2

Models of Technological Change

Modelle technischen Wandels

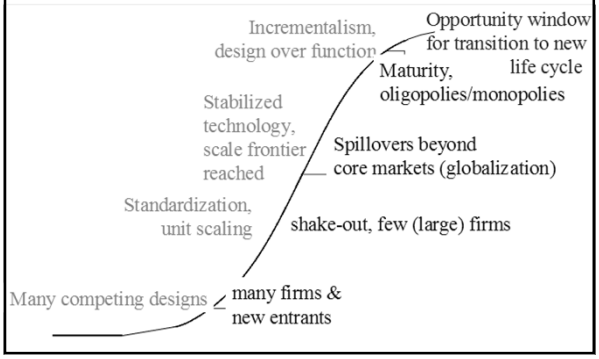
TC Models

Model: *A stylized, formalized representation of a system to probe its responsiveness*

Conceptual: Life Cycle, Innovation Systems

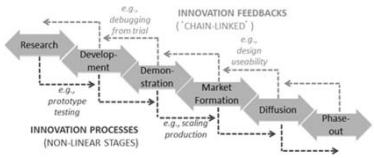
Formal:
- descriptive (Diffusion/Substitution)
- proxy causal (Learning Curves)

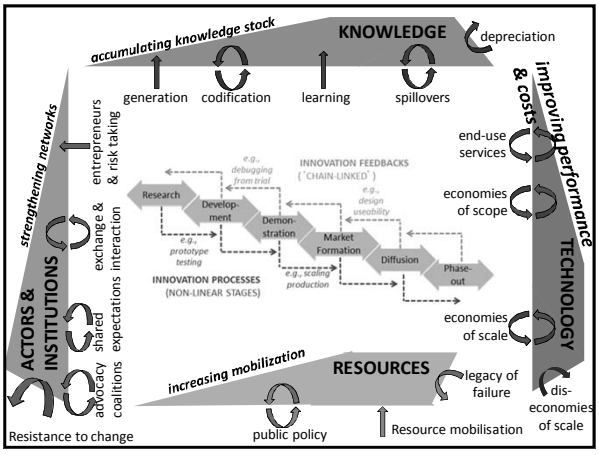
Industry and Technology Dynamics over a Life Cycle: Multiple S-curves: market size, performance,…



Innovation Systems: Key Concepts

- Innovation:
  -- stages
  -- processes
  -- feedbacks
- Supply Push vs demand Pull
- Drivers:
  -knowledge
  -actors/institutions
  - resources
  -technology performance & costs





Knowledge

- Accumulation
- Depreciation
- Non-rival
- Non-depleteable
- Fugitive (spillovers, leakage)
- Hard to appropriate
- Public goods nature and market failures

Heterogeneity: Example R&D Intensity ($R&D per $VA)

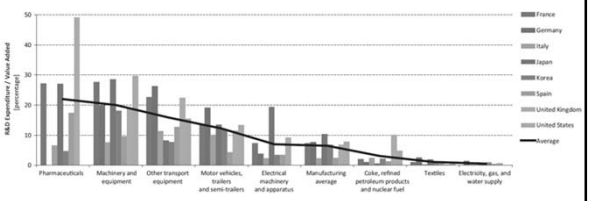
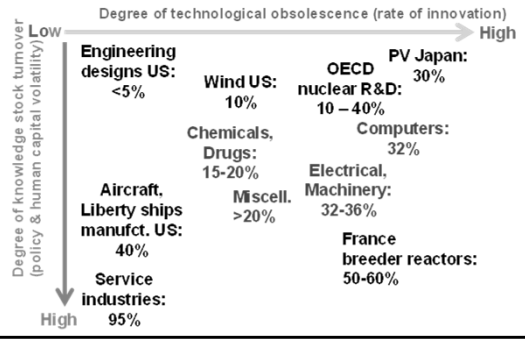


Figure 24.3 | R&D intensity (expenditures per value added, in percent) for selected sectors and OECD countries in 2002. Source: The OECD Research and Development Expenditure in Industry database and STAN Database.

Knowledge Depreciation Rates (% per year)

empirical studies reviewed GEA KM24 (2012) and
modeled R&D deprecation in US manufacturing (Hall, 2007)

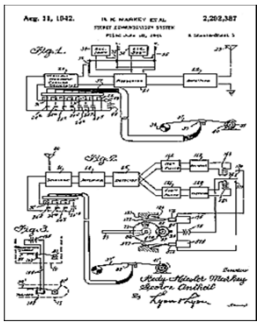


Actors & Institutions

- Innovators, entrepreneurs,….
- Actor networks
- Actor coalitions
- Institutions:
  -- R&D lab
  -- cooperation (formal/informal)
  -- knowledge exchanges
  -- regulation (standards, norms, externalities)
- Opposition

Technology Agents: E.g. 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!



Resource Mobilization

- Increases along life cycle
  (R&D < niche markets < diffusion)
- High variability across technologies/sectors
- Multiple actors:
  supply + demand
  public + private (firms + consumers)
- Increasing globalization (cooperation, trade)

Global Resource Mobilization for TC: Example Energy in 2005 (Billion $)

	innovation (RD&D)	market formation	diffusion
End-use & efficiency	>>8	5	300-3500
Fossil fuel supply	>12	>>2	200-550
Nuclear	>10	0	3-8
Renewables	>12	~20	>20
Electricity (Gen+T&D)	>>1	~100	450-520
Other*	>>4	<15	n.a.
Total	>50	<150	1000 - <5000
non-OECD	~20	~30	~400 - ~1500
non-OECD share	>40%	<20%	40% - 30%

* hydrogen, fuel cells, other power & storage technologies, basic energy research

Source: GEA KM24, 2012

Technology Improvements

- Service provision
- Economies of Scope
- Performance (efficiency, output,…)
- Unit scale (Economies of Scale)
- Costs/Prices

All lead to larger markets which feed back to innovation and improvements

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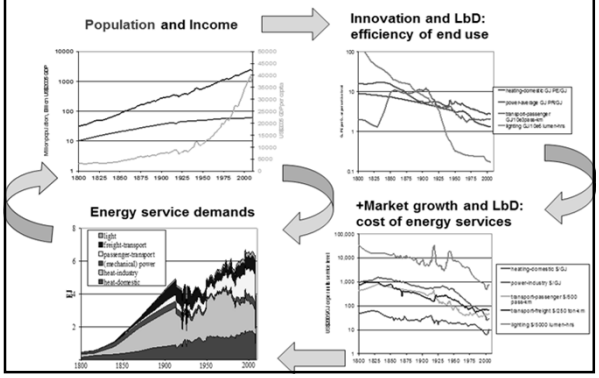
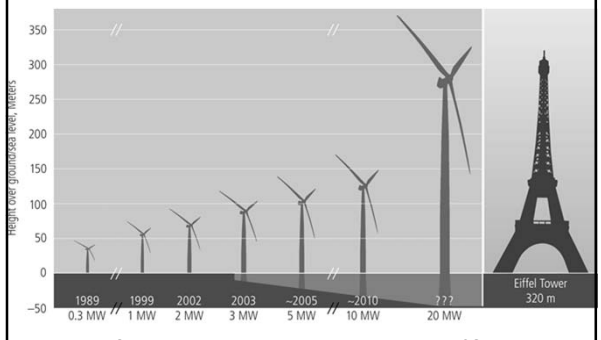
UK Energy History

Roger Fouquet's Data revealing a positive feedback loop



Size of Wind Turbines



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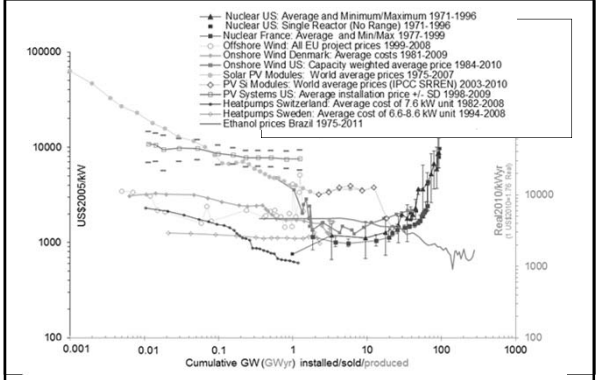
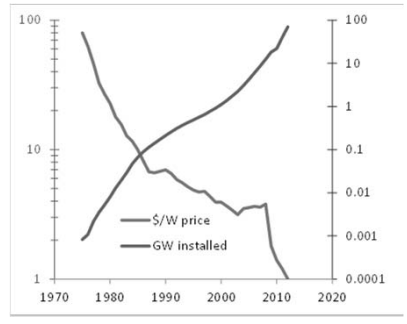
Post Fossil Technologies Cost Trends



Source: Grubler et al, 2012

Costs vs. Market Size: Example PV (global)



innovation **diffusion**

Formal Models of TC

Example Diffusion/Substitution

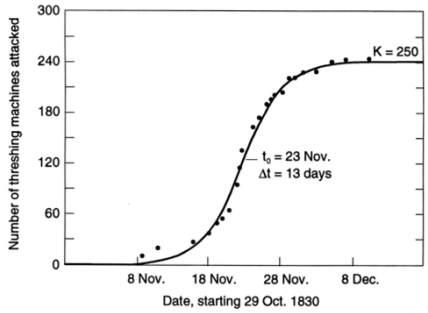
Why Emphasis on Diffusion?

- Significance of TC only when widely applied (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

- Innovation..
- Communicated..
- Over time..
- Among members of social system..

UK – Threshing Machines Destroyed during Captain Swing Riots
(first Luddist movement in agriculture)



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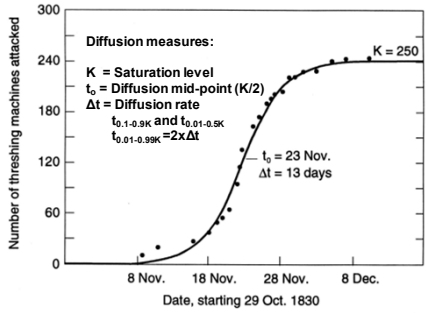

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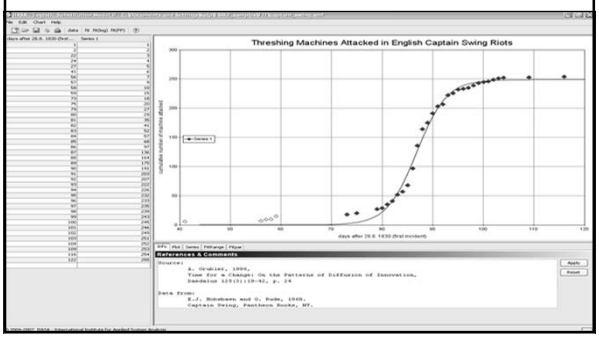
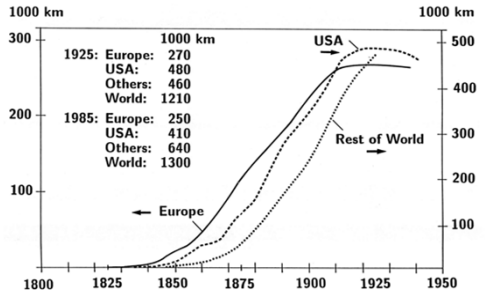
Screenshot LSM Model
(FIT option [growth curves]) download:
http://www.iiasa.ac.at/Research/TNT/WEB/Software/LSM2/lsm2-download.html?sb=6



Diffusion of Railways
(km network length)



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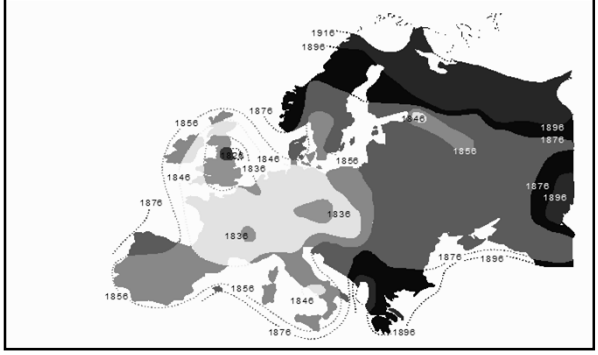
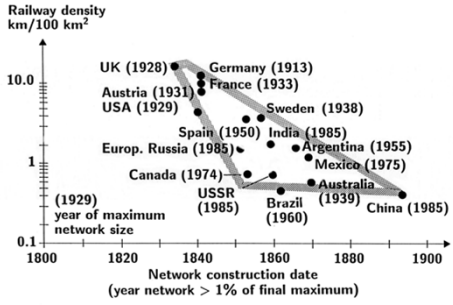
Spatial Diffusion of Railways in Europe
(Isolines of network coverage. Source: Godlund, 1952)



Rail Diffusion Envelope:
Maximum Network Size vs. Network Start-up Date



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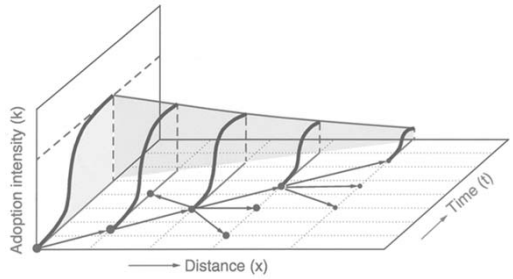
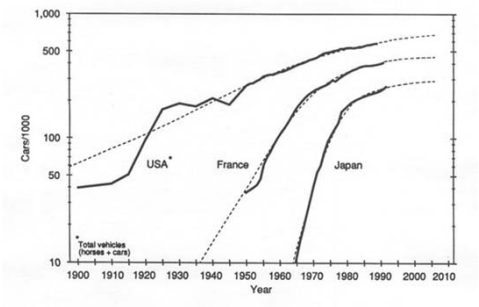
Diffusion in Time and Space

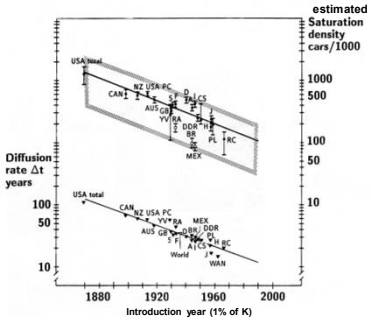
(modified after: R.L. Morrill, 1968, J.Reg.Sci.(8):1-18



Car Diffusion: Catch-up at Lower Levels



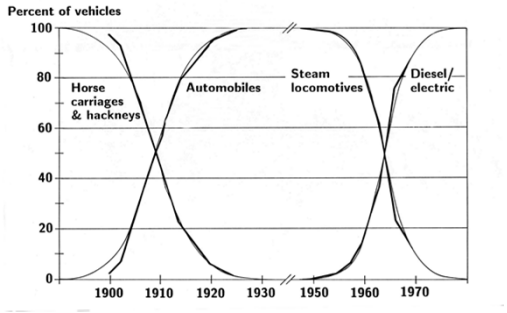
Car Diffusion: Catch-up at Lower Levels (Model Results)



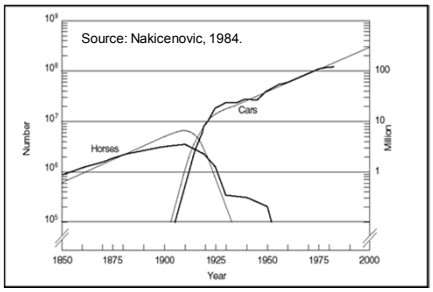
Joseph A. Schumpeter,
Capitalism, Socialism and Democracy, 1942:82–83

"The history of the productive apparatus… is a history of revolutions. So is the history of … transportation from the mail coach to the airplane.
The opening of new markets, foreign or domestic, and the organizational development from the craft shop and factory to such concerns as US Steel illustrate the same process of industrial mutation – if I may use this biological term – that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one.
This process of Creative Destruction is the essential fact about capitalism."

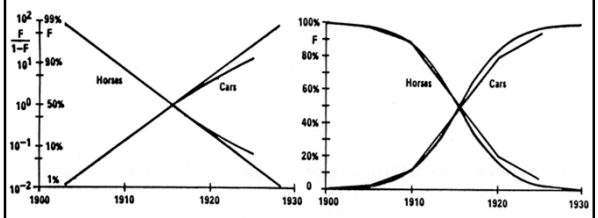
UK – Replacement within Vehicle Fleets



Number of Draft Animals and Automobiles in the USA



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



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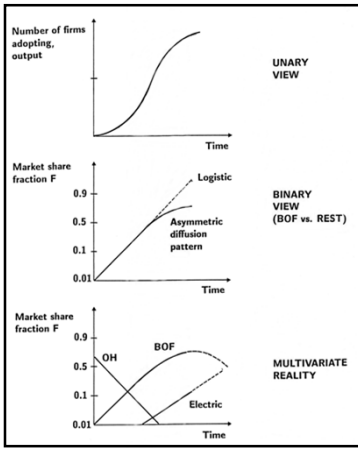

UNARY VIEW

BINARY VIEW (BOF vs. REST)

MULTIVARIATE REALITY

3 Views on Diffusion/ Substitution

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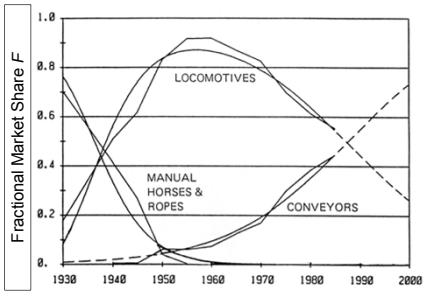
USSR – Substitution of Underground Transport in Coal Mines



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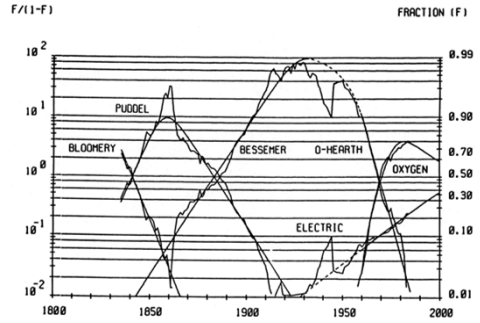
Germany – Raw Steel Production by Process



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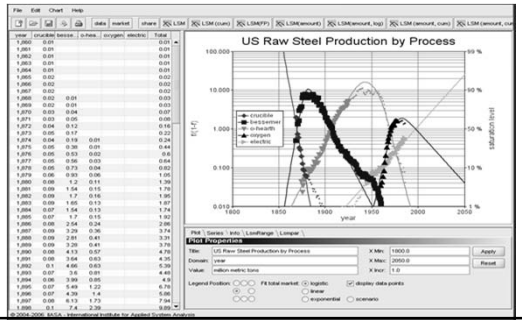
LSM Screenshot
(LSM substitution option) download:

http://www.iiasa.ac.at/Research/TNT/WEB/Software/LSM2/lsm2-download.html?sb=6



	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

Biggest Difference: Social "technologies"

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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

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%)

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).

Summary Block Models of TC 1/2

- Conceptual (innovation systems, life cycle) vs.
  Formal models (diffusion/substitution [LSM], learning curves→Block 1)
- Innovation systems: include ALL:
  -- components of technology system
  -- stages/processes/feedbacks of life cycle
  -- dimensions of innovation systems (knowledge, actors/institutions, resources, tech. characteristics)

Summary 2/2 Diffusion Models

- Techn. Change = diffusion vs. substitution
- Diffusion = temporal and spatial
- Diffusion = adoption intensities (catch up at lower levels)
- Measures: saturation level (K), inflection point ("when", t0 at K/2), diffusion rate/speed ("how fast" Δt)
- Explaining diffusion speed = qualitative (type of decision, communication channels, social system) vs. quantitative (change agents, relative attributes: advantage, compatibility, observability, trailability)
- Substitution = sequence of replacements
- Logit transform = log (F/1-F): linearization of logistic substitution model
- Hierarchy of diffusion/substitution rates

Diffusion Case Studies (Exam)

- One example per student (own choice, but no examples from LSM or Arnulf's book)
- Analyze: a) competition (substitution) in relative market shares
  b) total market volume
  c) absolute market per technology (=axb)
- Report back any software bugs
- Download:
  http://www.iiasa.ac.at/Research/TNT/WEB/Software/LSM2/lsm2-index.html

  Use "Windows installer" option to download to your computer (web-based model runs are slow)

  Manual is online!!