1

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 ($0>\alpha<1$)
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**

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

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	?	?

Technology

τεχνε λογοσ

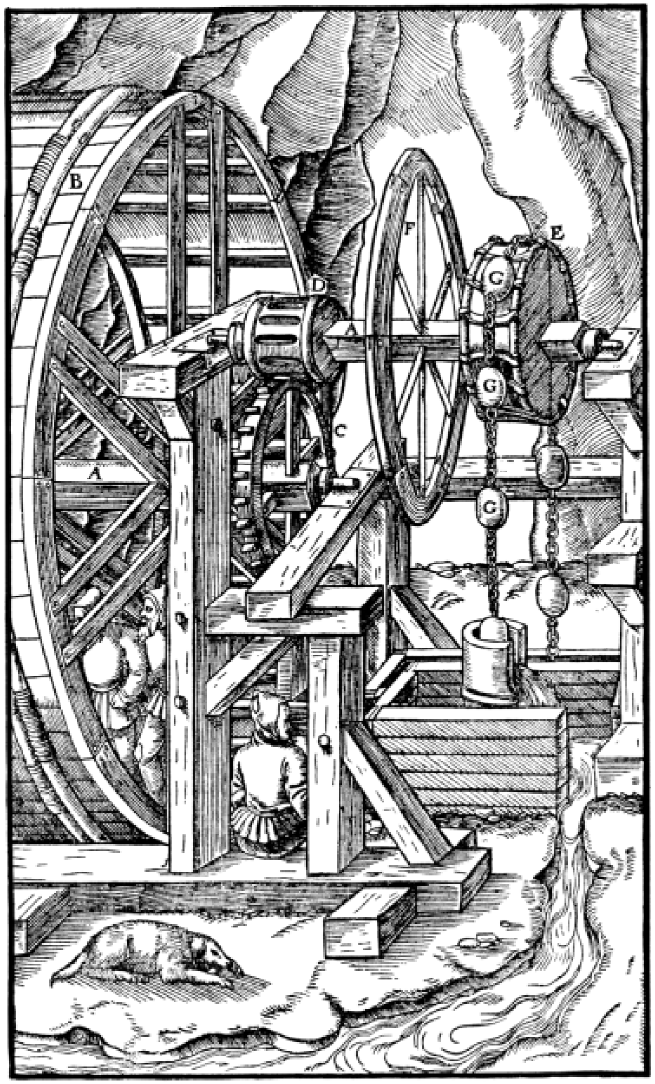
Origin: the science of the art of the practical

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

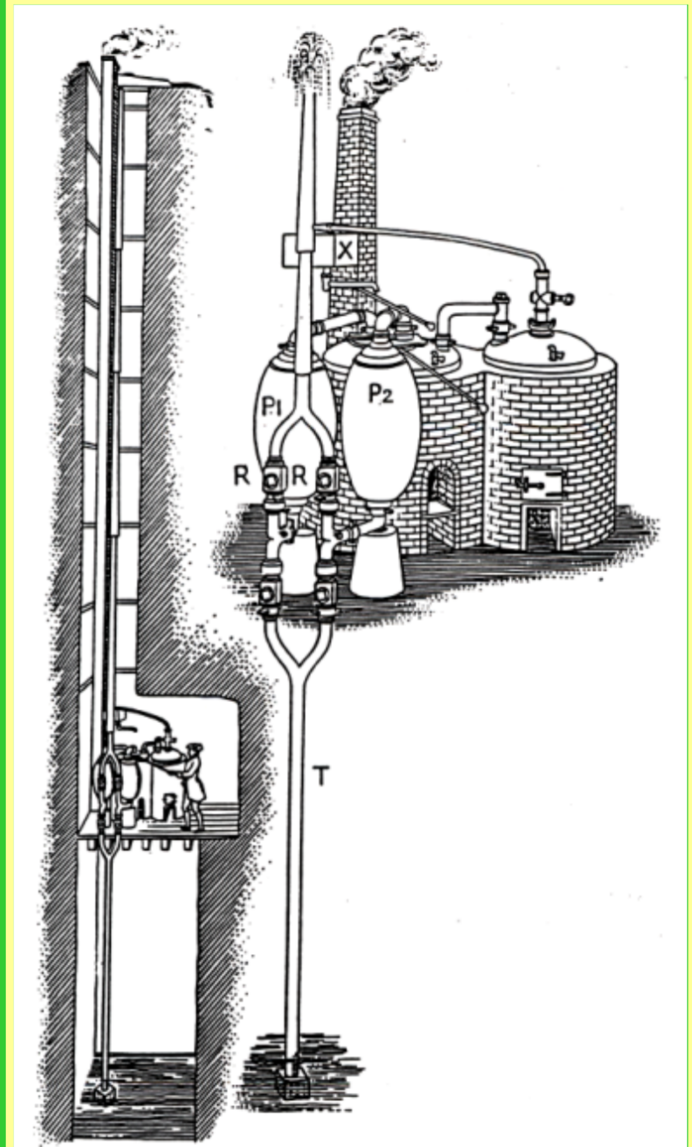
Creating Technological Knowledge (Usher's cumulative synthesis model)

- 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



A—Axles. B—Wheel which is turned by treading. C—Toothed wheel. D—Drum made of rundles. E—Drum to which are fixed iron clamps. F—Second wheel. G—Balls.



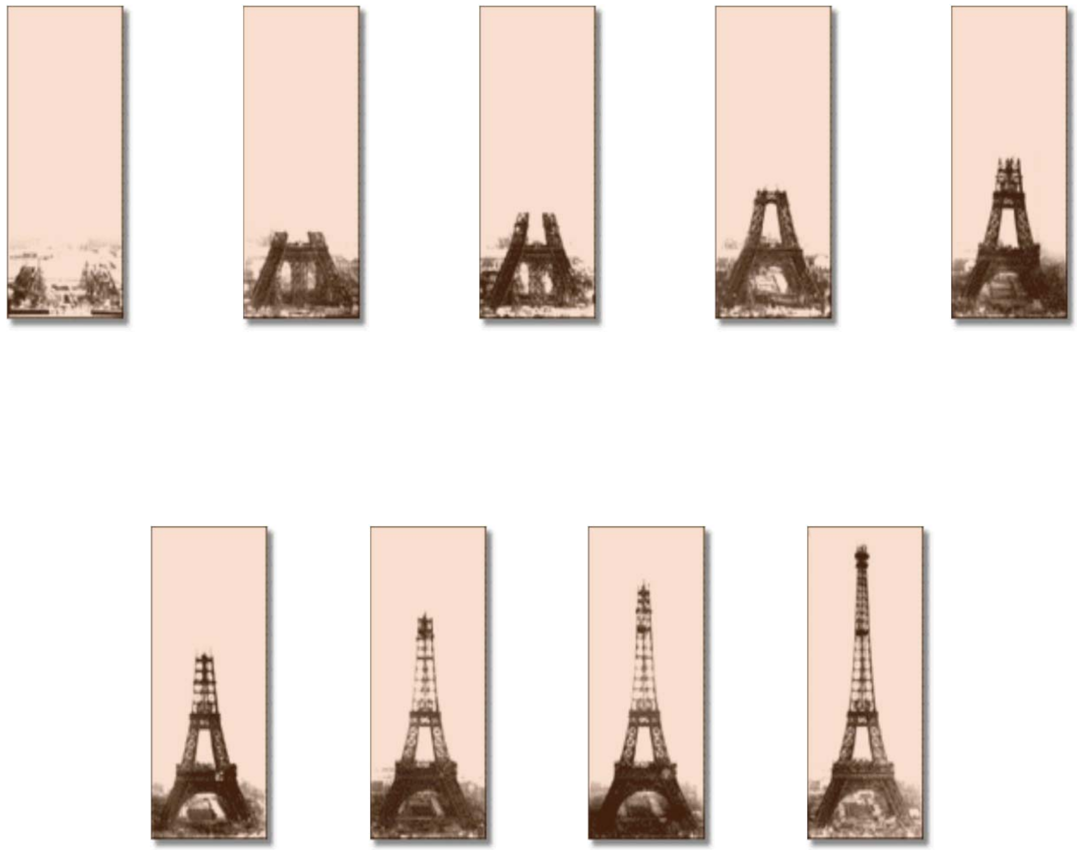
The Industrial Revolution

- 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

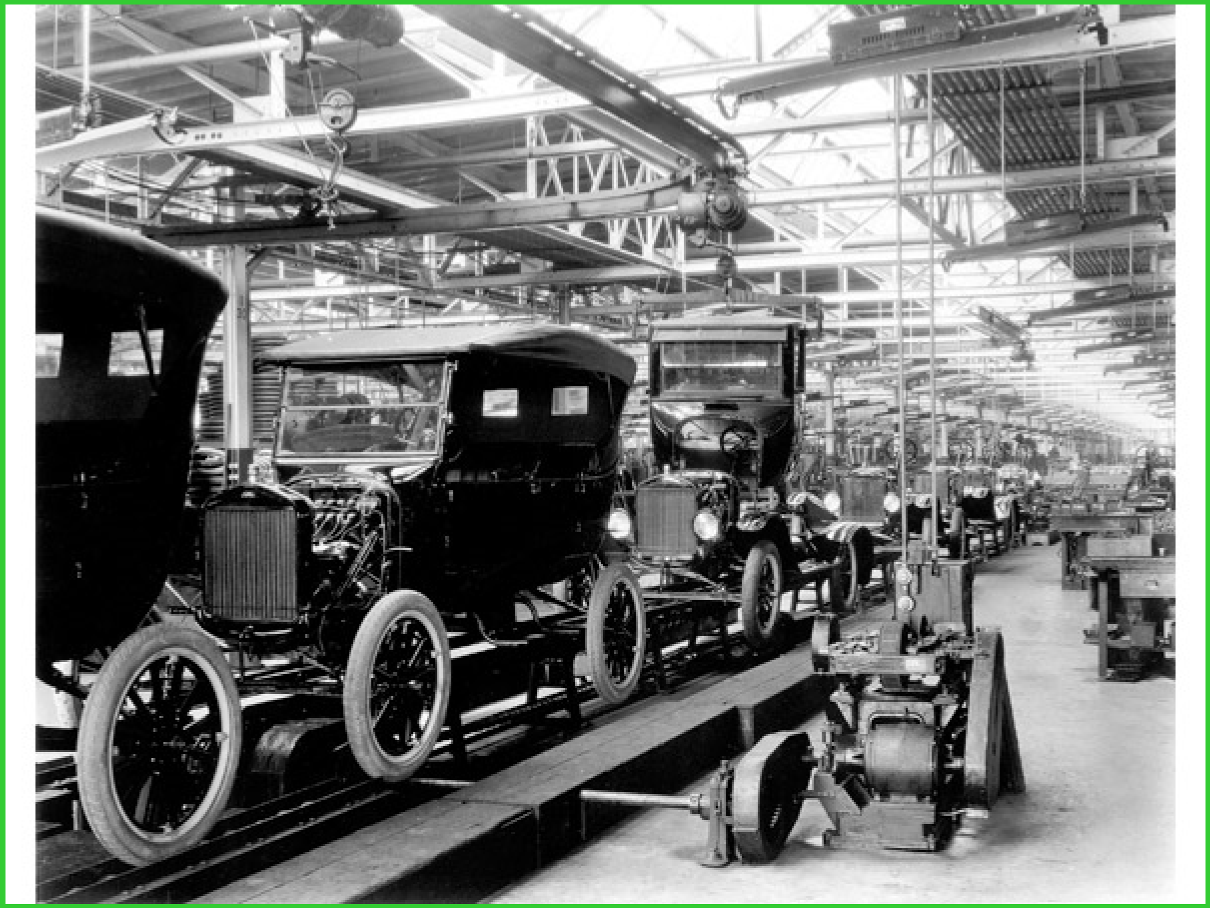
David Landes: *Prometheus Unbound*, *1969.*

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

New Steel Demand 1: Structures

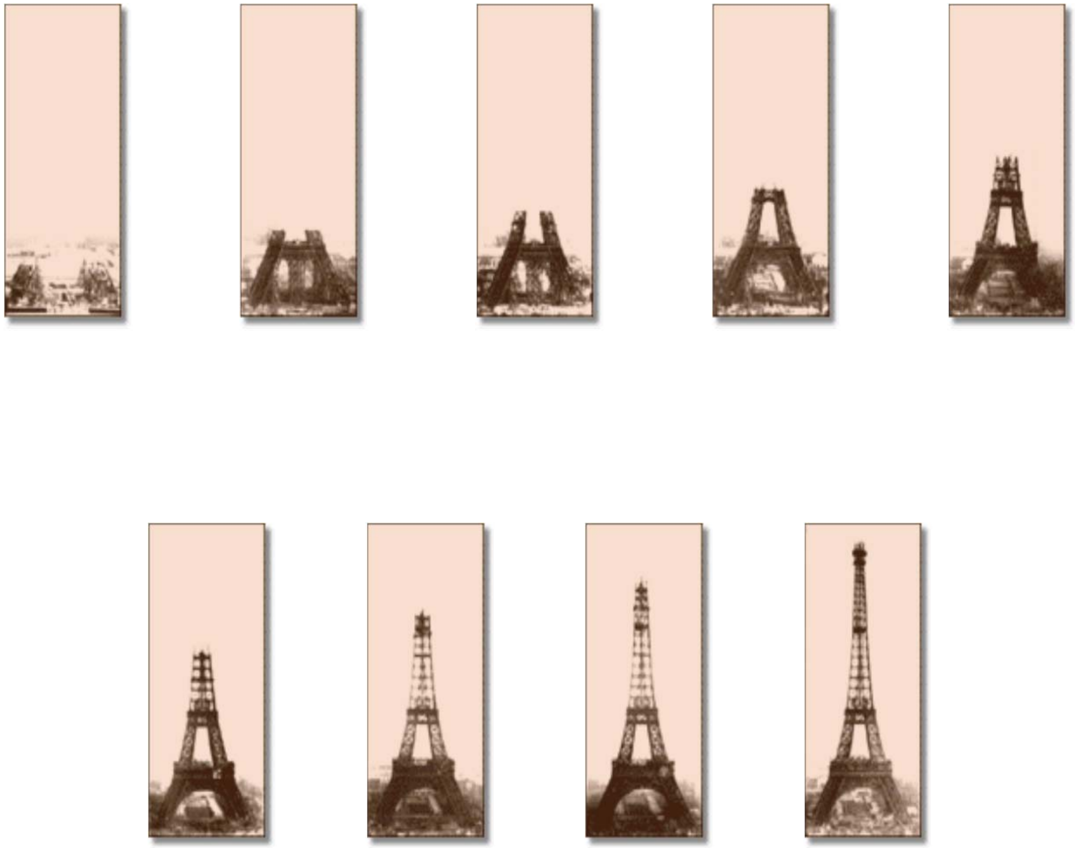


New Steel Demand 2:
Fordist Mass Manufacturing of Automobiles



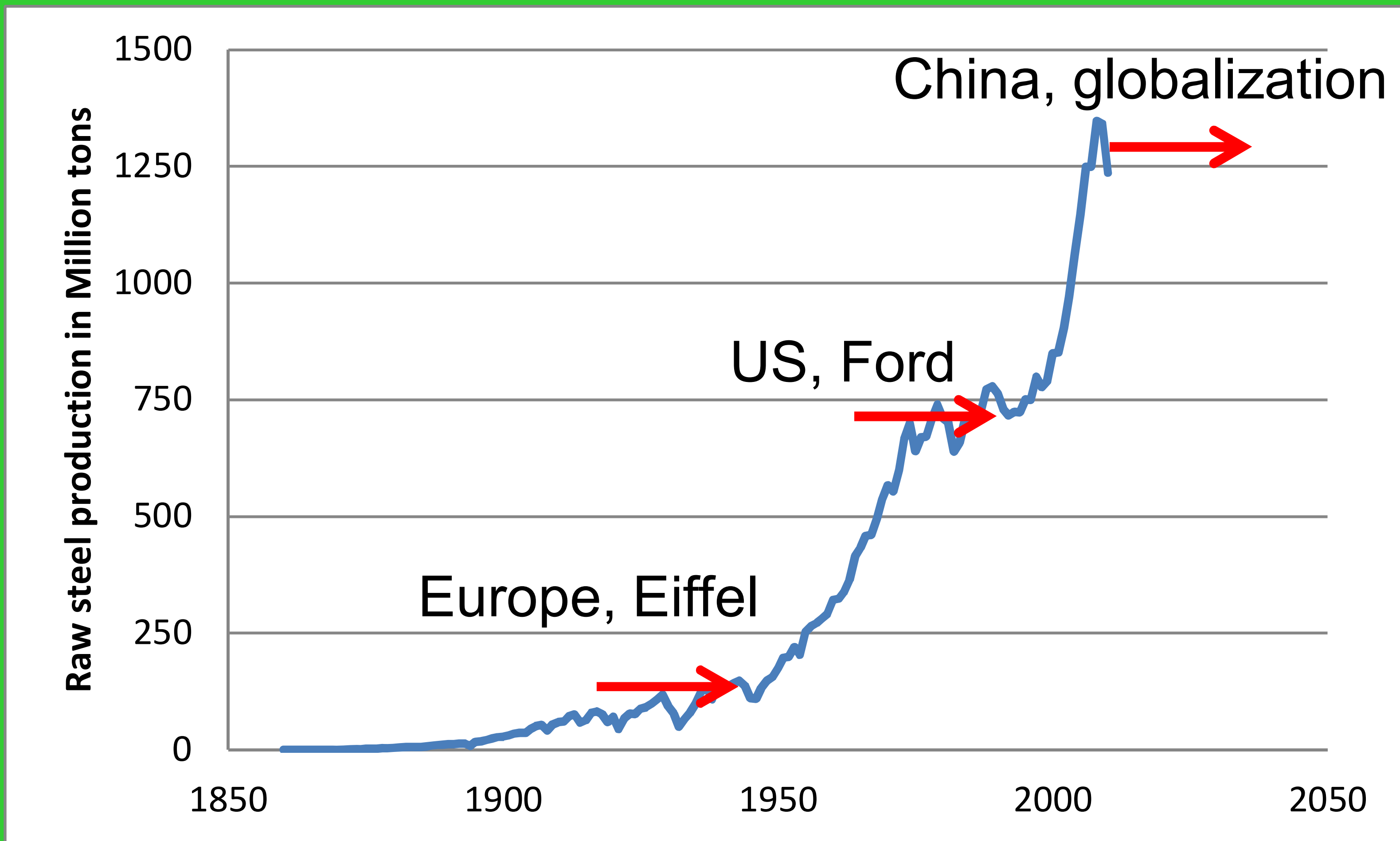
http://www.youtube.com/watch?feature=player_detailpage&v=nQhgC2vIqFQ

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



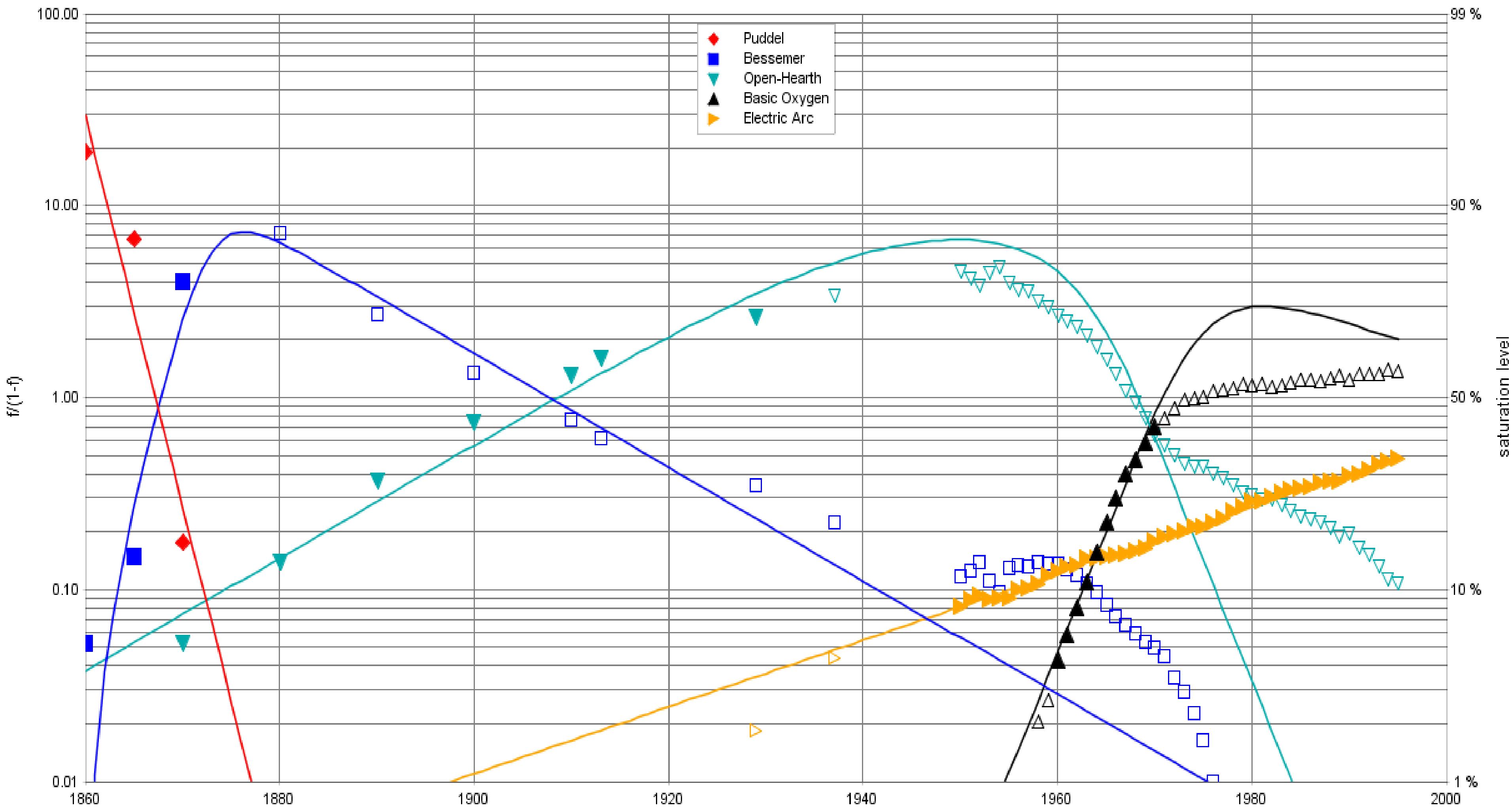
Growth to Limits

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):

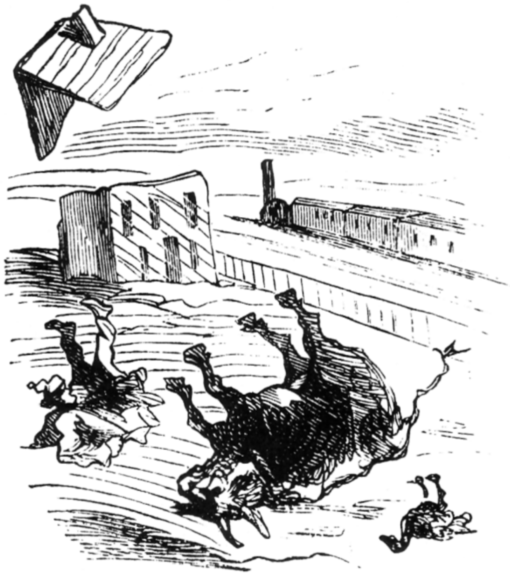
larger market size, but slower diffusion.

All Technological Change is Constructed

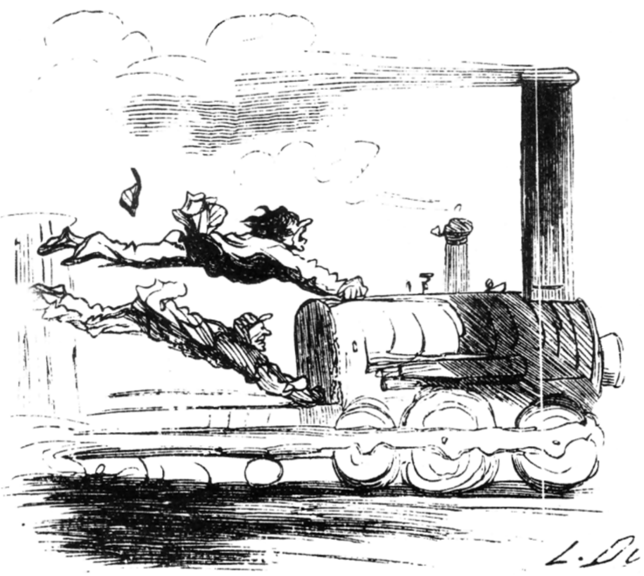
- Socially (push and objection)
- Economically (incentives, opportunities)

- 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

Arnulf Grübler

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

Arnulf Grübler

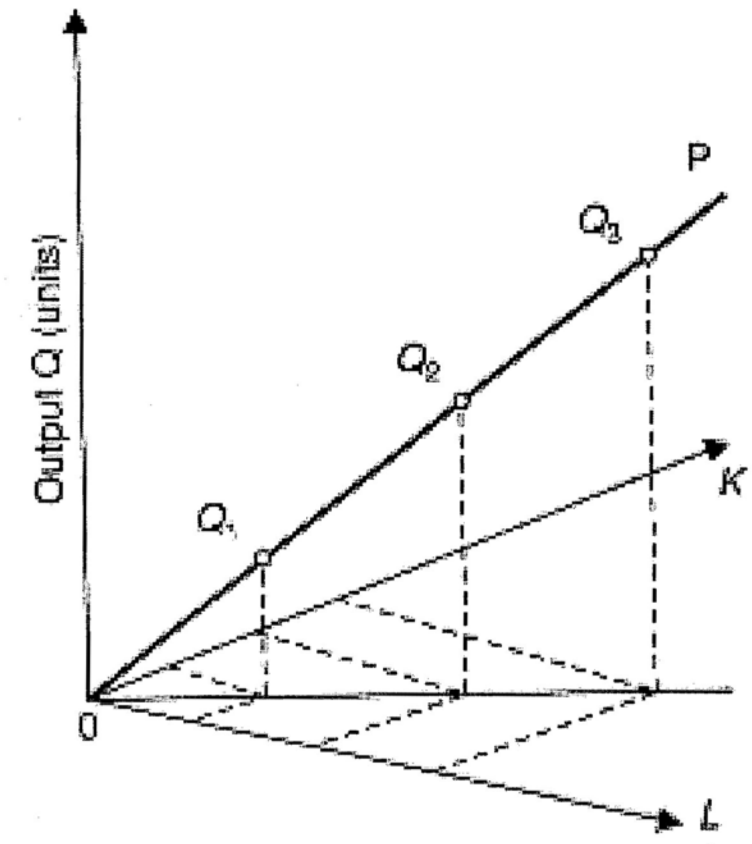
Rover Safety Bike 1895

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.

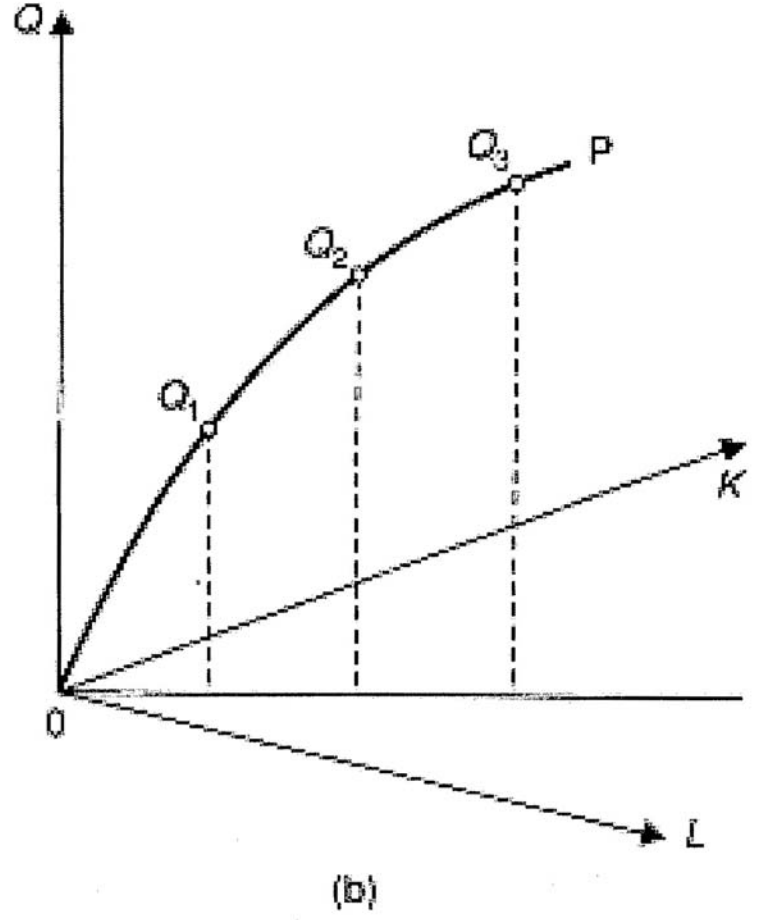
Technological Change: Key Concepts

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

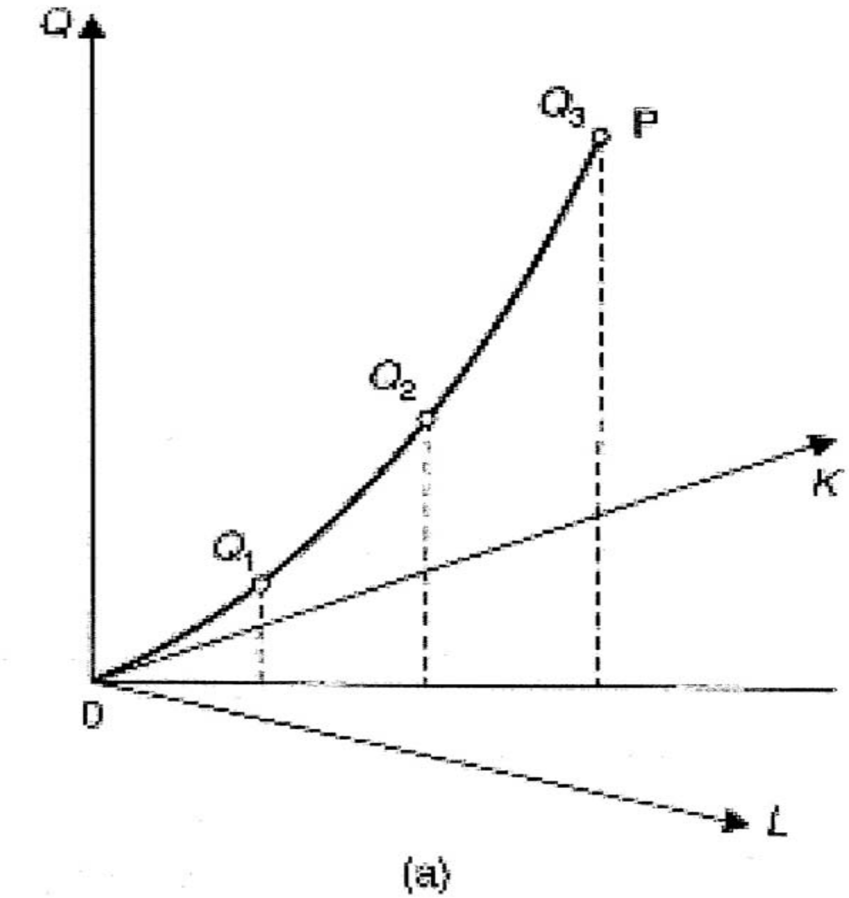
Constant Returns to Scale (heroic assumption)



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

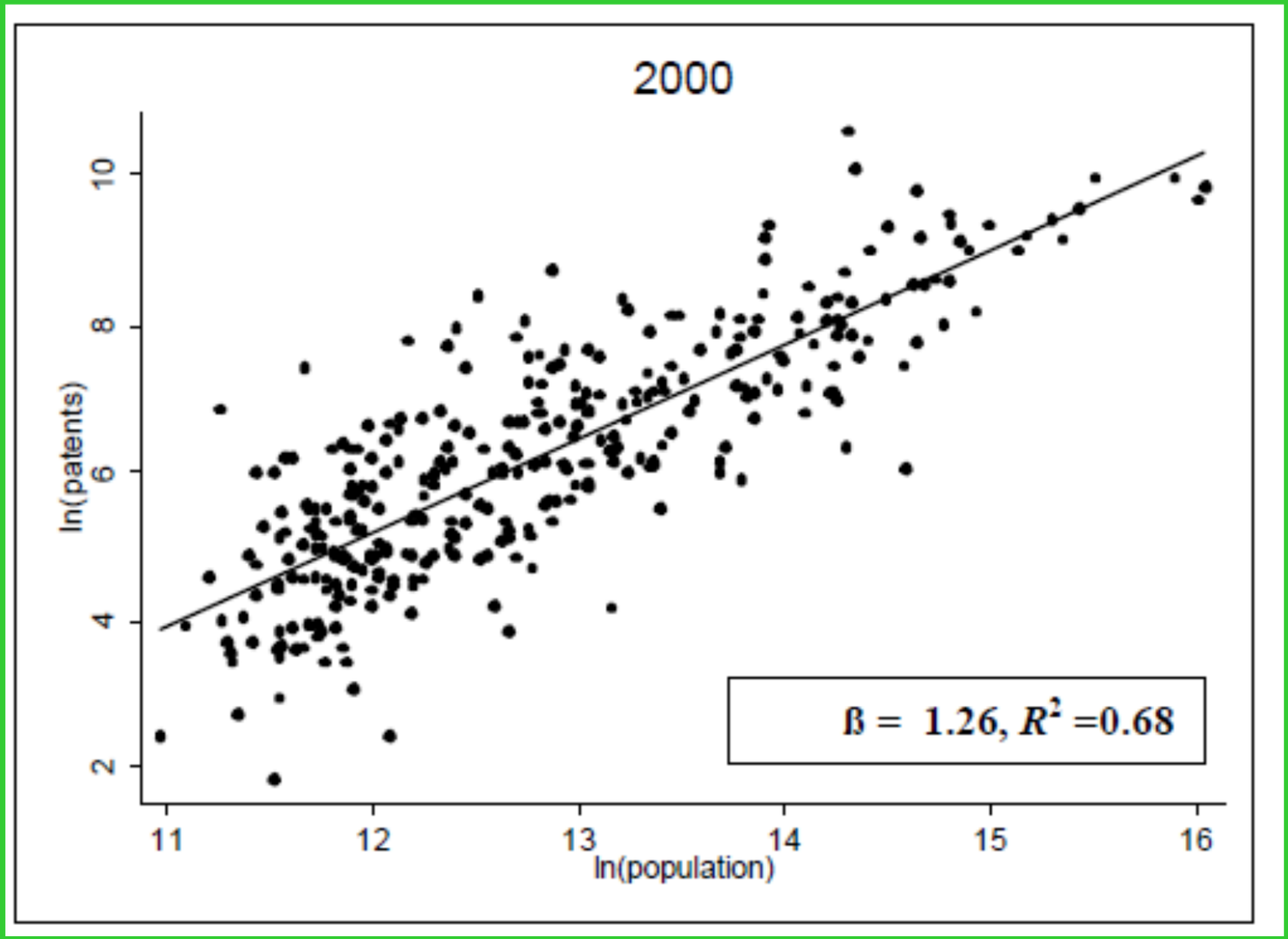
Increasing Returns

- 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)

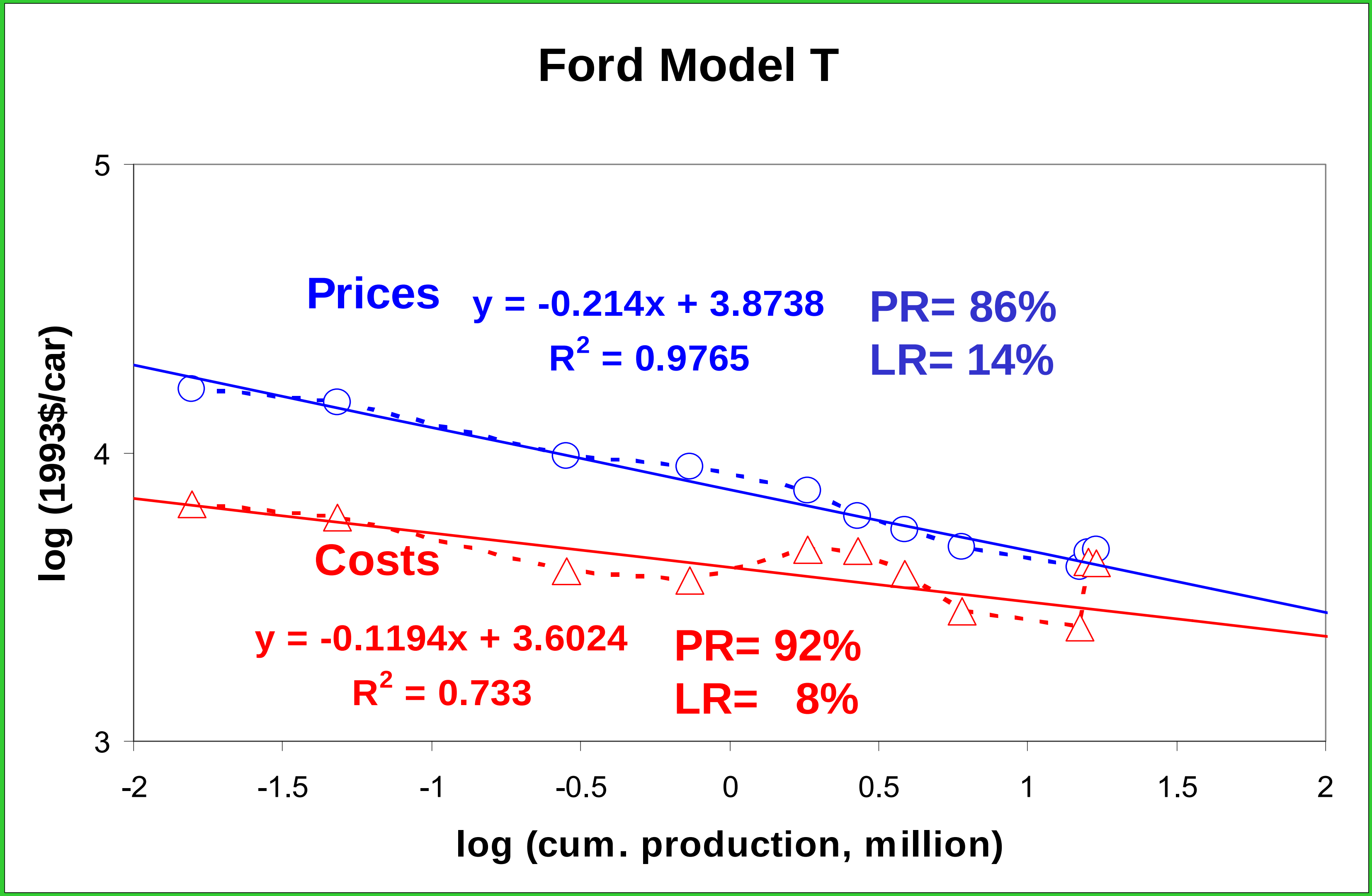
- Agglomeration and network externalities (R/S distribution, “laws”: Zipf, Metcalfe,...)

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

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

$PR = 2^{-b}$

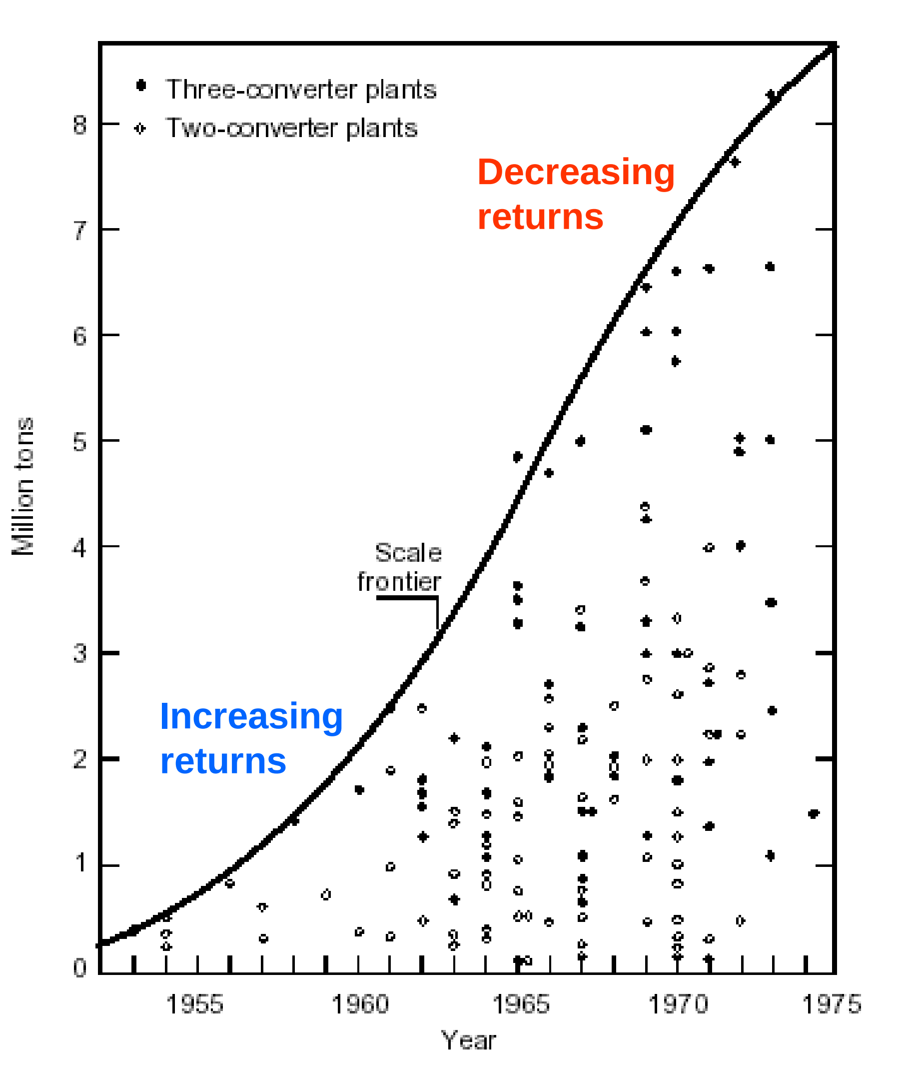
$LR = 1 - PR$

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.

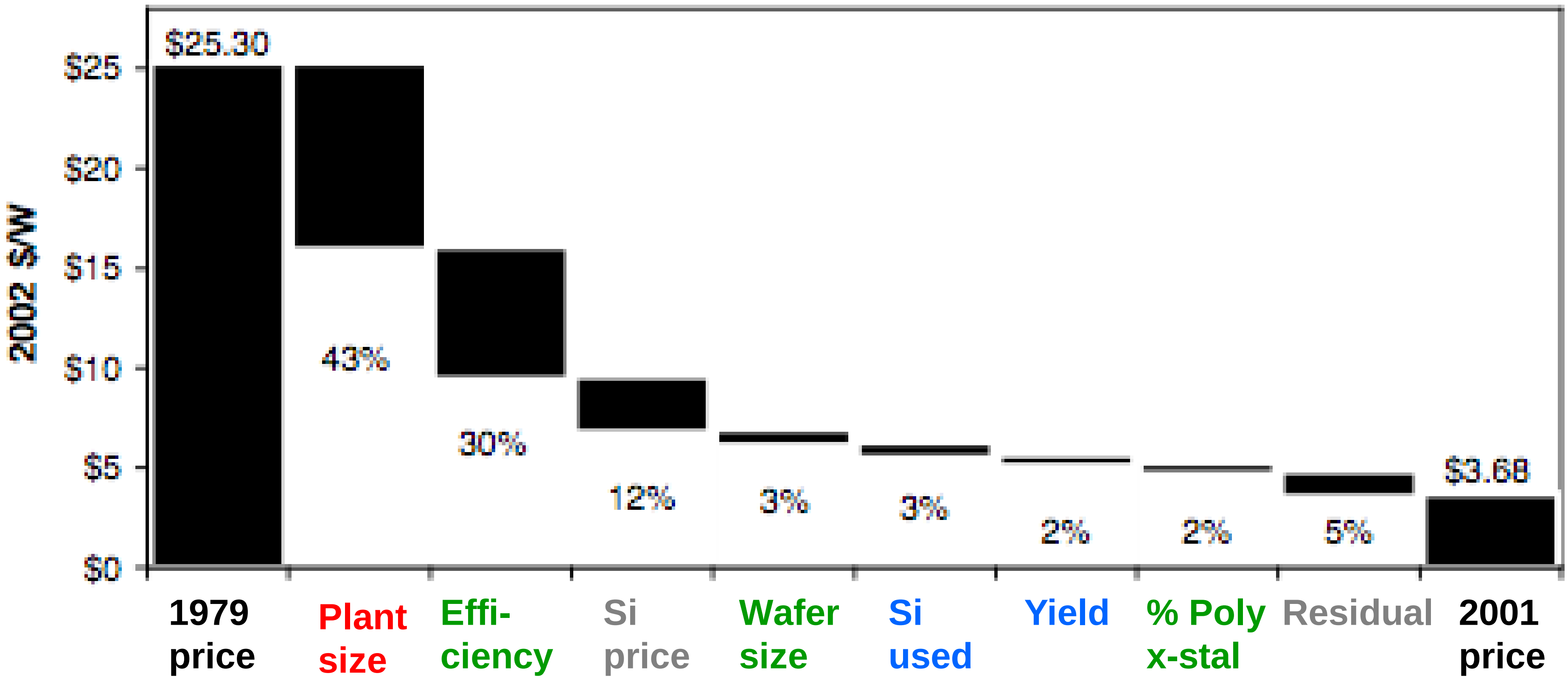
Arnulf Grubler

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

"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%)

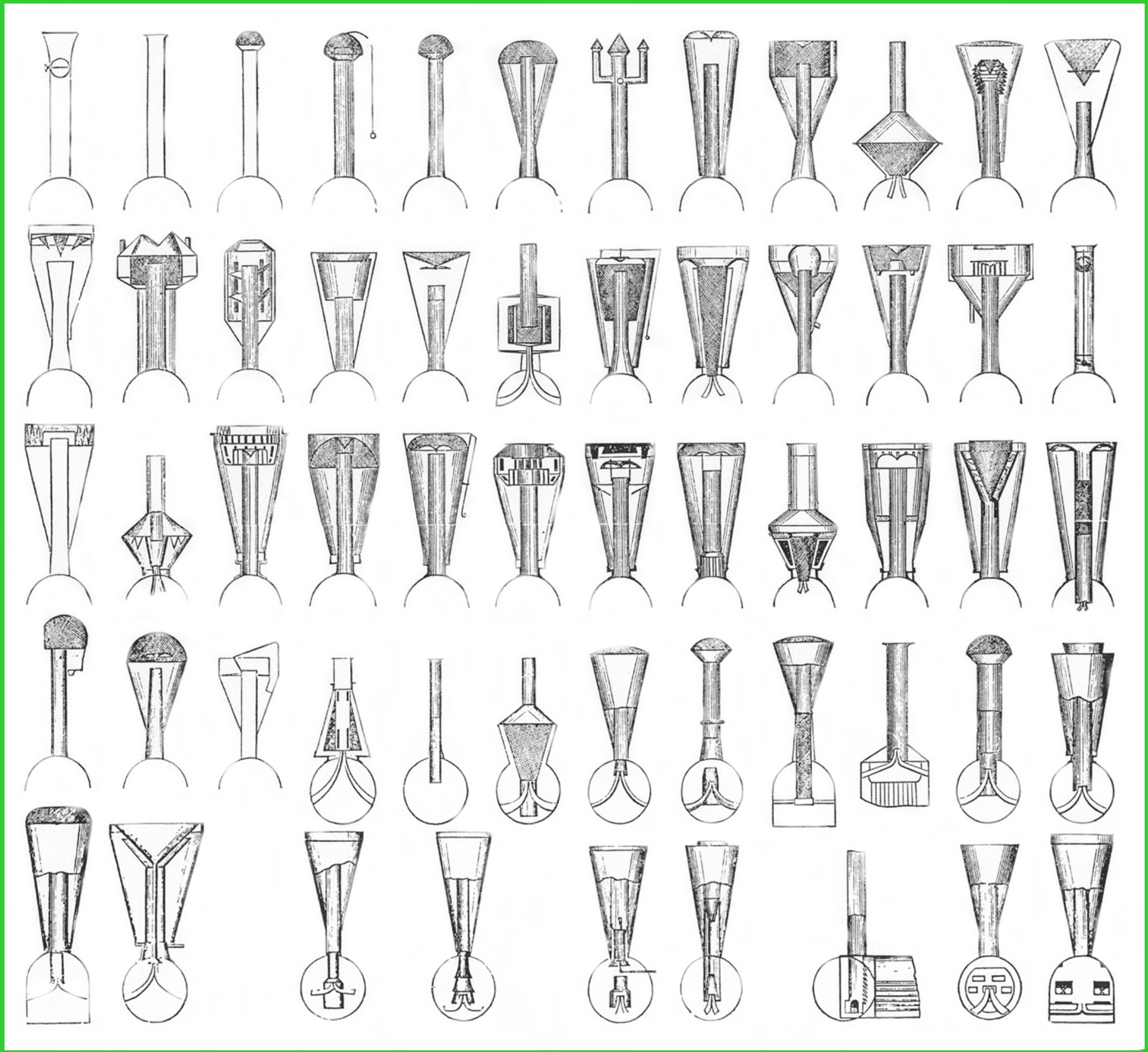


Source: Greg Nemet, 2004, 2008

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

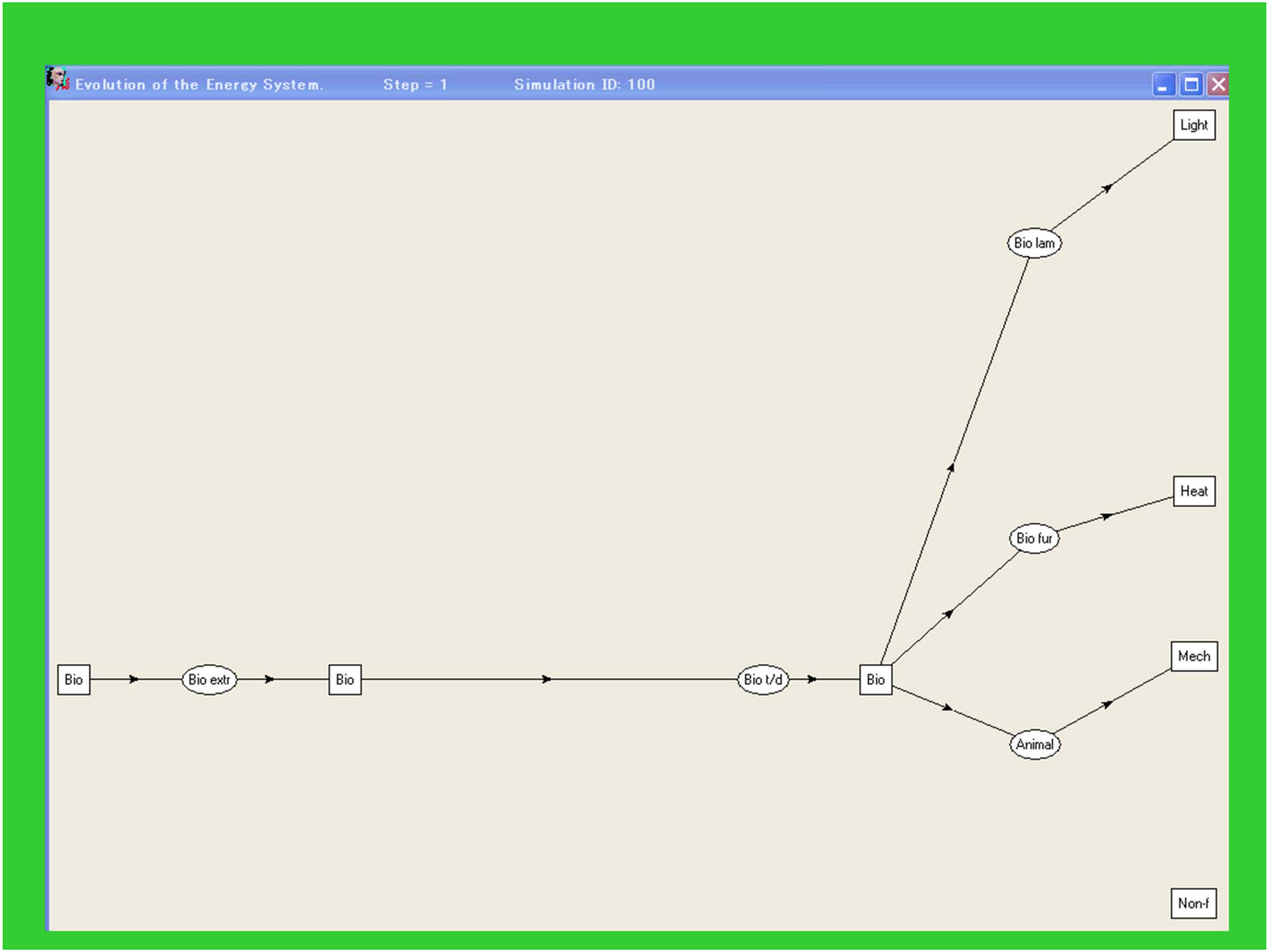
Innovation Uncertainty:
Patented but non-functional smoke-spark arrestors



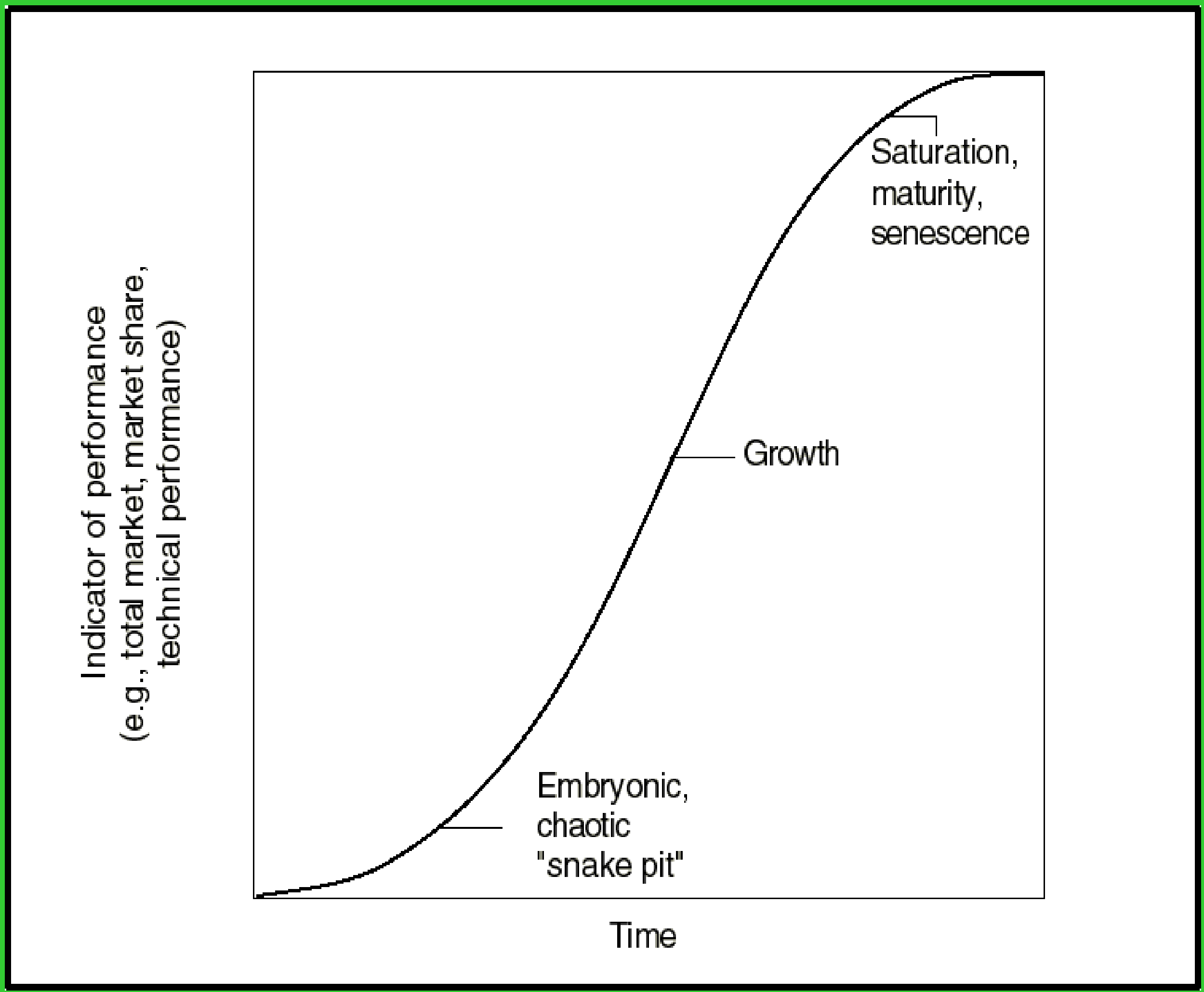
Source: J. White, *American Locomotives*, 1968.

Interdependence

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


Evolution of the Energy System.
Step = 1
Simulation ID: 100
Bio
Bio extr
Bio
Bio t/d
Bio
Bio lam
Bio fur
Animal
Light
Heat
Mech
Non-f

A Stylized Technology Life Cycle Model



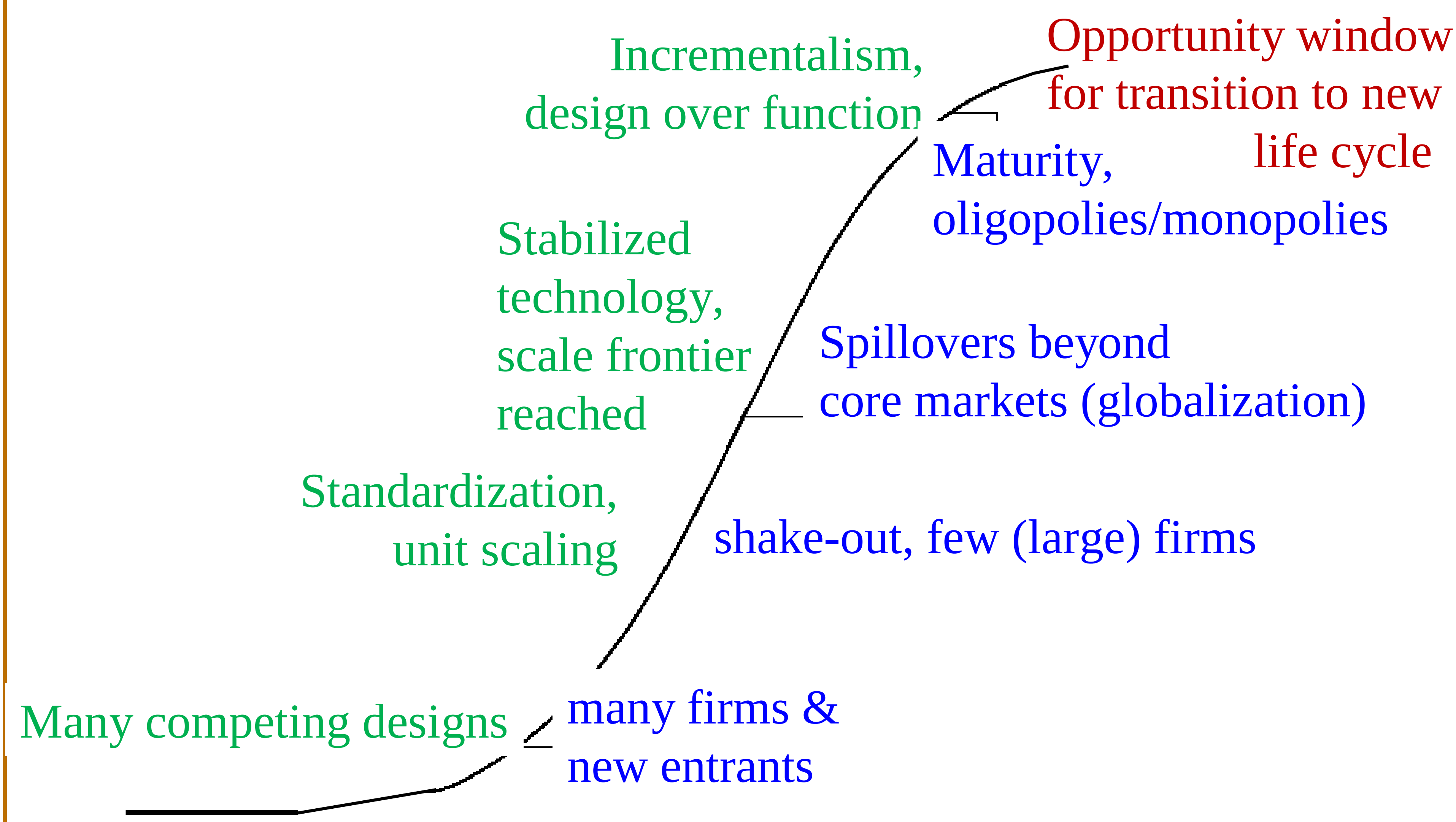
Technological Change

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

A Chronology of UK Railways

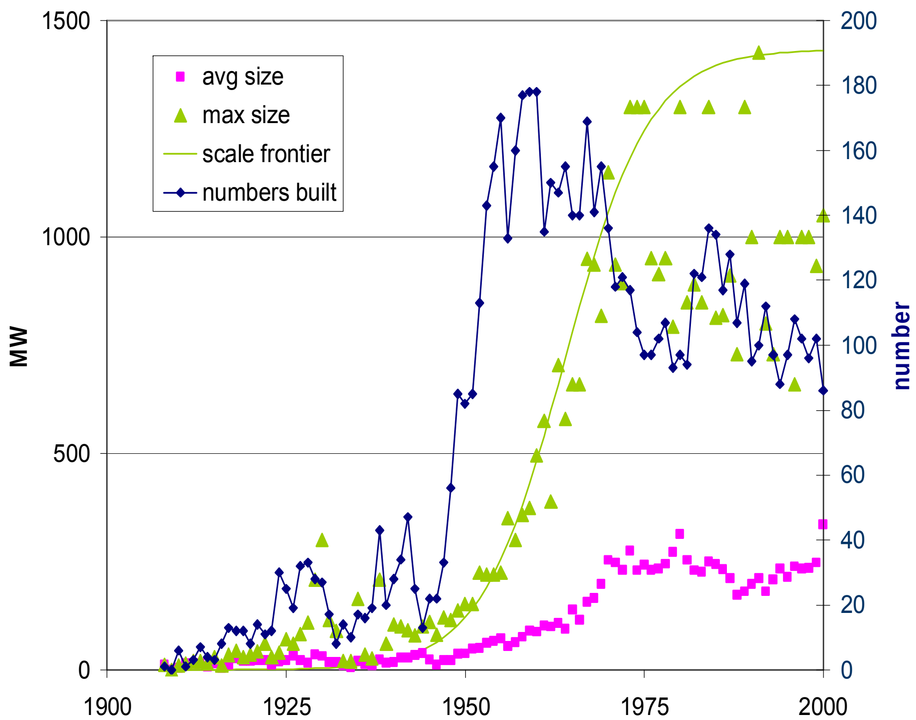
- **1769 Watt patents low-pressure steam engine -- invention**
- 1800 Watt patent expires
- 1820 40 km private horse railways
- **1824 Stevenson builds first locomotive plant -- (innovation)**
- 1825 Stockton-Darlington railway line opens
- **1830 Opening of Manchester-Liverpool, national railway network: 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**

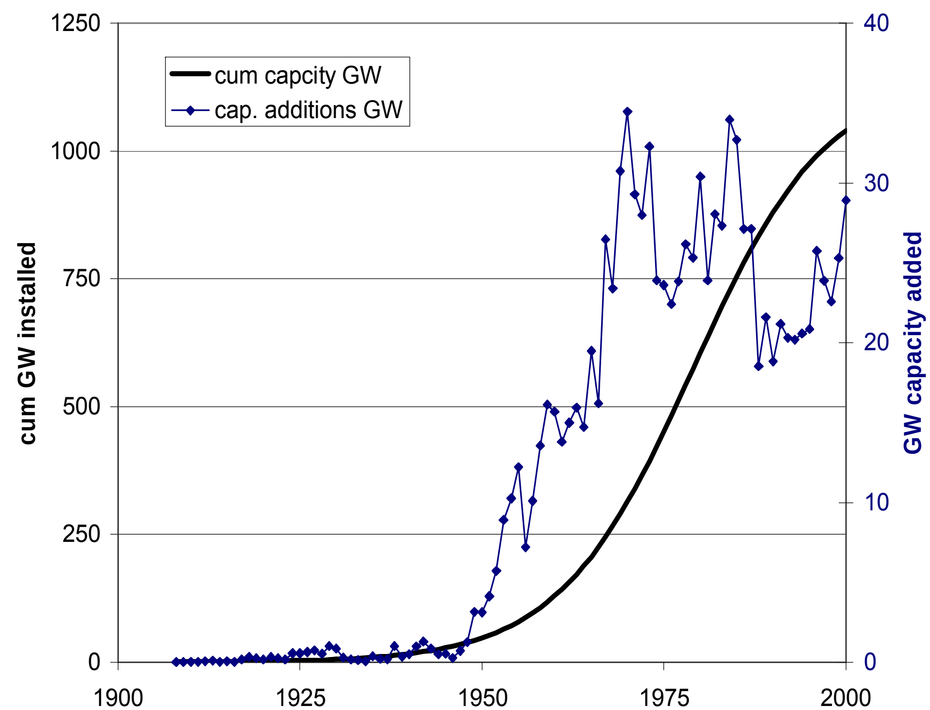
Industry and Technology Dynamics over a Life Cycle



World – Coal Fired Power Plants

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





numbers built

capacity added each year

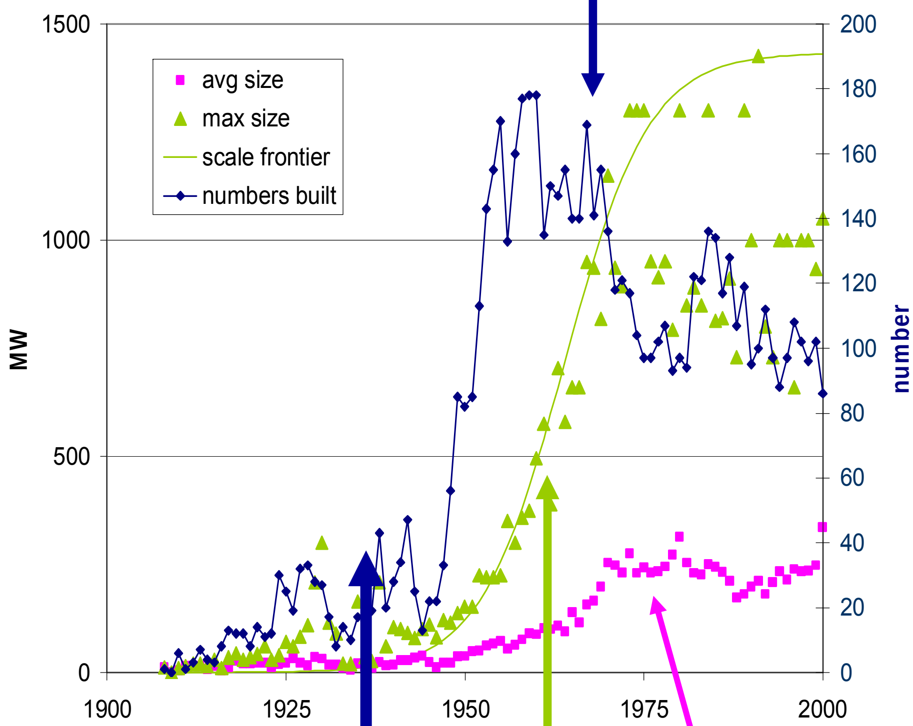
max and avg size of units built

Cumulative capacity installed

5 Phases in Scaling-up Technology:

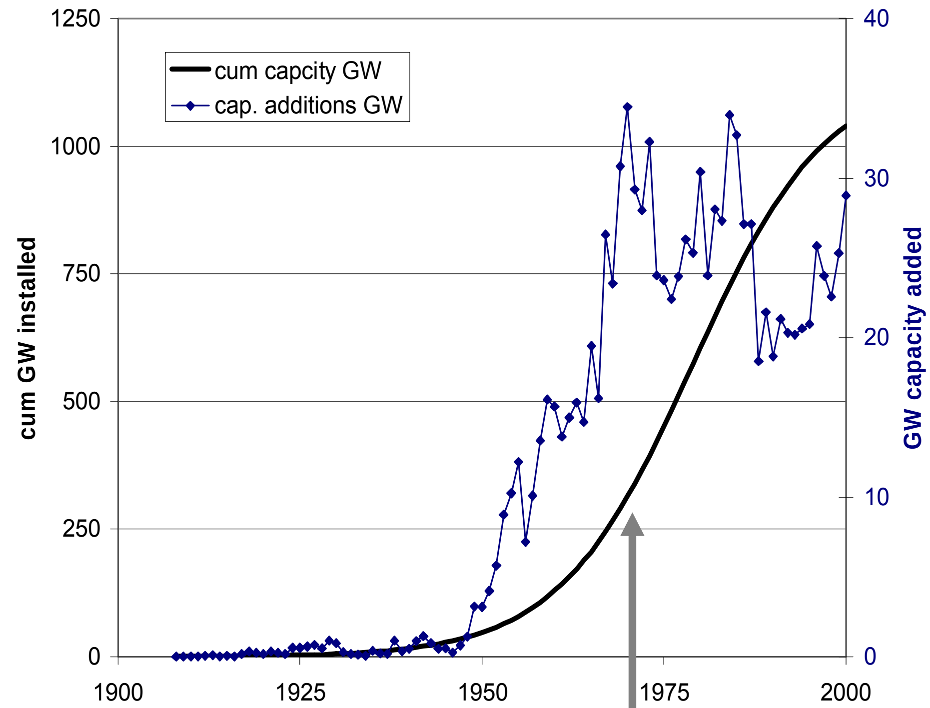
Example Coal Power Plants

3: build many (large) units



1: build many (small) units

2: scale-up units:
2.1. at frontier
2.2. average



4: scale-up industry

5: grow outside core markets (globalize)

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 (-)