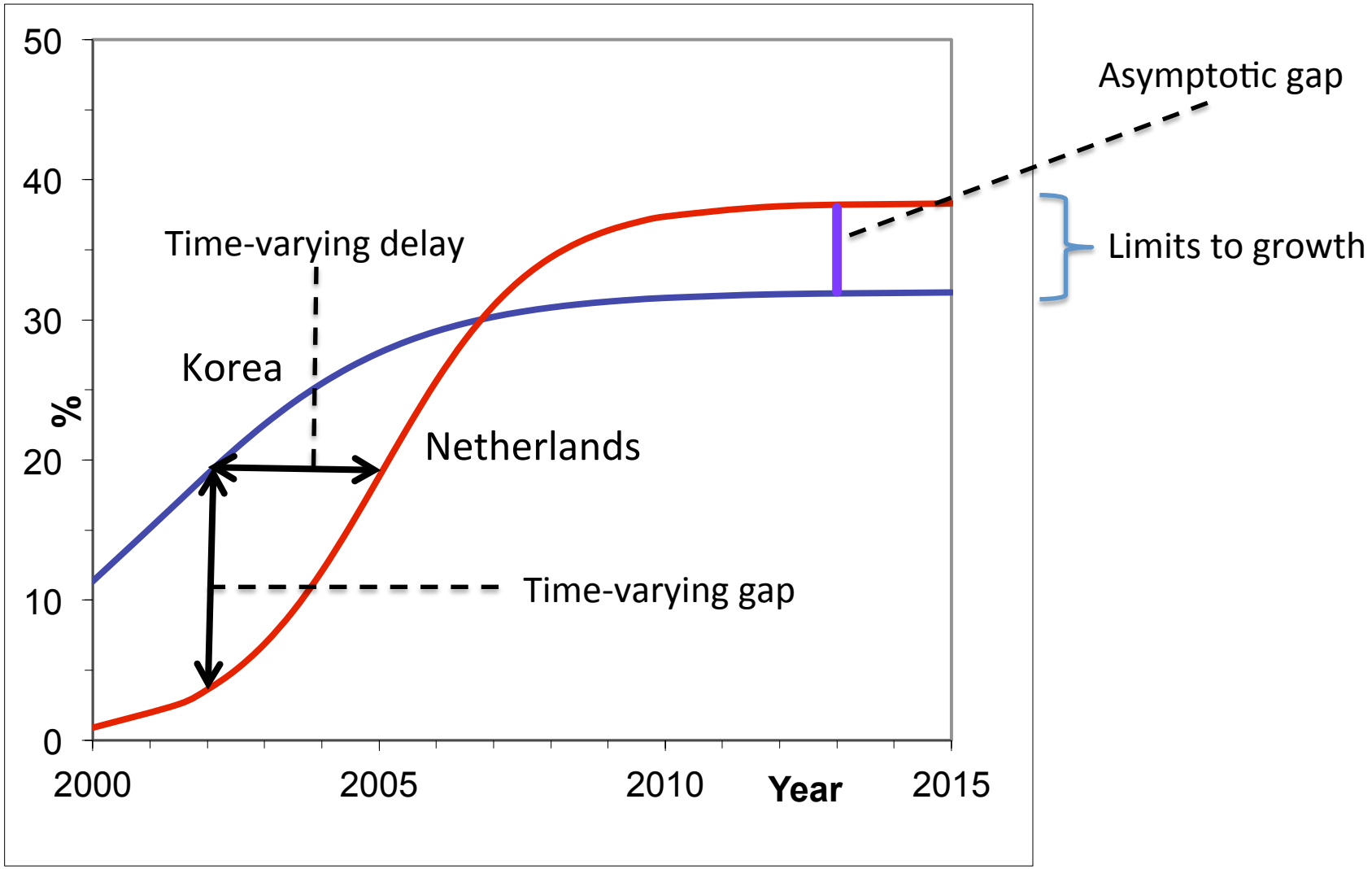
Continuous models

$$x(t) = \frac{a}{1 + \exp[b(c - t)]}$$

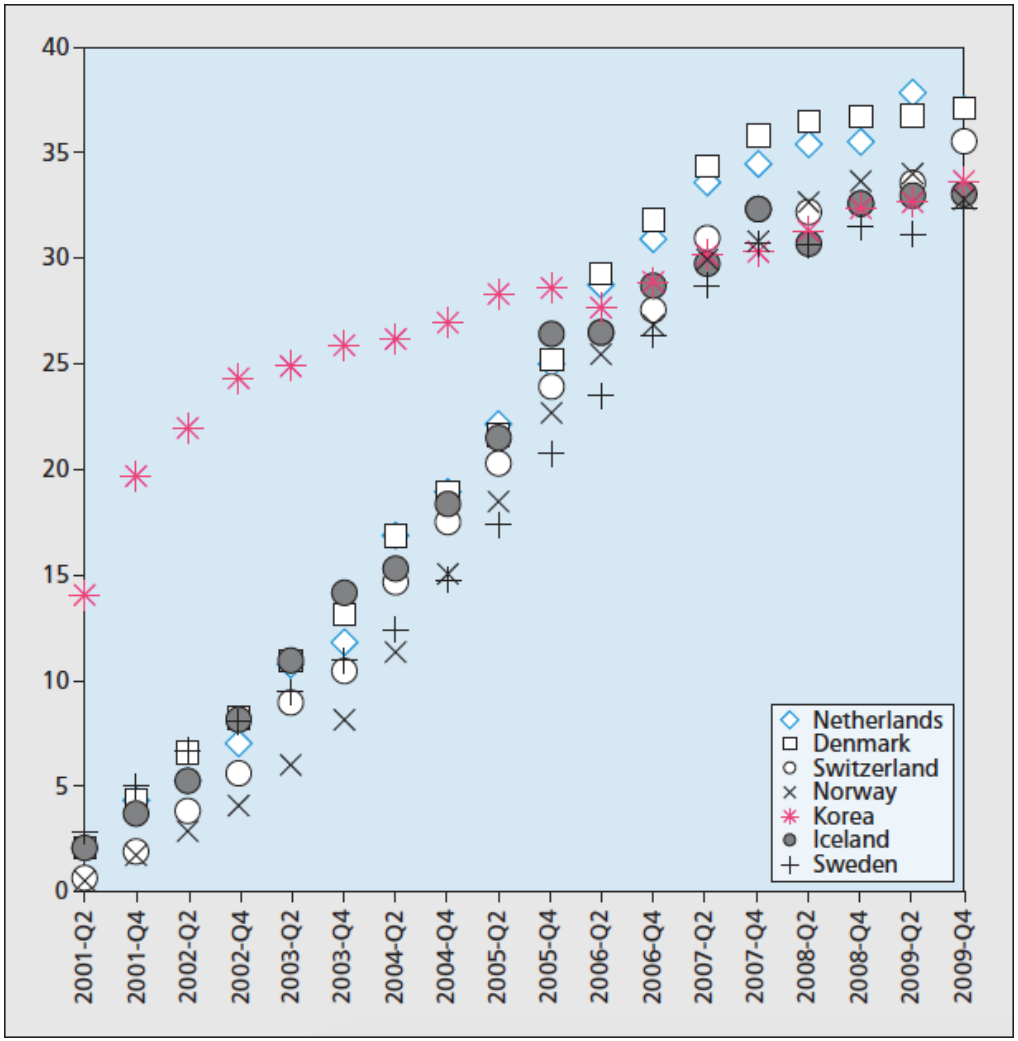


- Numerical values of a, b, c represent all the relevant factors: financial, technical, regulatory, cultural, etc.
- They are determined individually for each country

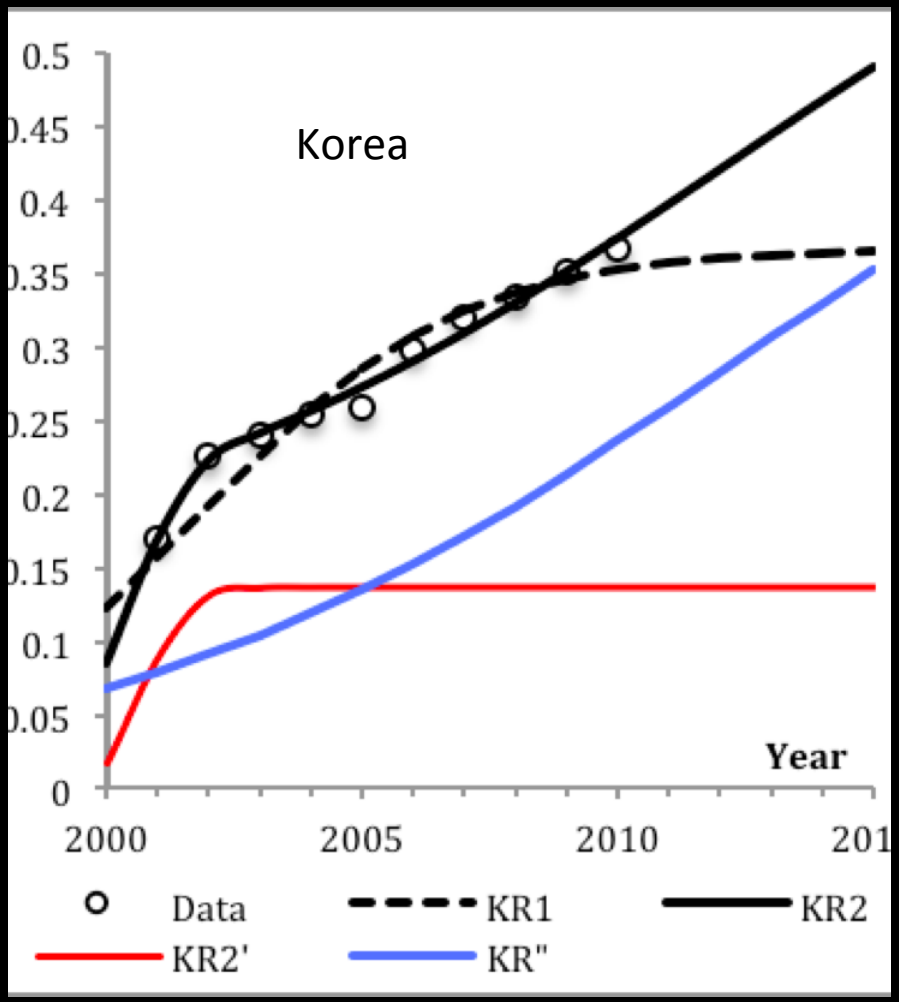
Penetration models: delays & gaps



Bb penetration in 7 countries



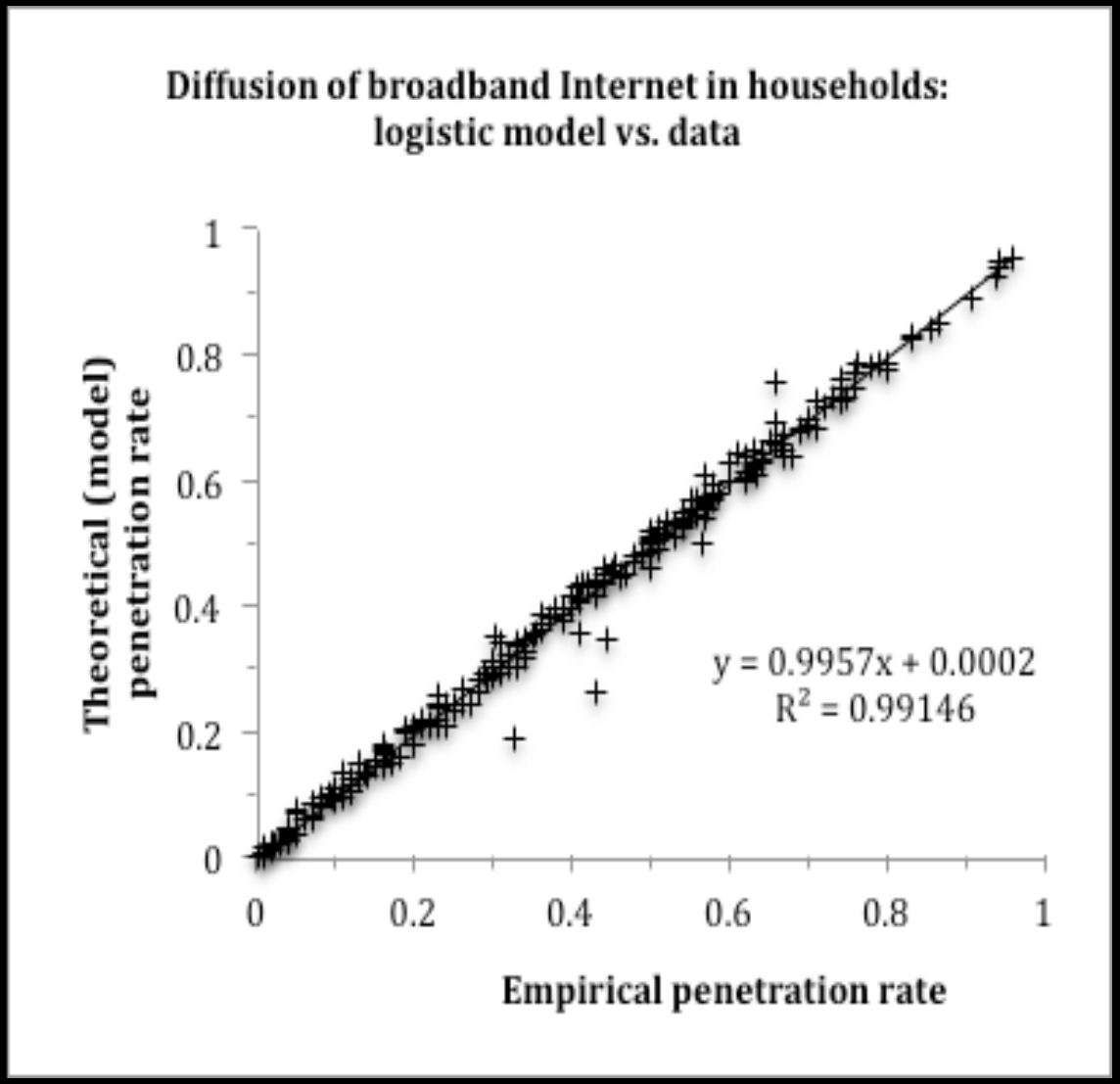
Multiple logistic models



- The logistic function cannot approximate decreasing trends
- Two (or more) logistic functions can model both increasing and decreasing trends

$$p = \sum_{i=1}^{N} \frac{a_i}{1 + \exp[b_i(c_i - t)]}$$

Comparison of models and data

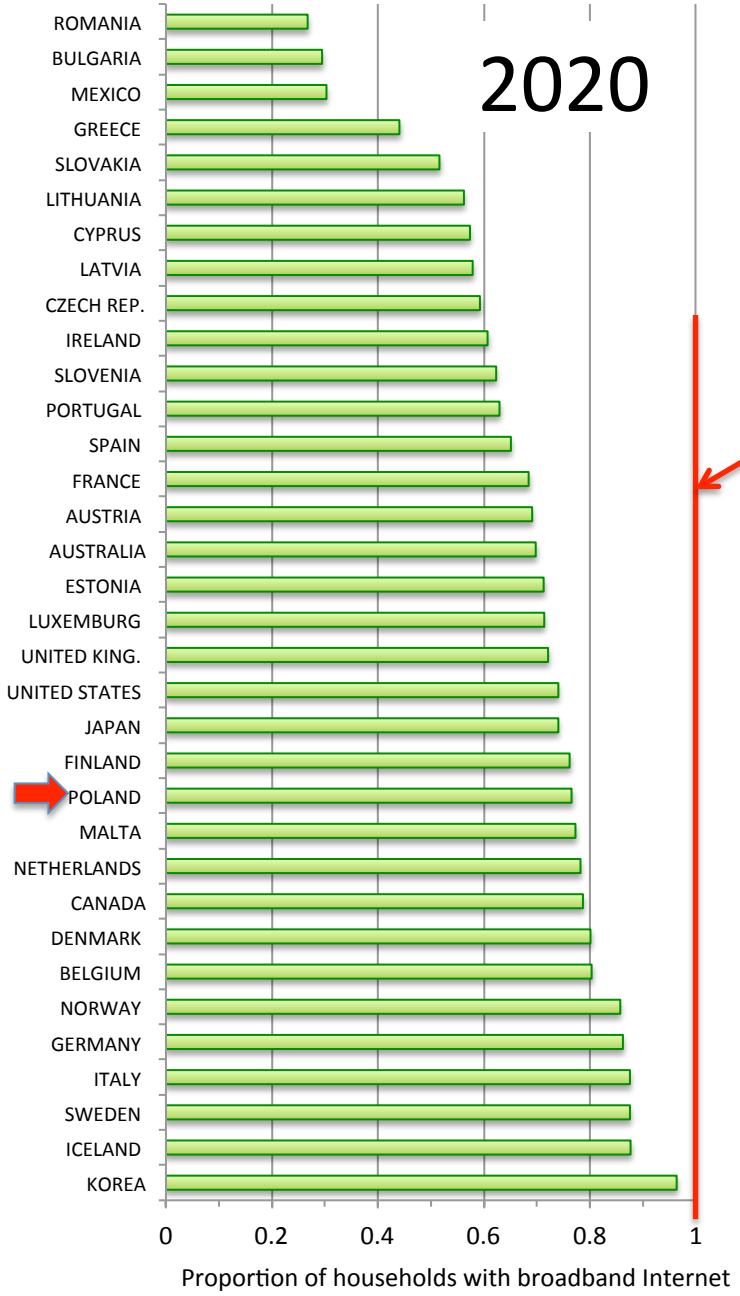


10 years
35 countries
240 data-points

The models match empirical data very well

Outline

- Introduction
- Models
- Application examples
- Conclusions & Future work



EU target 2020

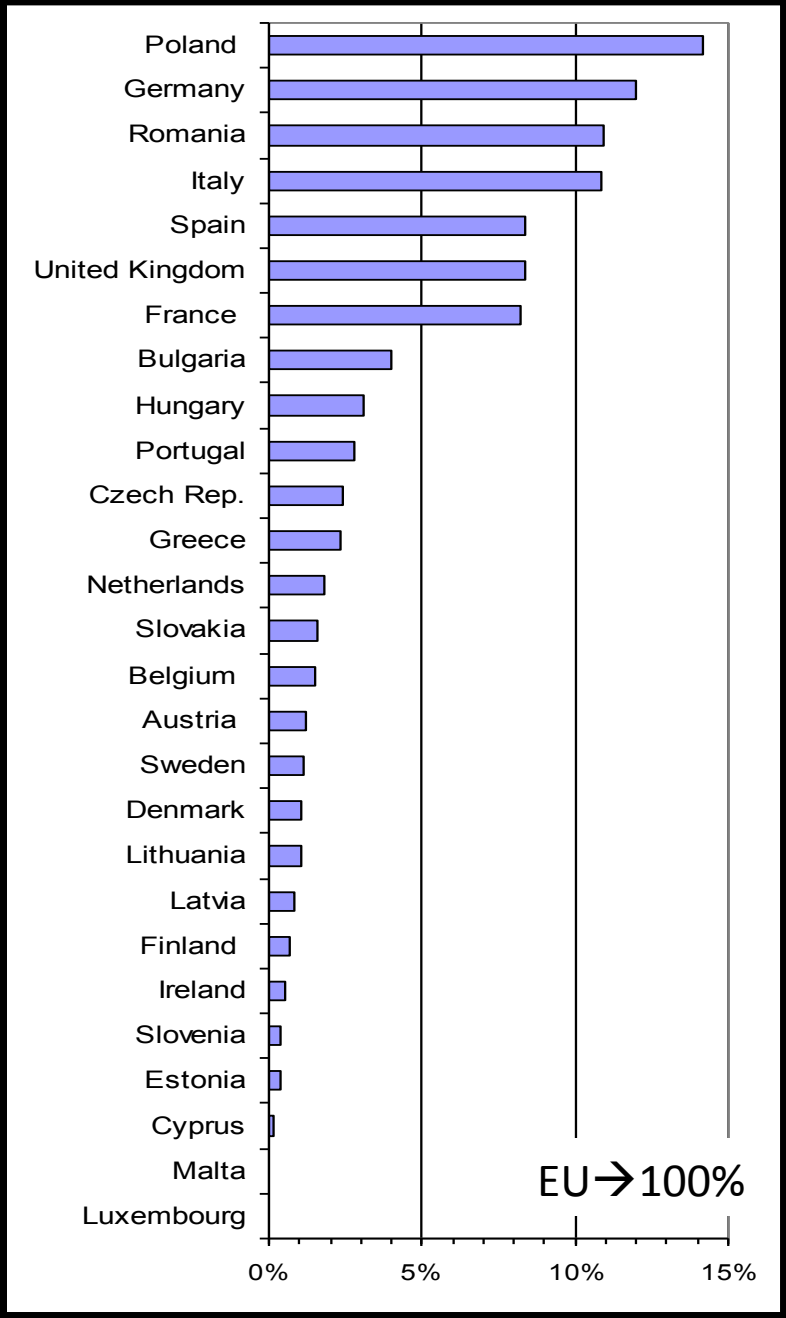
- The EU 2020 target: 100% of households (30 Mbytes/s)

  (and > 50% with 100 Mbytes/s.)

- No EU country can reach the target in present conditions

  (with the standard >256 kb/s.)

- The targets must be changed, or the free-market mechanism must be complemented by extra aid



Distributing the EU aid

- Reaching an uniform penetration rate means diversified aid
- The models can help in the distribution of aid in a reasonable and just way

Source: R Struzak: „*Broadband Internet in EU Countries: Limits to Growth*"; IEEE Comms. Mag. Apr.2010

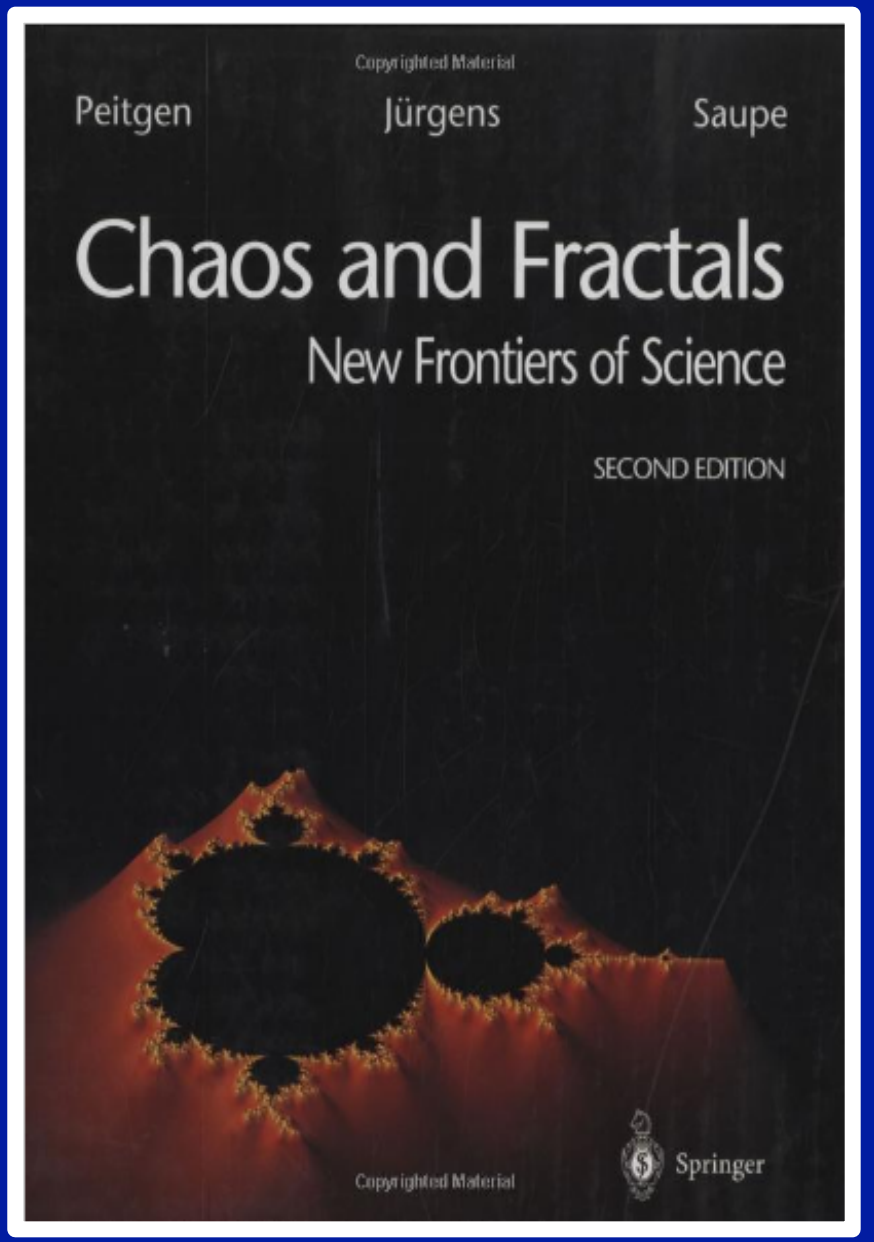
Discrete Models (normalized)

Difference equation:

$$\frac{\Delta x}{\Delta t} = x(1-x)$$

Discrete logistic model:

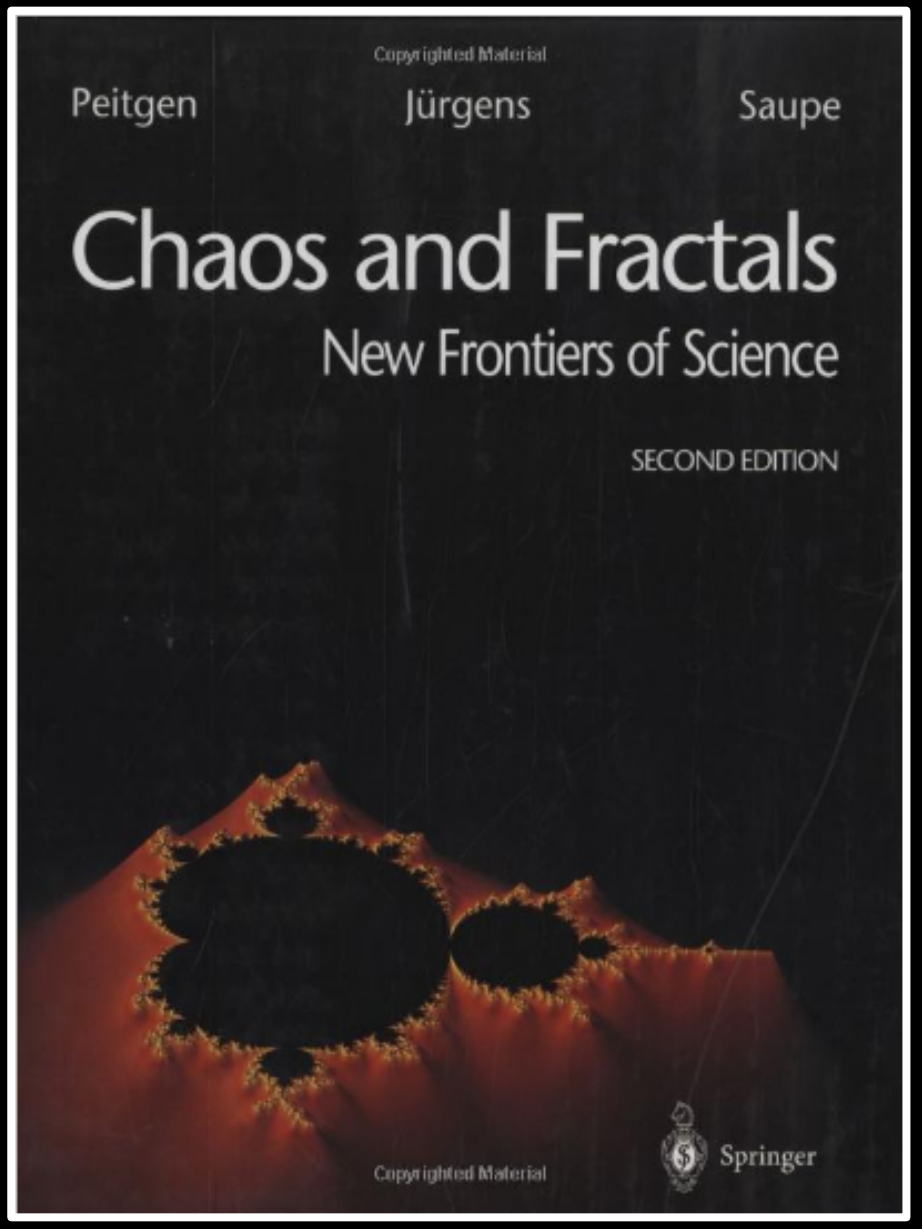
$$x(t+\Delta t) = rx(t)[1-x(t)]$$



Discrete model

$$x(t+\Delta t) = rx(t)[1-x(t)]$$

- Finite difference (discrete) model, or logistic map may lead to monotonic, non-monotonic, periodic, or chaotic behavior, depending on “r”

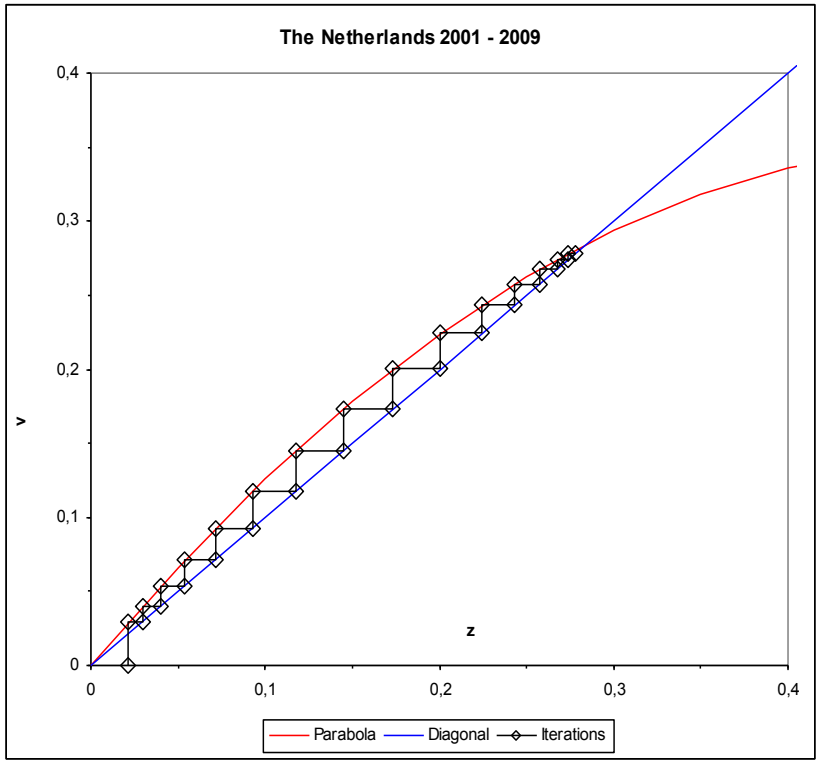


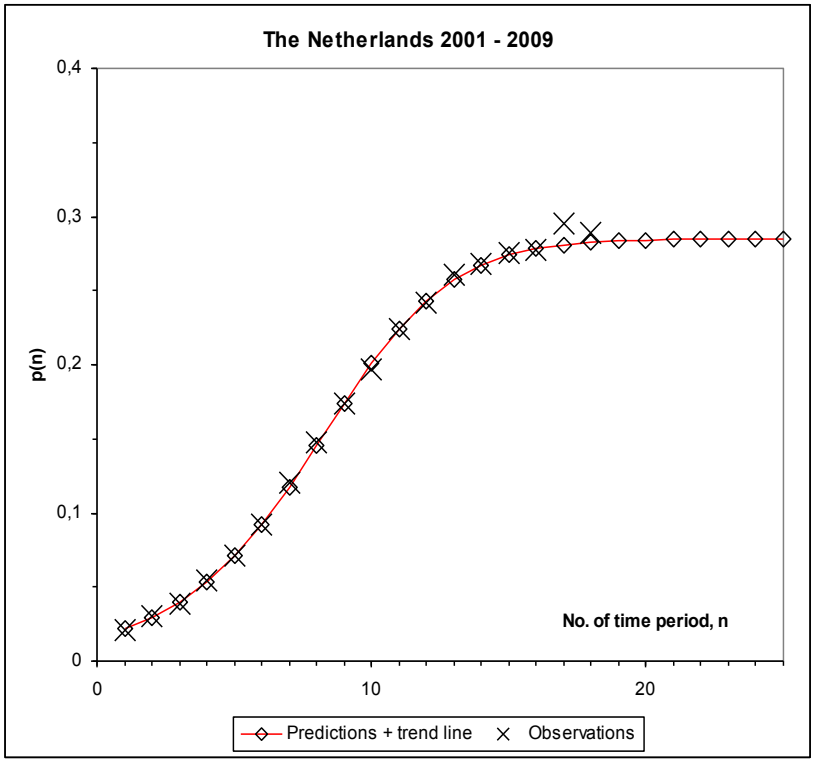
Discrete models

$$x(t+\Delta t) = rx(t)[1-x(t)]$$

- Discrete logistic map may lead to chaotic behavior depending on "r"

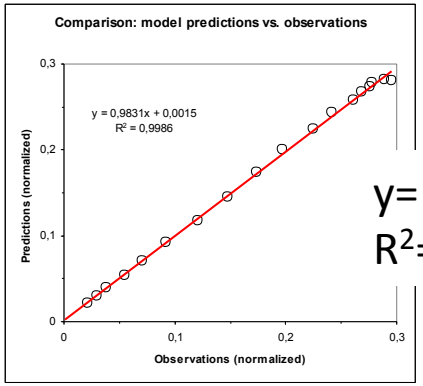
Discrete model: monotonic growth





$$z_n = \frac{a}{1+ab} p_n, \; or \;\; p_n = \frac{1+ab}{a} z_n$$

$$z_{n+1} = r z_n (1 - z_n), \; with \;\; r = (1+ab)$$



y= 0,9831x+0,0015

R^2=0,9986

Discrete model: cyclic variations

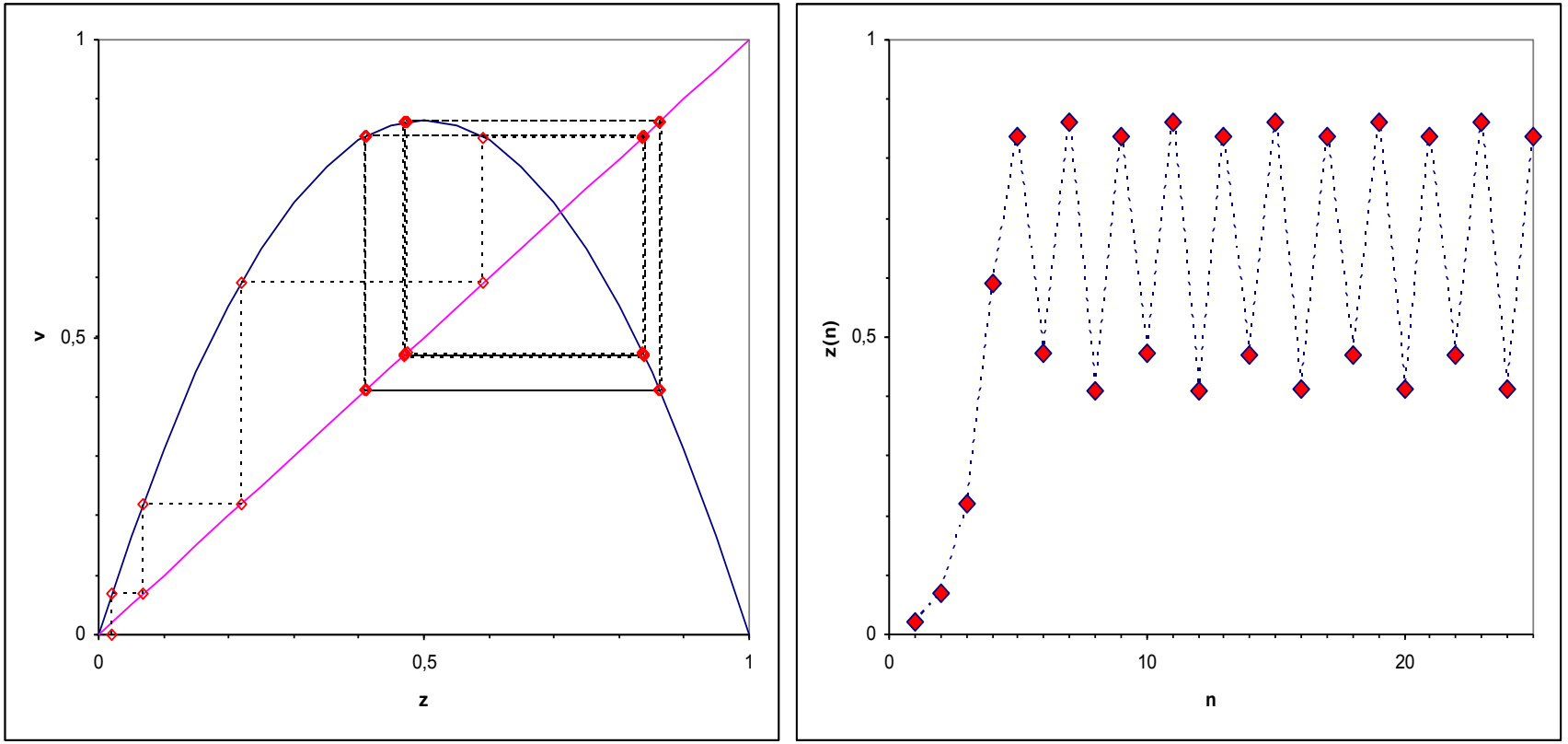


Figure 8. Left: Graphical iteration of relation (11) for z_0 = 0,02 and r = 3,46.
Right: Results of 25 iterations (left diagram) as time series.

Discrete model: chaotic fluctuations

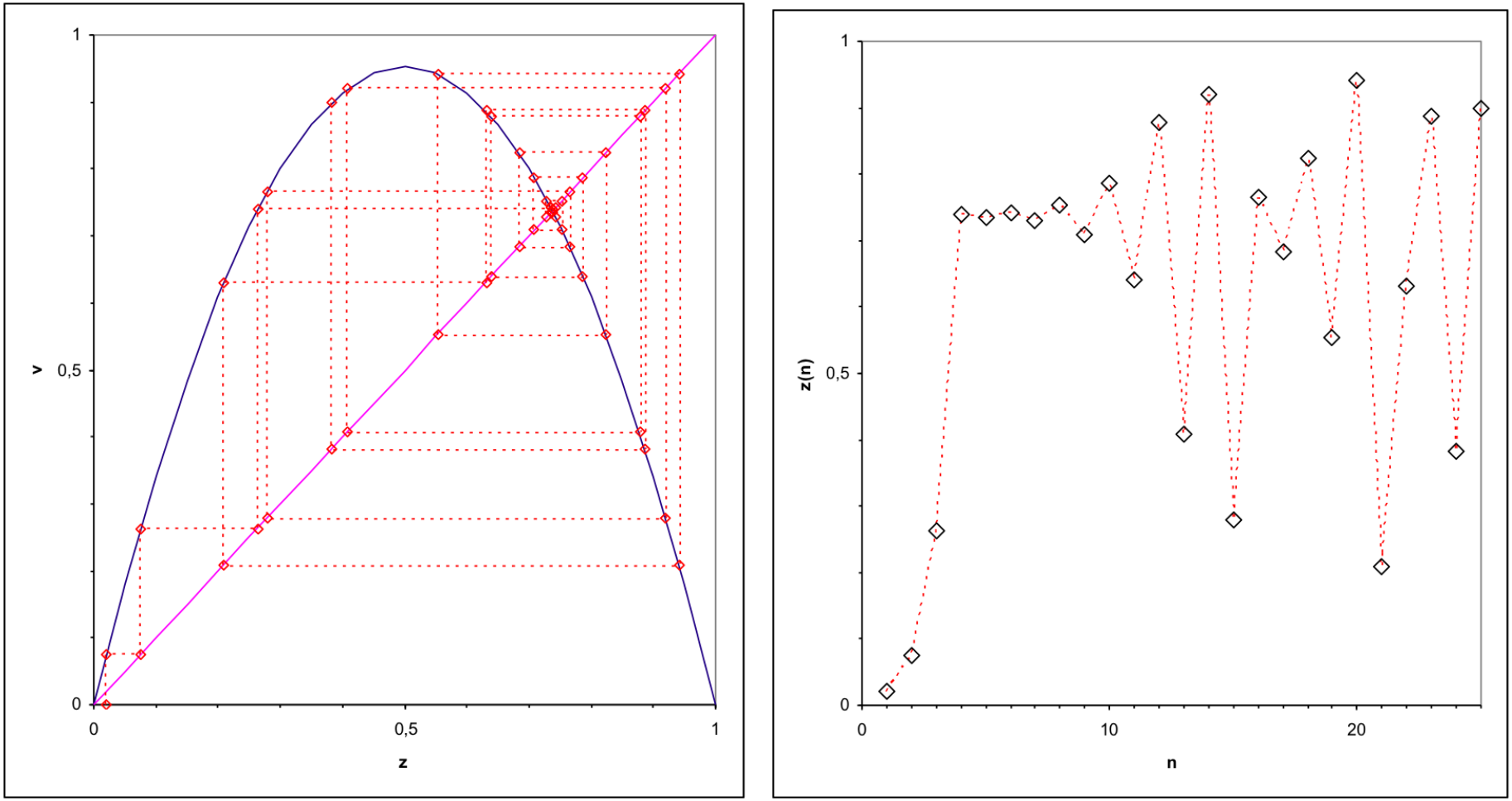
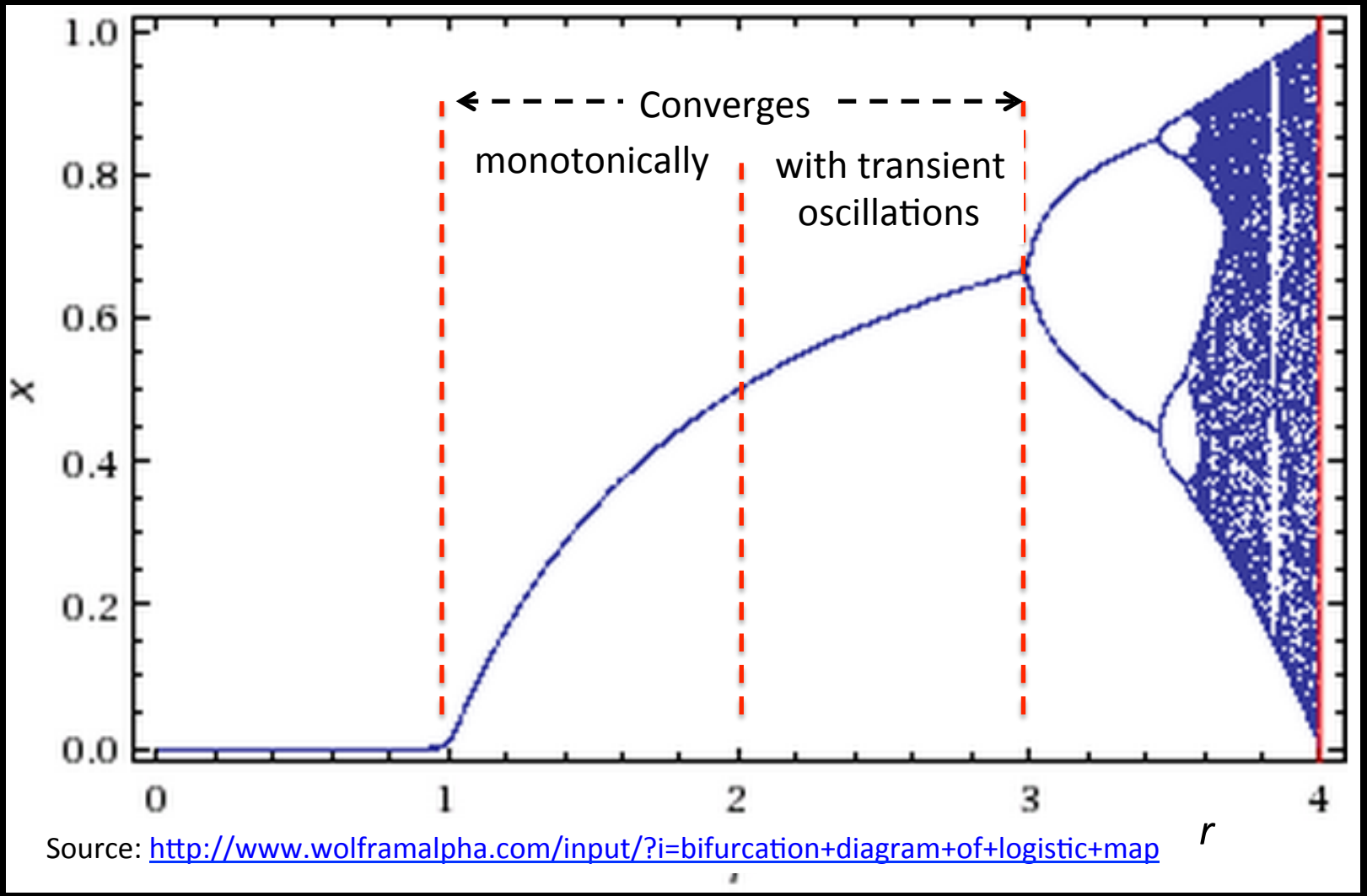


Figure 10. Left: Graphical iteration of recurrence relation (11) for z_0 = 0,02 and r = 3,81. Right: Results of 25 iterations (from the left diagram) as time series.

Bifurcation diagram of the logistic map



Source: http://www.wolframalpha.com/input/?i=bifurcation+diagram+of+logistic+map

Regions of bb. penetration rate growth

7 leading EU countries

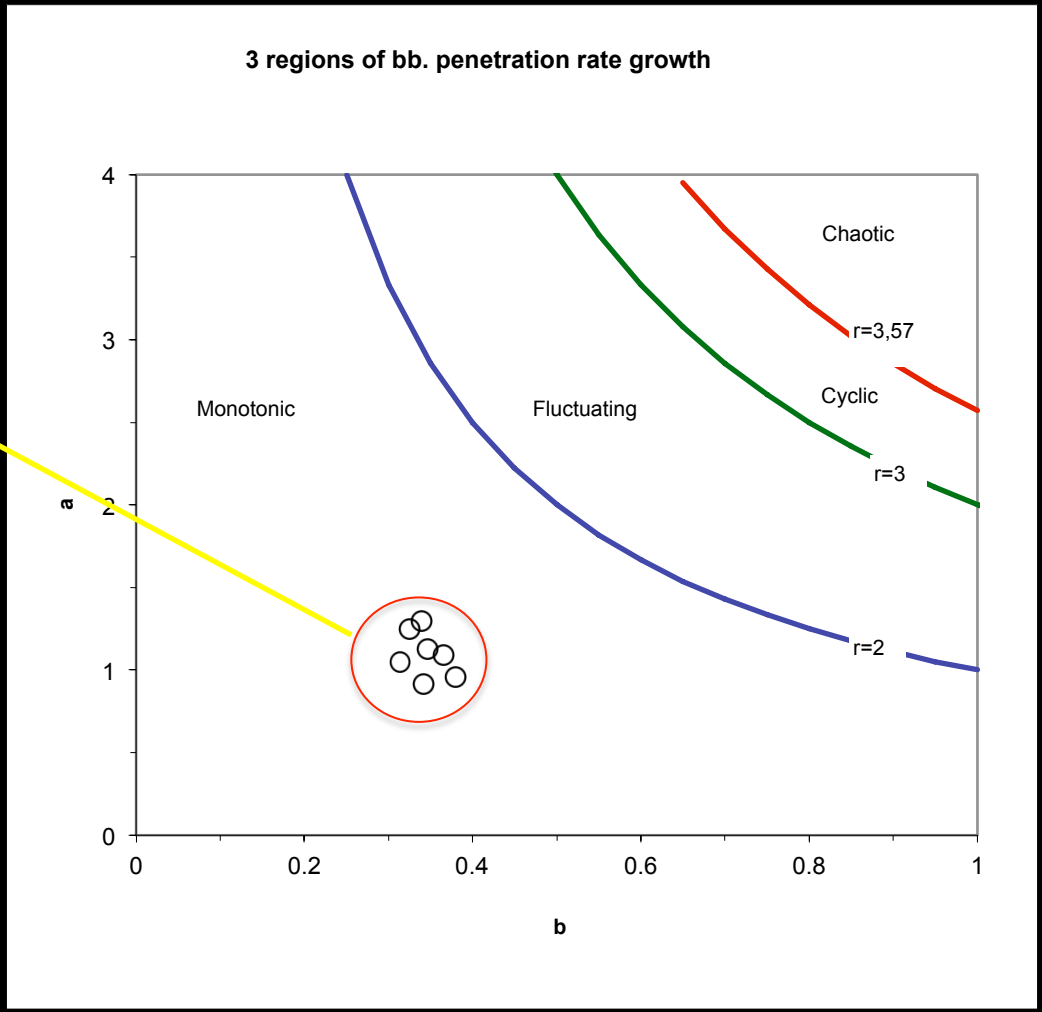
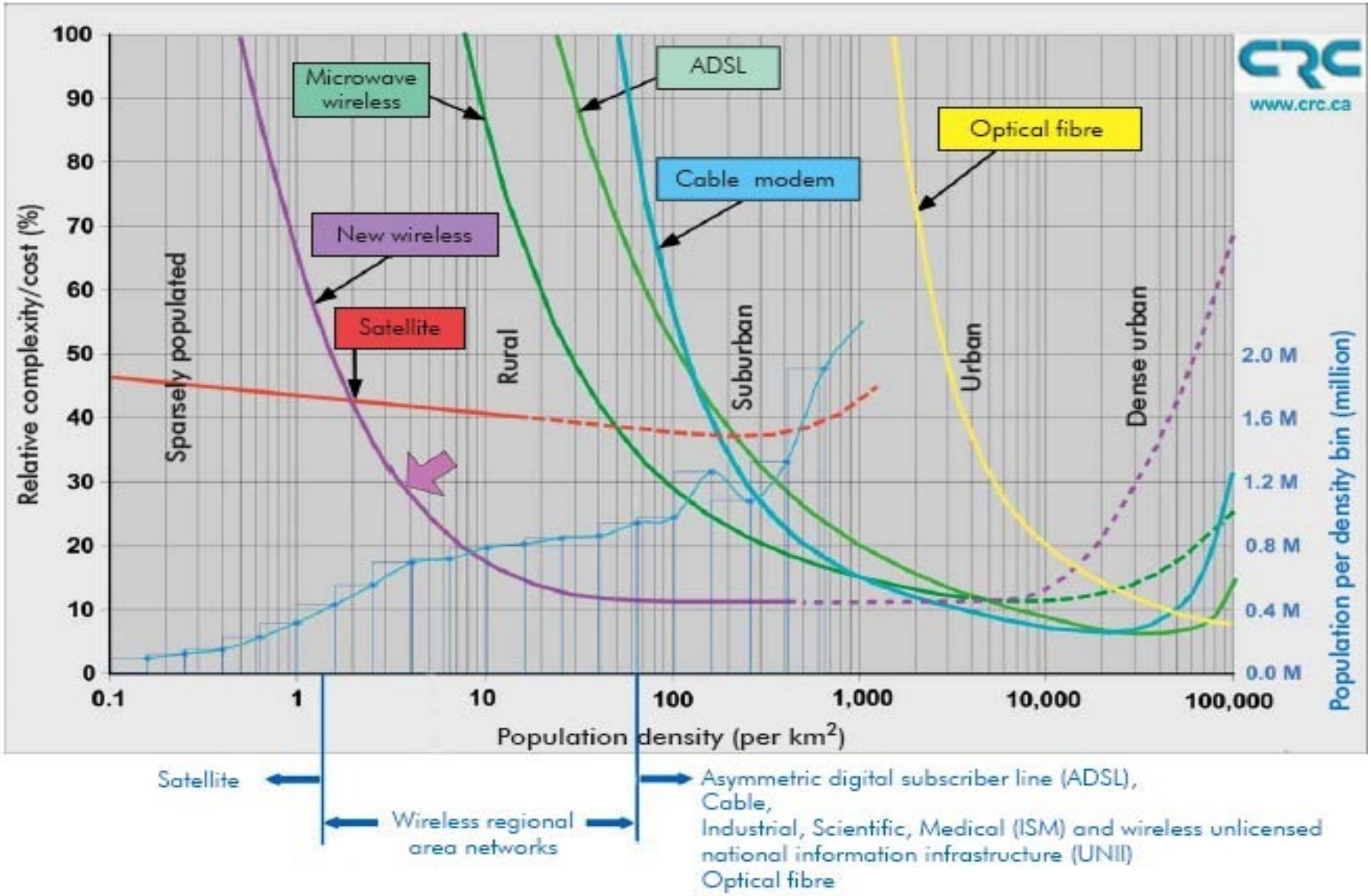
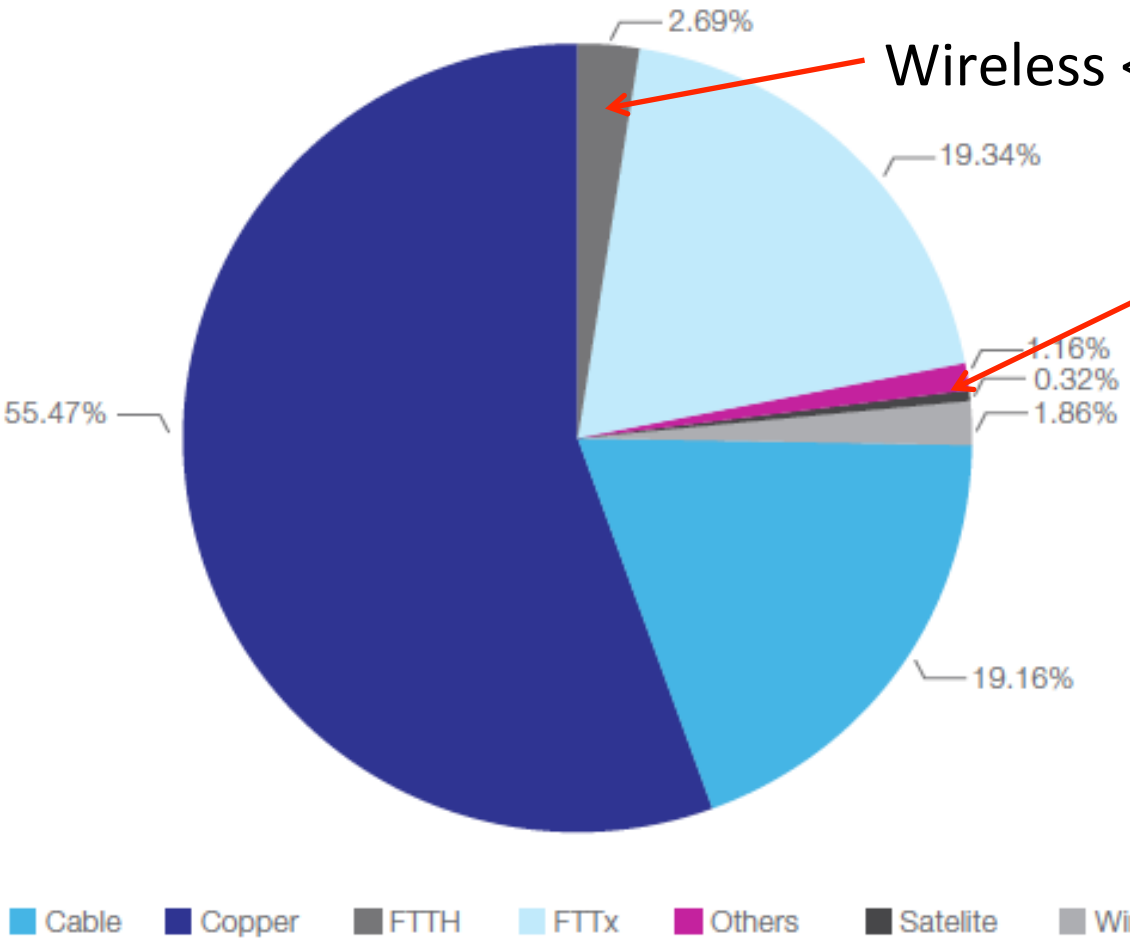


Figure 1 — Suitable broadband access technologies as a function of population density



Technologies sharing bb. market (2013)

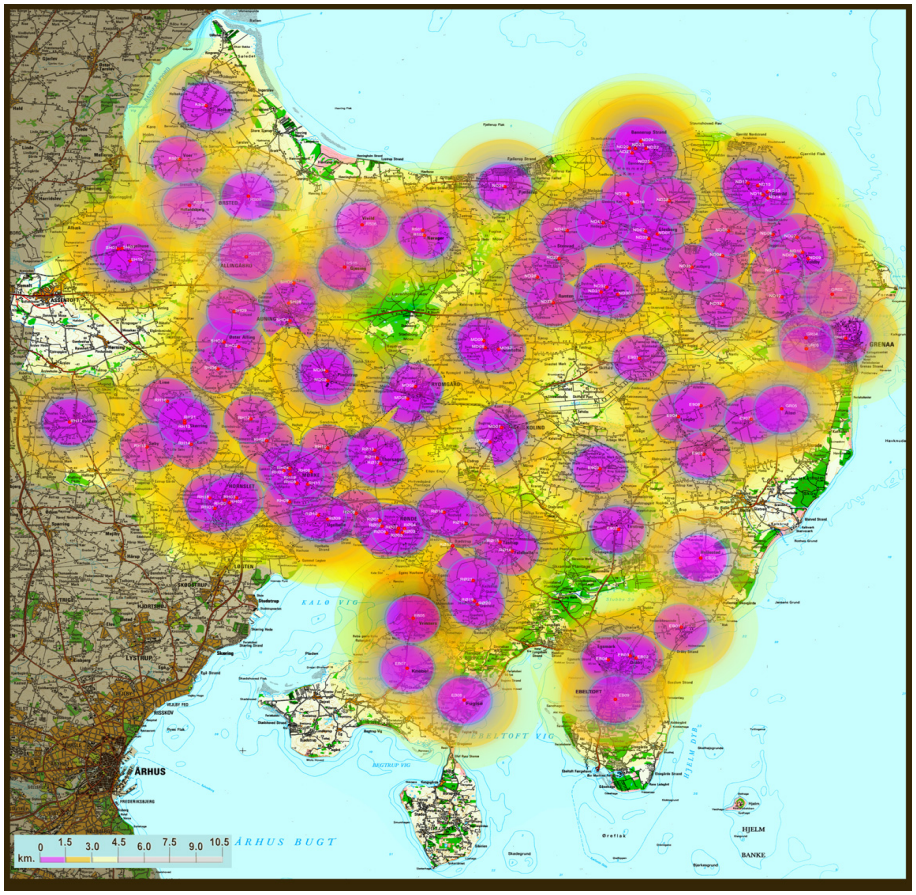


Wireless < 3%

Satellite < 0.4%

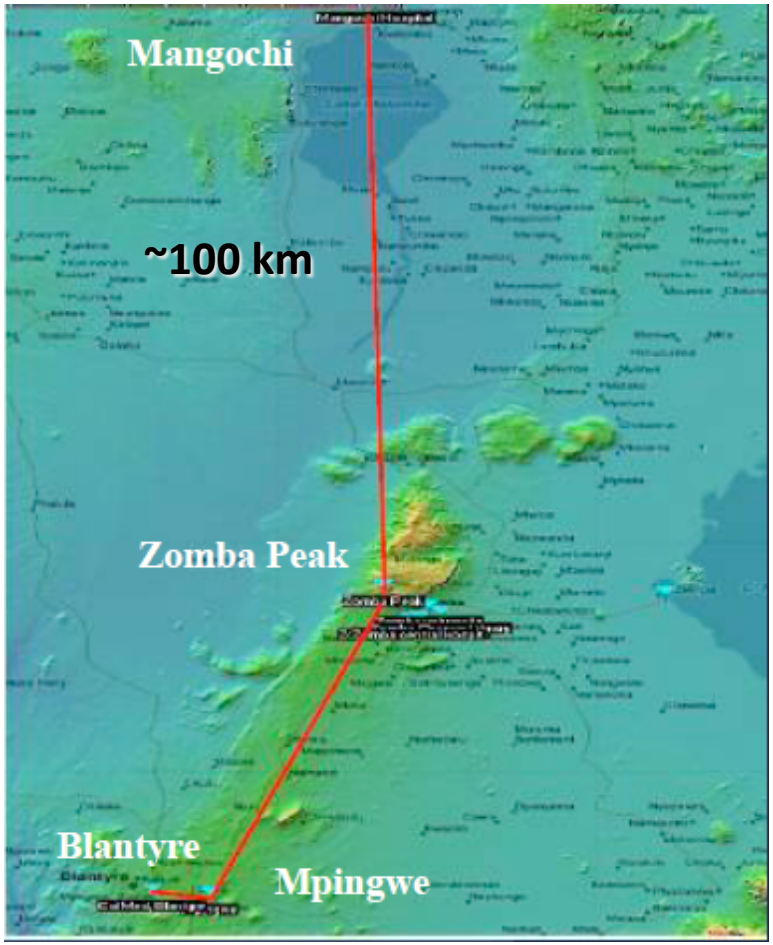
Possible explanation: most of broadband users are in rich/ urban regions

Source: The State of Broadband 2013: Universalizing Broadband. A report by the Broadband Commission September 2013



Denmark (Djursland): 1491 km2
Population: 82420 (58/ km2)
6000 houses w.access (1/3 cost)

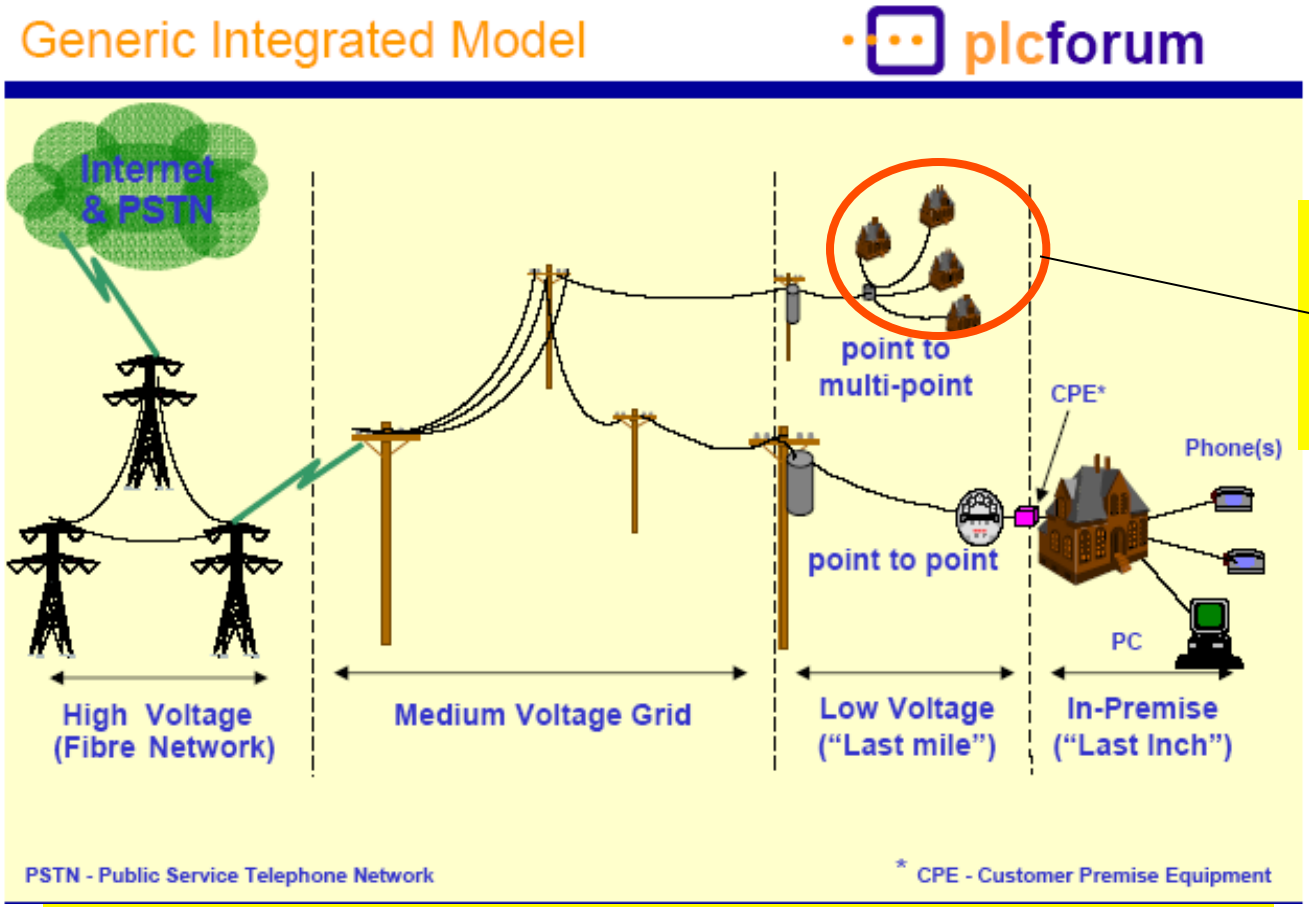
http://hos.nr-djurs.net/bjarke/DIIRWB-presentation_final-2.pdf



Malawi

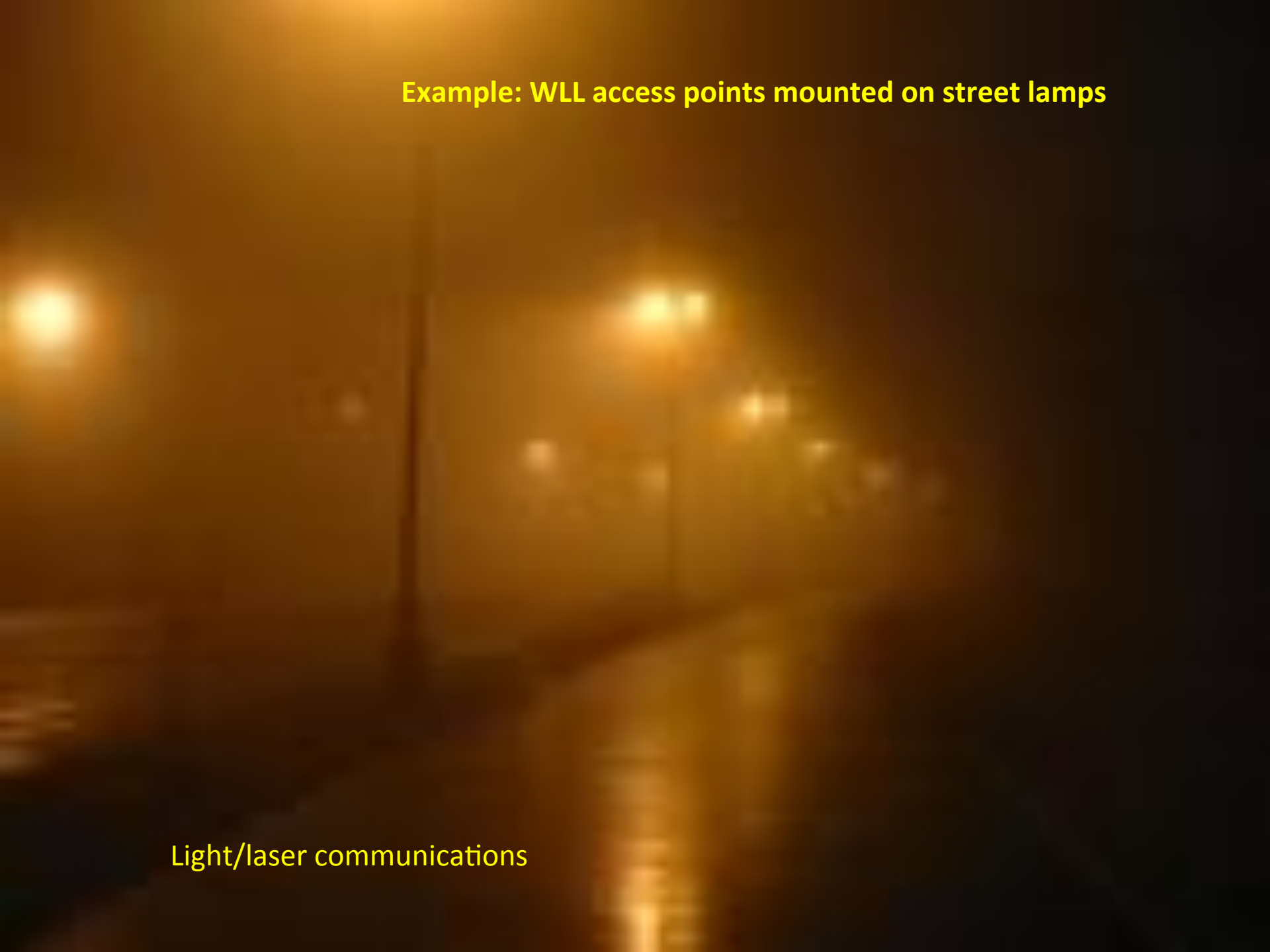
(Malawi Polytechnic + ICTP + NIT)

PowerLine Communications (PLC)



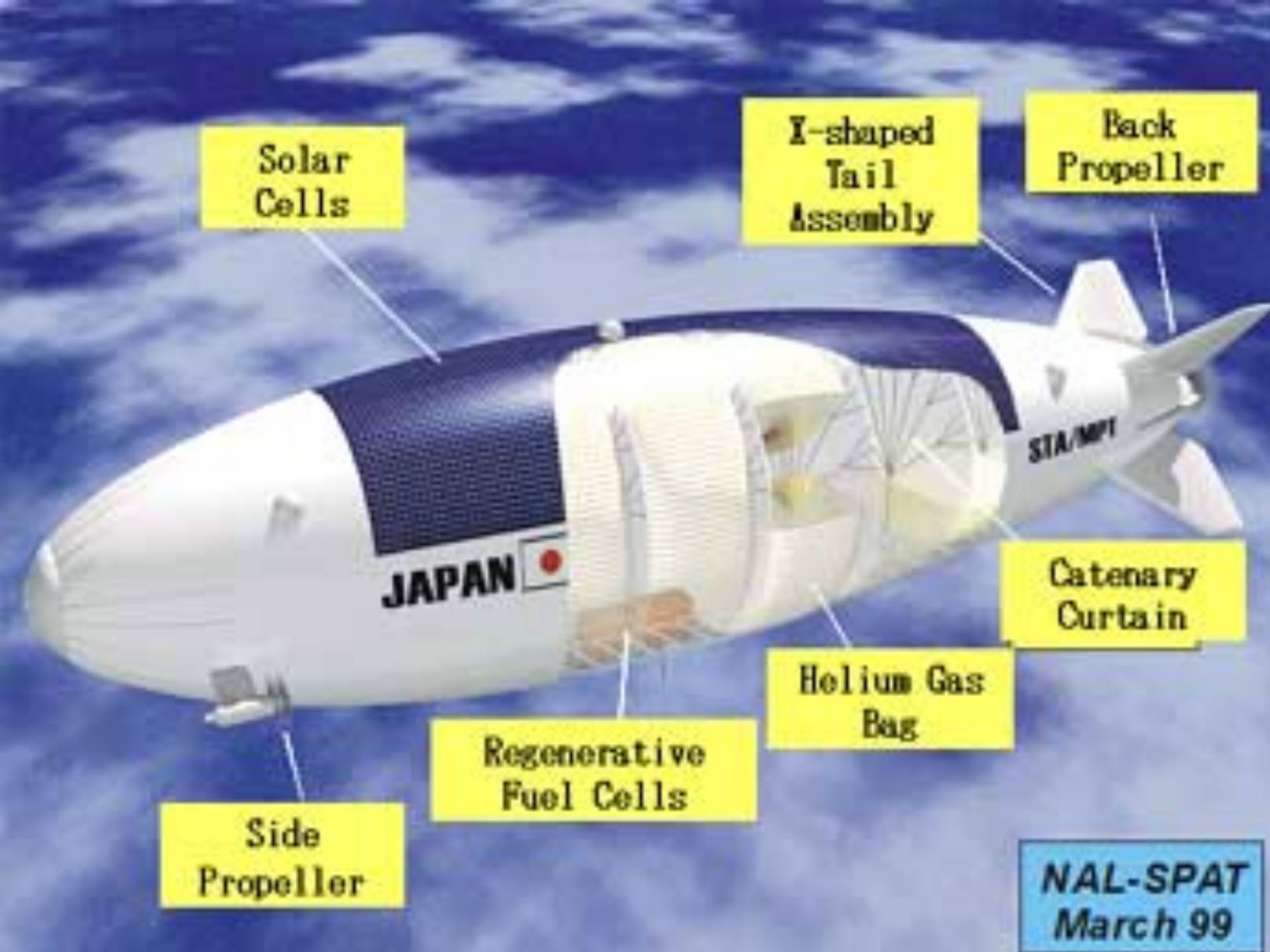
Wired or wireless

Integration with Automatic Meter Reading!

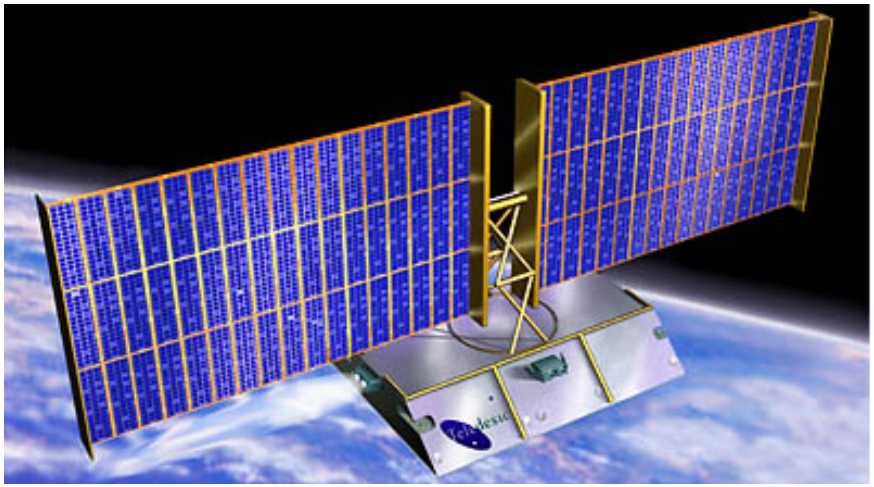

Example: WLL access points mounted on street lamps
Light/laser communications

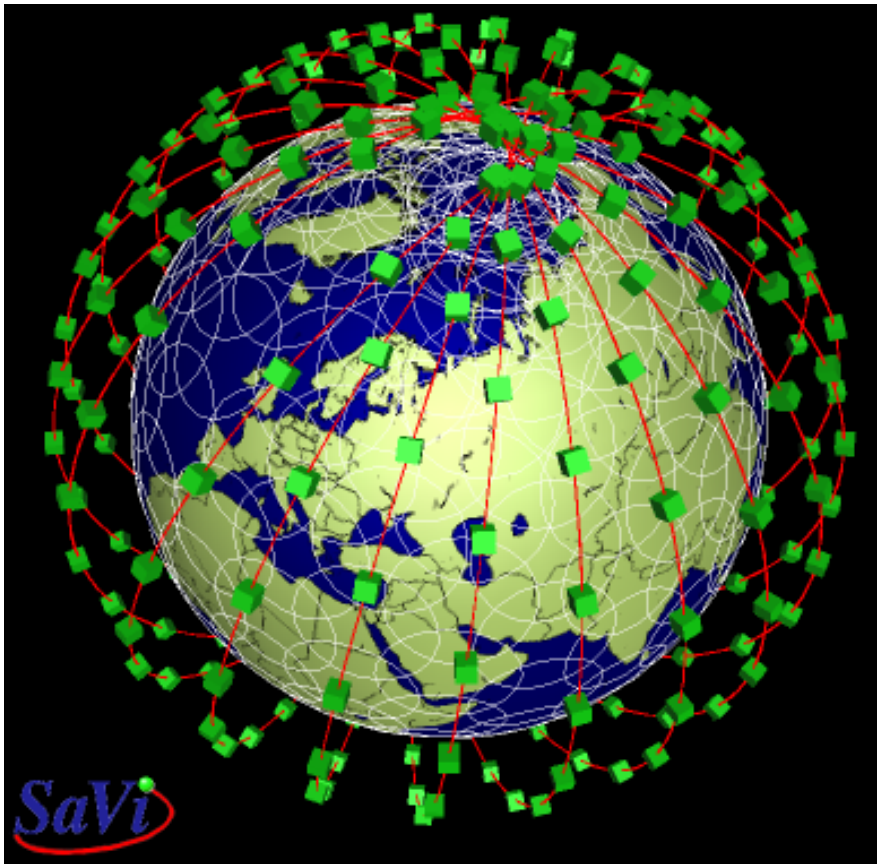
HAPS – high altitude platform station

R. Struzak: Mobile telecommunications via stratosphere;
http://www.intercomms.net/AUG03/content/struzak1.php http://www.ursi.org/files/RSBissues/RSB_334_2010_09.pdf


Solar Cells
X-shaped Tail Assembly
Back Propeller
JAPAN
Catenary Curtain
Helium Gas Bag
Regenerative Fuel Cells
Side Propeller
NAL-SPAT March 99

Internet-in-the-Sky





Teledesic - a bb. LEO network :
the global coverage, low latency, robustness, "fiber-like" QOS and affordable access from nearly 100% of the Earth's population and 95% of the landmass. Designed to support millions of simultaneous users.

http://en.wikipedia.org/wiki/Teledesic

http://web.archive.org/web/20011217200708/http://www.teledesic.com/

Conclusions

- Key contributions:
  - Quantification (models) of bb. internet penetration in households and „digital divide” (in stationary conditions)
  - Identification of
    - Generic model form verified in 35 countries
    - Limits and irreducible “digital gaps”
    - Market perspectives
    - Bottlenecks (i.e. where to allocate resources)

- The models presented here uncover the underlying structure of the Bb. diffusion process, hidden in the empirical data.
- They may be of interest for those desiring to gain insight into the scientific, business, and other aspects of the process.

Models – basic tools

→ to understand better the process

→ to evaluate trends, to compare alternative solutions possible, to plan

→ to analyse & monitor implementation

→ to identify bottlenecks & learn from the past policy/regulations/planning

- The findings can be useful in:
  - planning,
  - design,
  - implementation/deployment,
  - performance tracking

  of broadband infrastructure

For further details

- R. Struzak: Growth of broadband Internet in Poland – models, trends and limits; Telekomunikacja I Techniki Informacyjne 1-2/2009, pp. 38-49
- R. Struzak: Broadband Internet in EU Countries: Limits to Growth; IEEE Comms. Magazine, April 2010, 52 – 57
- R. Struzak: Diffusion of Broadband Services: An Empirical Study; IEEE Comms. Magazine, August 2012, 129 – 134
- R. Struzak: Internet in the Sky: Tests have Started...; ITU News No. 6/98, p. 22 – 26 (in English, French, Spanish)
- R. Struzak: Mobile telecommunications via stratosphere; http://www.intercomms.net/AUG03/content/struzak1.php

Thank you for your attention

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