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What is Technology?

Was ist Technik/Technologie?

Technology

- "Advances in knowledge": Single most important source for productivity (income) growth
- Paradox: Source and remedy of global environmental change
- Knowledge: embodied (artifacts)
  disembodied ("blueprints")
- Externality: private < social ROI

Macro-economic Production Function (e.g. Cobb-Douglas)

$Y = K^{\alpha} L^{1-\alpha} + \varepsilon$

Y = GDP
K = capital
L= labor
α = elasticity of substitution (0>α<1)
ε = residual (TFP, knowledge advance)

Growth accounting
$\Delta Y = \Delta F + \Delta L + \varepsilon$

R. Solow (Nobel prize) ε = 85% of GDP/capita growth in US

Accounting for Economic Growth

Factors in US Nat. Income Growth (%/yr)

1929 – 1982 (Denison, 1985, US Hist.Stat., 1997)

Employment males:	+ 0.50
Employment females:	+ 0.88
Average hours worked*:	– 0.51
Education, etc.:	+ 0.87
LABOR:	+ 1.34
CAPITAL:	+ 0.56
TECHNOLOGY:	+ 1.06
TOTAL:	+ 2.96
Population growth:	+ 1.08

* Indirect impact of technology

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Factors of Growth: The Last 200 Years

	1800	2000	factor
World population, billion	1	6	x 6
Life expectancy, years*	35	75	x 2
Work hours per year*	3,000	1,500	÷ 2
Free time over life*	70,000	300,000	x 4
Mobility, km/day* (excl. walk)	0.04	40	x 1000
World income, trillion $	0.5	36	x 70
Global energy use, Gtoe	0.3	10	x 35
Carbon, energy, GtC	0.3	6	x 22
Carbon, all sources, GtC	0.8	8	x 10

* Industrialized countries

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Estimates of Private and Social Rates of Return on R&D (in %)

	Private	Social
AGRICULTURE		
Evenson et al. 1979	14 - 87	45 - 130
INDUSTRY		
Bernstein/Nadivi 1991	14 - 28	70 - 84
Sveikanskas 1981	10 - 23	60 - 73
Mansfield et al. 1977 range (17 innov.) sample mean	 4 - 214 25	 13 - 307 56
SERVICES	?	?

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Technology

τεχνε λογοσ

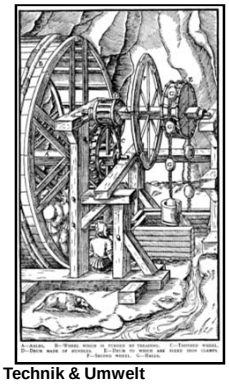
Origin: the science of the art of the practical

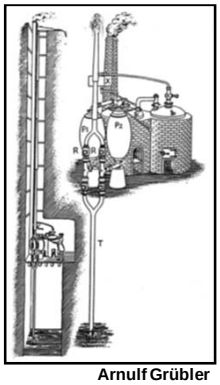
A systems of means to particular ends that employs both technical artifacts and (social) information

Creating Technological Knowledge (Usher's cumulative synthesis model)

- Perception of problem/opportunity
- Setting the stage (drawing elements together, "act of skill")
- Act of insight (high uncertainty on outcome)
- Critical Revision

Dewatering Coal Mines



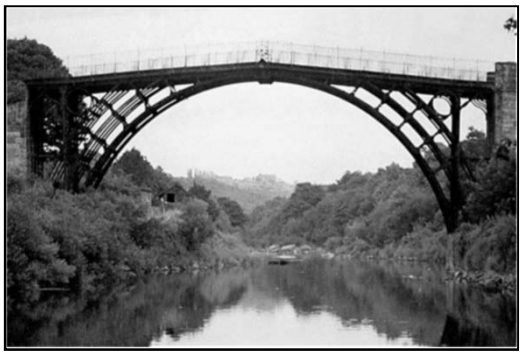


The Industrial Revolution

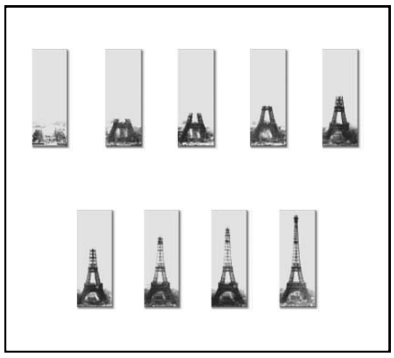
- Substitution of human labor by machines
- Substitution of traditional (renewable) energy by fossil fuels (coal)
- Use of new materials, rendered available (geologically, economically) by new technologies for new purposes

David Landes: *Prometheus Unbound*, *1969.*

The World's First Iron Bridge (picture AD 2000)



New Steel Demand 1: Structures

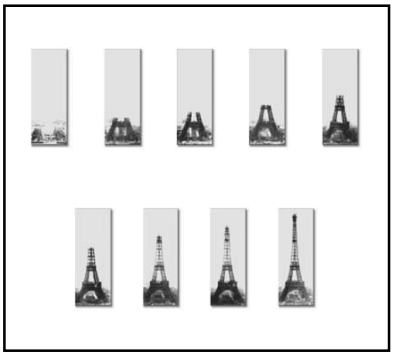


New Steel Demand 2:

Fordist Mass Manufacturing of Automobiles

http://www.youtube.com/watch?feature=player_detailpage&v=nQhgC2vlqFQ

Technology: hardware (Model T) + software (Fordist Manufacture)



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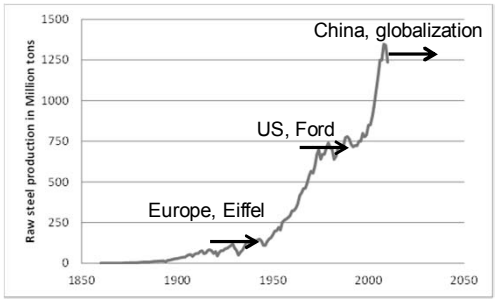
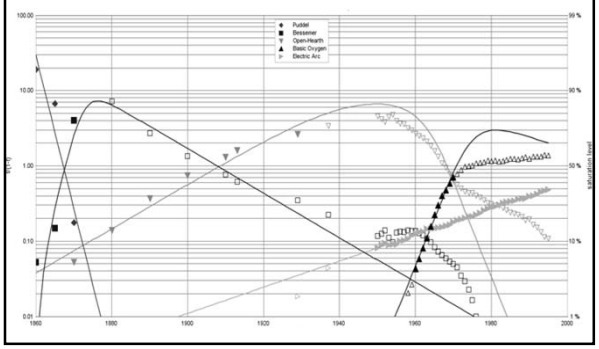
Growth to Limits

3 Phases in World Raw Steel Production



World Steel Production by Process

Data and LSM2 Modeled Dynamics



Technology is...

H - Hardware (artifacts, "machines")

+

S - Software (know-how, "know-why")

+

O -"Orgware" (institutions, regulation, "rules of the game")

Hierarchy of Technological Change

Incremental (H)
Radical (H^n + S)
Systems (H^n + S^n + O)
Clusters & Families (H^n + S^n + O^n)

With increasing hierarchy (complexity):
larger market size, but slower diffusion.

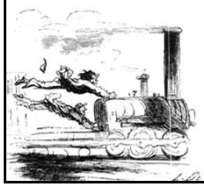
All Technological Change is Constructed

- Socially (push and objection)
- Economically (incentives, opportunities)

- Institutionally (furthering or blocking)
- Regulatory (mandated or rejected)

- Actor based (joint expectations, coordination, agreed “trajectories”

Auswirkungen eines mit 60 km/h fahrenden Zuges auf die Umgebung (1862)

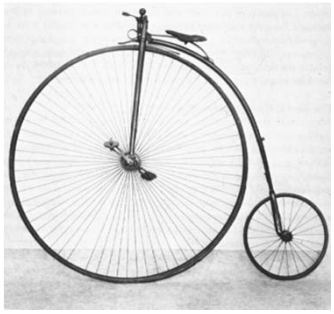


Lok-Führer und Heizer auf einem mit 60 km/h fahrenden Zug (1862)

Innovation: Scepticism and Resistance in View of the Unknown

Speed kills..... 19th century sceptical German cartoons reflecting Science's (Prussian Academy of Sciences) verdict

The Social Construction of Technology: The Bicycle (betting on the wrong horse allows breeding a new one)



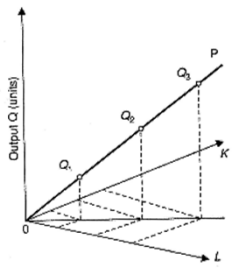
Rover Safety Bike 1895

More: Bijker, Wiebe E., Thomas P. Hughes, and Trevor J. Pinch, eds. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press, 1987.

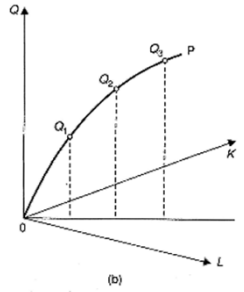
Technological Change: Key Concepts

- Returns to scale (scale, knowledge/experience)
- Economies of scale & scope
- Knowledge/Learning (multiple sources)
- Uncertainty (innovation, diffusion, returns)
- Interdependence (complexity)
- Life cycle

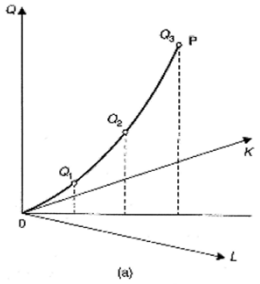
Constant Returns to Scale (heroic assumption)



Decreasing Returns to Scale
(equilibrium economics, size/scale)



Increasing Returns to Scale
(knowledge/learning, networks, agglomerations)

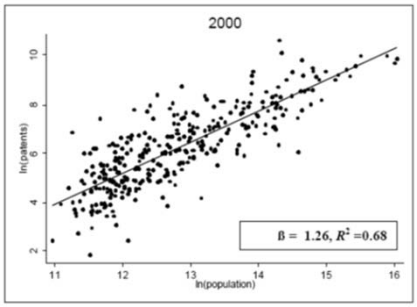


Few models (except IIASA) as non-convex (stochastic) optimization

Increasing Returns

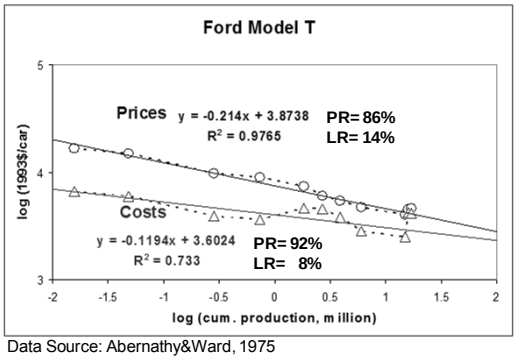
- Firmly established:
  cost improvements in manufacturing and with increasing market size
  ("learning"/"experience" curves)
- "new growth" theory: concept of knowledge stocks (need to include knowledge depreciation)
- Agglomeration and network externalities
  (R/S distribution, "laws": Zipf, Metcalfe,...)

Urban Scale and Inventive Activity (patents) 331 MSA in the US



Source: Bettencourt, Lobo & Strumsky, 2004, SFI WP 04-12-038

Improved Economics: Prices vs. Costs



Data Source: Abernathy&Ward, 1975

Learning/Experience Curve Terminology

Costs: *C*

Learning Rate: *LR*
(% cost decline per doubling of output)

Progress Ratio: *PR* = 1 – *LR*
(remaining fraction of initial costs after doubling of output)

Learning parameter: *b*

Output: *O*

Learning investment: Cumulative expenditures above break-even value

$C_t = C_0 * (\Sigma_0^t O)^{-b}$

$PR = 2^{-b}$

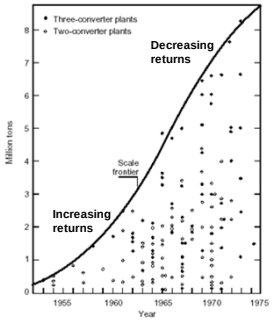
LR = 1 - *PR*

e.g. 30% cost reduction per doubling of output:
C_o =100 C_t = 70 O_o =1 O_t = 2 LR = .3 *PR* = .7 *b* = -.51477

Increasing Return to Scale (Steel Plants) →Economies of Scale

Note difference between:
Scale Frontier (leads)
Average scale (lags)

Source:
Rosegger, 1996.



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Economies of Scope

- Economic gains from:
  -- diversity
  -- product differentiation
  -- joint production (cogeneration, industrial symbiosis)
- No simple measurement and metrics
- Akin (often conflated) with:
  -- division of labor
  -- agglomeration externalities
  -- quality improvements

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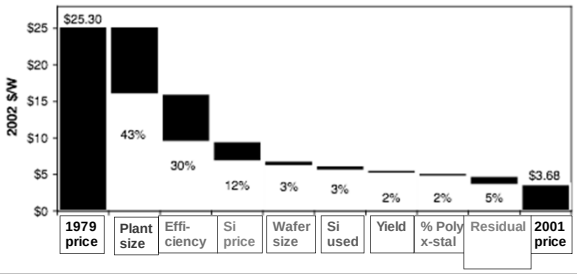
"Learning" from Multiple Sources: Factors in US PV Cost Declines 1979-2001:

Economies of Scale (43%), R&D (35%), Learning by Doing (5%), Others (17%)

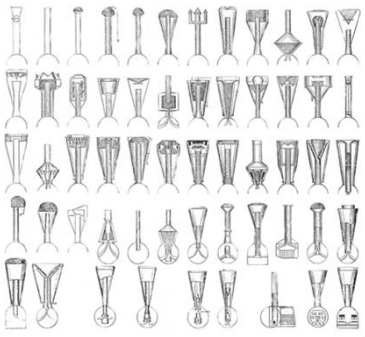


Source: Greg Nemet, 2004, 2008

Innovation & Diffusion Uncertainty

- "Heavier-than-air flying machines are impossible." Lord Kelvin, 1895.
- "I think there is a world market for maybe five computers." Tom Watson, IBM chair, 1943.
  - "But what ... is it good for?" IBM engineer commenting on the microchip in 1968
- "There is no need for any individual to have a computer in their home." Ken Olson, President, Digital Equipment, 1977.
- More fun: http://my.athenet.net/~jlindsay/SkepticQuotes.html

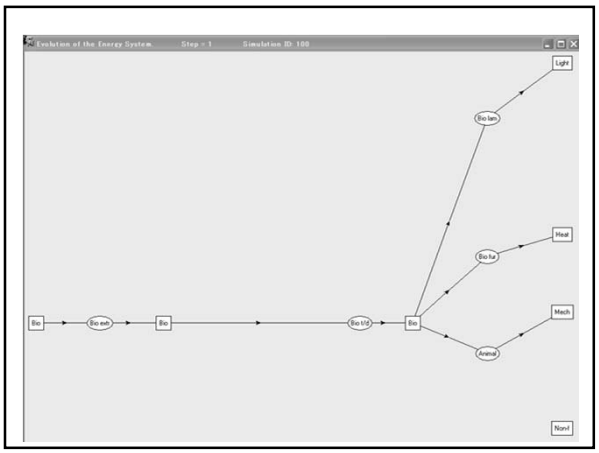
Innovation Uncertainty:
Patented but non-functional smoke-spark arrestors



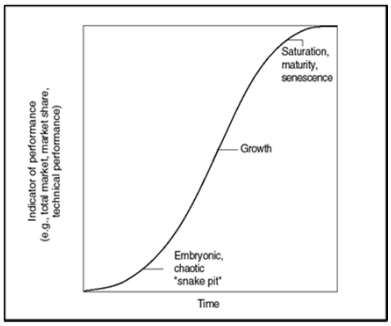
Source: J. White, *American Locomotives*, 1968.

Interdependence

- Markets: Supply – demand (manufacturing – marketing)
- Technological (e.g. electric cars + grid) need for standards (interoperability)
- Infrastructural (transport AND communication, electricity AND internet)
- Complexity



A Stylized Technology Life Cycle Model



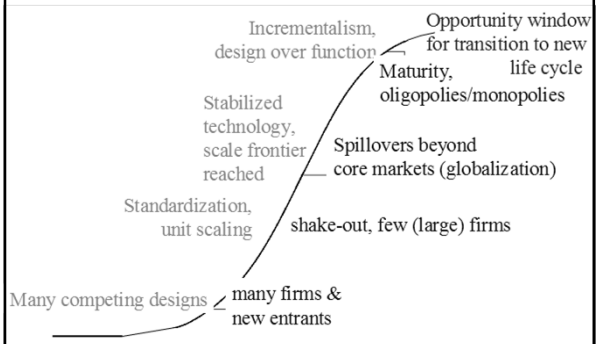
Technological Change

Stage	Measure/Mechanism
Invention	Basic R&D, breakthrough
Innovation	Applied research, demonstration plants
Niche markets	Investment, learning-by-doing and using
Commercialization	Standardization, mass production, economies of scale
Pervasive diffusion	

A Chronology of UK Railways

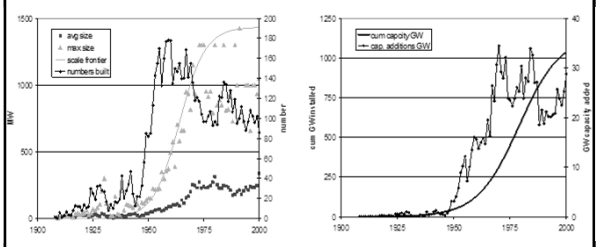
- **1769 Watt patents low-pressure steam engine -- invention**
- 1800 Watt patent expires
- 1820 40 km private horse railways
- **1824 Stevenson builds first locomotive plant -- (innovation)**
- 1825 Stockton-Darlington railway line opens
- **1830 Opening of Manchester-Liverpool, national railway network: 157 miles (niche market)**
- 1845 3931 km railways (.2% of coal to London transported by rail)
- 1875 23,365 km railways (65% of London's coal arrives by rail) – diffusion midpoint
- **1920s: 32,846 km railways (70-80% of all goods and passenger traffic by rail) – saturation and onset of decline**

Industry and Technology Dynamics over a Life Cycle



World – Coal Fired Power Plants

(Data: Wilson, 2009 IIASA IR-09-29)



numbers built

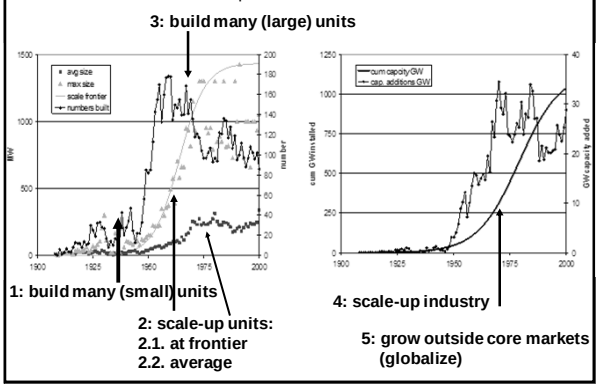
max and avg size of units built

capacity added each year

Cumulative capacity installed

5 Phases in Scaling-up Technology:

Example Coal Power Plants



Summary Block 1

- TC main source of productivity and output growth (and indirectly of environmental impacts)
- Tech= hardware+software+"orgware"
- Tech = embodied (artifact) + disembodied knowledge (know how, know why)
- Lifecycle stages: invention, innovation, niche markets, diffusion, senescence
- Dominant phase: Diffusion (adoption of new technologies)
- Social processes work at all stages (social construction of technology)
- Technology properties not *ex ante* given but constructed (innovation, economics, actor networks)
- Main drivers of change:
  - returns to scale and scope (+/-)
  - knowledge: learning (+), knowledge depreciation/obsolescence (-)
  - interdependence: spillovers, clustering (+/-)
  - uncertainty (-)