CC: Rates of Change and Constraints for Adaptation and Mitigation

SF Sustainability Summer School 2009

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Reminder: Innovation Life Cycle
(and main drivers, ex. technology)

- **Invention** (new knowledge, research)
- **Innovation** (new application of knowledge, R&D)
- **Niche markets** (exploration of application possibilities and debugging via supplier-user interaction)
- **Diffusion** (standardization, cost reductions via learning curve and scale effects, globalization of markets)

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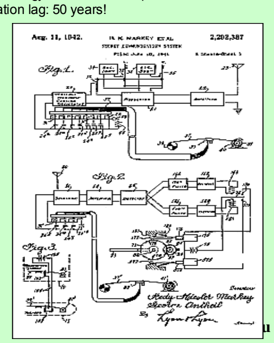
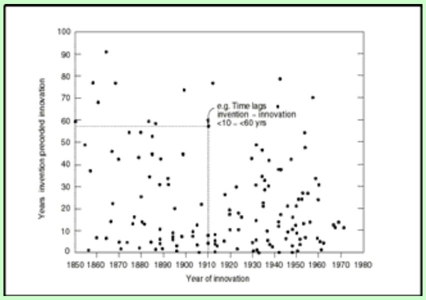
Invention – Innovation Lag: The Unrecognized Inventor

Movie Actress Hedy Lamarr (Eva Kiesler) together with musician George Antheil patented “secret communication system” in 1942 which US Navy thought useless
Now as “spread spectrum technology” basis of all cell phones.
Invention-Innovation lag: 50 years!



Time Lag Between Invention and Innovation: No shortening of stochastic variation



Source: Rosegger, 1996

Why Emphasis on Diffusion?

- Significance of innovation only when widely applied (society, economy, environment)
- Generally life cycle phase taking longest
- Equalizing force (but no homogeneity): Importance for DCs
- Availability of descriptive & causal formal models (≠ invention, innovation)
- Diffusion <u>and</u> Substitution

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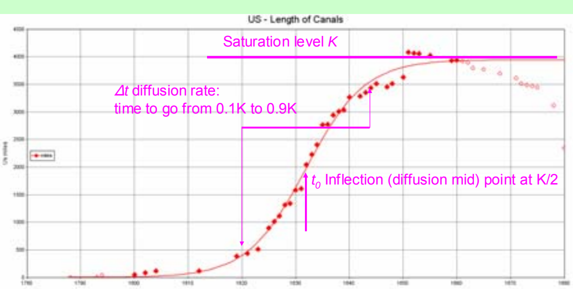
Logistic Growth Primer



K = 4000 miles, t_0 = 1832, Δt = 24 years

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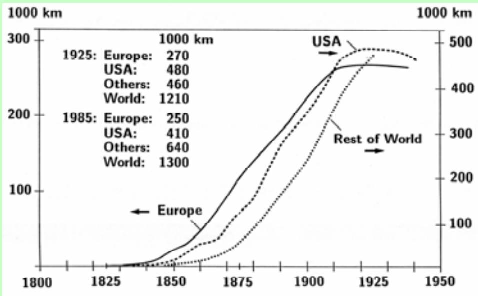
Diffusion of Railways
(km network length)



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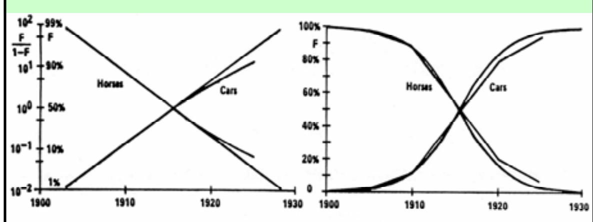
USA – Horses vs. Cars for Road Transport
(fractional share F in total fleet;
linear plot and logit transformation)



Δt = 13 years

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Fractality

- Diffusion processes operate at levels of:

  Technology (size, performance, efficiency,..)

  Industry (production AND use) regional to global markets

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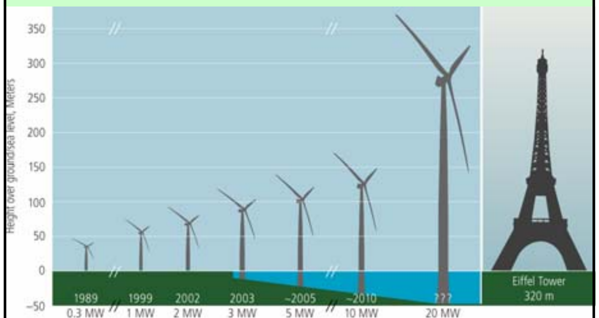
Growth in Unit Scale of Wind-turbines



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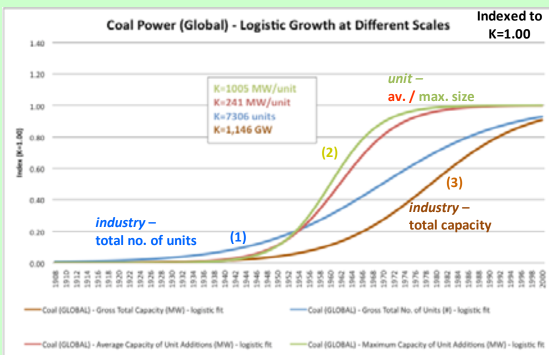


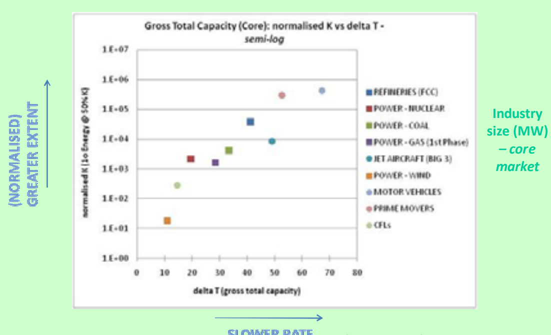
(1) Initial growth in unit numbers – experimentation!

(2) Unit scaling (max. & average, i.e., capturing scale economies)

(3) Industry scaling sustained by unit numbers

cf. nuclear, gas, aircraft, cars

Historical relationship between <u>EXTENT</u> and <u>RATE</u> of industry scaling is consistent across technologies



Source: C. Wilson, 2009

	USA		USSR	
	t_0	Δt (years)	t_0	Δt (years)
primary energy				
wood	1883	65	1919	77
coal	1885	66	1926	76
oil	1956	79	1985	120
gas	1990	112	1983	47
energy technologies				
surface coal	1975	70	1986	59
infrastructure				
canals	1840	48	1843	113
railways	1913	90	1941	101
roads	1916	92	1941	101
passenger transport				
rail	1920	51	1971	57
car/bus	n.a.	50	1976	53
air	2004	67	2006	80
transport technologies				
steam/motor ships	1886	75	1900	66
diesel/electric locomotives	1951	13	1961	14
military				
nuclear warheads	1970	31	1982	27
labor force				
agriculture	1893	115		
manufacturing	1930	120		
service	1975	224		
education				
literacy rate	1822	160	1923	38

Diffusion/Substitution Rates and Timing US - USSR

Note similarities despite fundamental different diffusion environment: Central Planning vs. Market

Exception: social change (diffusion of literacy)

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Diffusion: Macro variables

- Involves time and space (S-curve and spatial hierarchy centers)
- First mover vs. follower: longest (slowest) diffusion time & highest adoption (first mover) vs. catch-up at lower levels (follower)
- Market size vs speed and impact:
  Large size & impact = slower diffusion
  Small size and impact (fashion) = fast diffusion
- Diffusion (slower) vs. substitution (faster)
- Always look at: market share AND absolute volume; watch out for competitors

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Hierarchies of Rates of Change: (Diffusion Rates of Transport Systems)

	USA		USSR	
	t_0	Δt	t_0	Δt
Total length of transport infrastructure	1950	80	1980	80
Growth of railways				
1830-1930	1858	54	1890	37
1930-1987	Decline	Decline	1949	44
Treated ties (USA)	1923	26		
Track electrification (USSR)			1965	27
Replacement of steam locomotives	1950	12	1960	13

t_0 = diffusion midpoint (50% completion rate)
Δt = diffusion rate (years to grow from 10% to 90%)

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Determinants of Diffusion Speed (beyond macro)

- Type of adoption decision (individual, collective, authoritative)
- Type of communication channels (mass media vs. word-of-mouth)
- Nature of social system (interconnection, sources of learning: internal vs. external)
- Existence and efforts of change agents
- *Perceived* attributes of innovation:
  -- relative advantage (e.g. performance, costs);
  -- adoption effort (e.g. investment size);
  -- compatibility (technological, social integration);
  -- observability (social visibility, learn from neighbors);
  -- trialability (learning from own experience).

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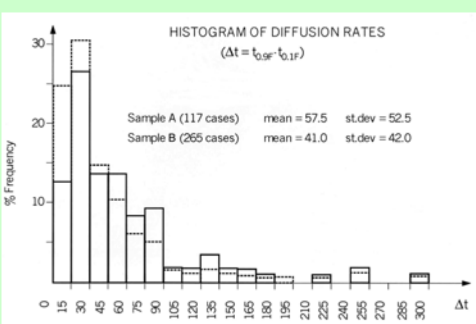
Explaining Differences in Diffusion Speed

(each additional + implies *ceteris paribus* slower diffusion)

Δt	Example	Diff/ Sub.	Rel. advantage	Scale	Infra-structure needs	Techn. Interde-pendence
80/110	coal vs wood USA/World	S	++	+++	+++	+++
47/60	railways France/World	D	+++	+++	+++	+++
25	% US homes with radio	D	+++	++	+	++
28	mechanization coal mines Russia	S	++	+	+	++
16	Car vs. horse, France, UK	S	++	+	++	++
15	Color vs. B/W TV, USA	S	+	++	+	+

Source: Grübler/Nakicenovic/Victor, 1999, Energy Policy 27:247-280

Innovation Diffusion Rates in the US



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Is Change Accelerating?

- More Myth than reality
- Frentic incremental innovations in maturing markets (cars, Microsoft,…)
- Piggy-back on existing infrastructures (nuclear, Internet, cell-phones)
- With growing capital stock: More to change!
- Basic diffusion patterns in time and space unchanged
- Big hits require time!

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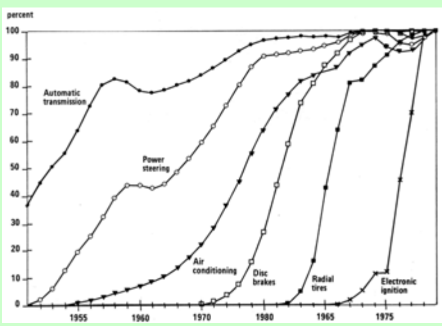
Diffusion of Novelties in US Car Fleet (% of sales):
Acceleration of incremental innovation in maturing technology



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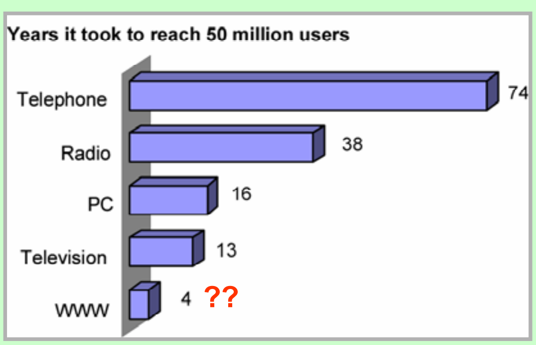
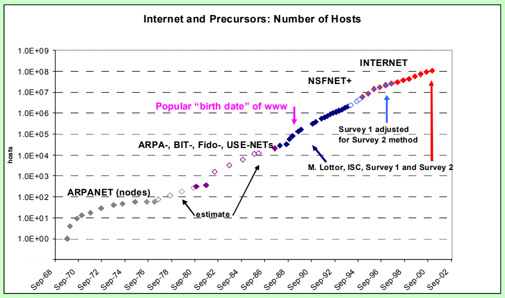
The Conventional View: Accelerating Change



http://www.un.org/cyberschoolbus/briefing/technology/tech.pdf

Growth of the Internet:

25 years as public (military/academic) infrastructure before commercialization!



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Technology Systems (Interrelatedness)

- Increasing interdependence: Change constrained by slowest component
- To date: Poor theoretical/empirical understanding
- Key importance in transformative change (CC)
- Insights from agent-based model of evolution of technological complexity (Ma/Grubler/Arthur/Nakicenovic IIASA IR-08-02)

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The Evolution of Technological Complexity

- Agent-based simulation model of the global energy system since 1800
- Random walk model of invention discovery and stochastic combination with other technologies into energy chains and systems
- Evolutionary selection environment
  - uncertain increasing returns
  - market share gains *f*(rel. advantage)
  - externalities (stochastic C-tax)

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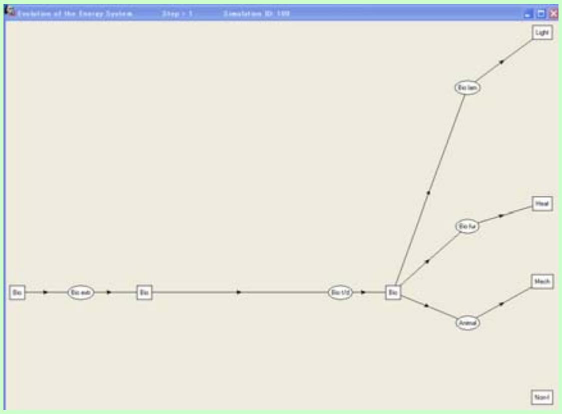
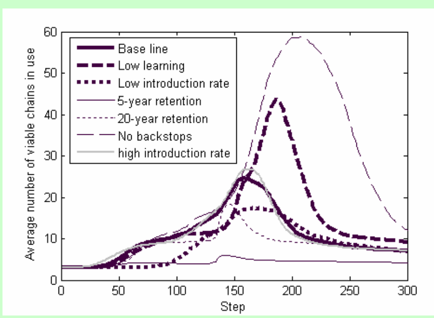


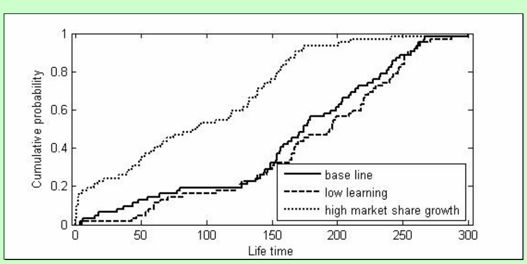
Evolution of Complexity

(avg. of 200 simulations each) and main determinants

- Learning rate and availability of backstops
- Innovation “impatience” (invention-innovation time lag)



Long Survival Time of Technologies:



Need to consider policy mechanisms for Schumpeterian “gales of creative destruction” under changing market environment, e.g. climate constraints

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Rates of Change

- History suggests typical turnover rates of systems of between 20-70 years depending on:
  -- Market size
  -- Technology characteristics (e.g. costs)
  -- Adoption environment (e.g. market growth, capital)
  -- Policy support
- Fastest: short lifetime, low capital (<10 yrs) e.g., fashion gadgets, appliances
- Slowest: long lifetime, capital intensive (>70-100 yrs) infrastructures, settlements
- Inverse relationships:
  (larger) size → (slower) speed
  (larger) importance/significance → (slower) speed
- CC adaptation/mitigation constrained by slowest system components
- Need for policy mechanism of retiring of long-lived vintages
  (Schumpeterian "gales of creative destruction")