The Second Law of Economics: Energy, Entropy, and the Origins of Wealth

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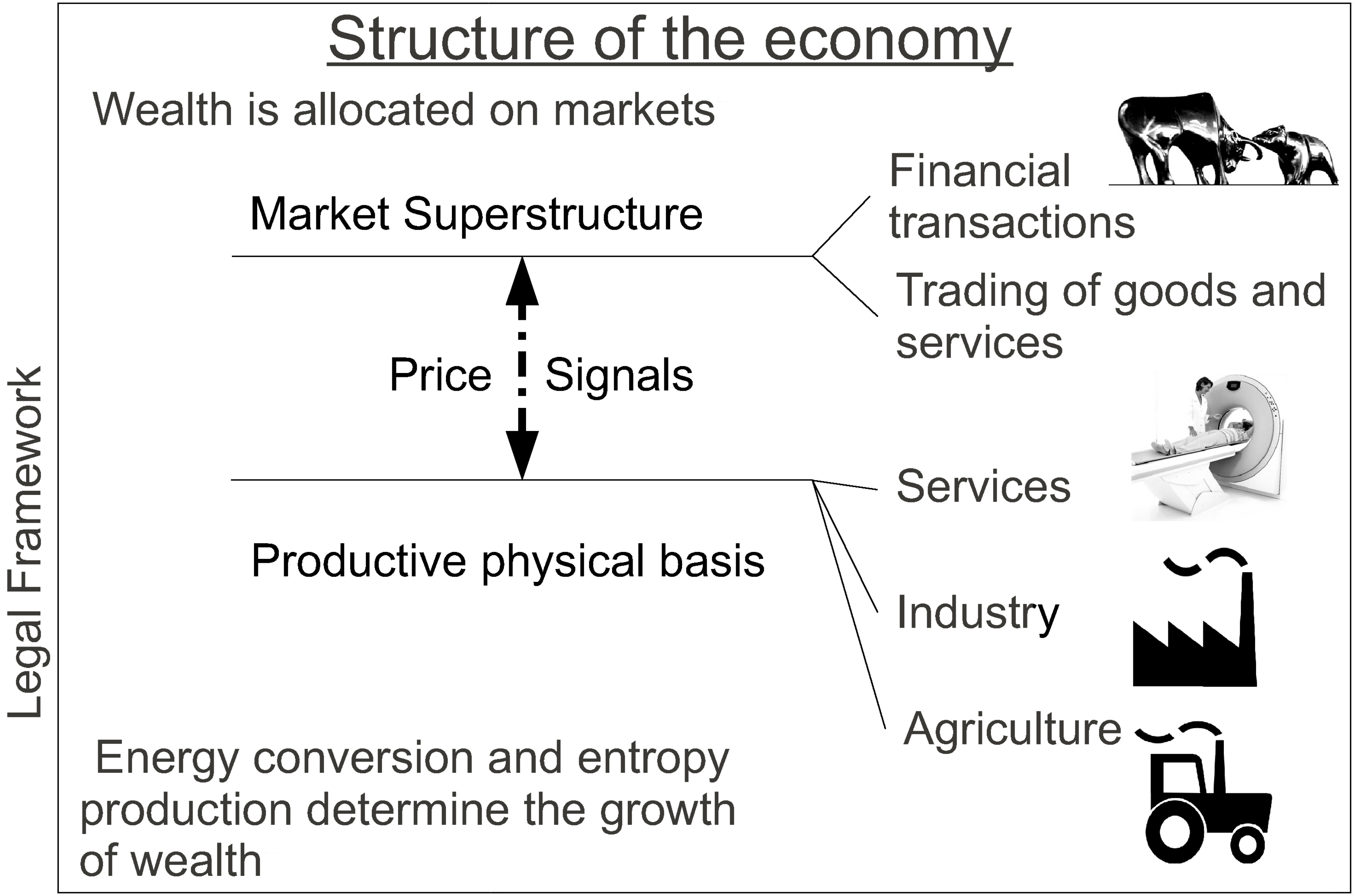
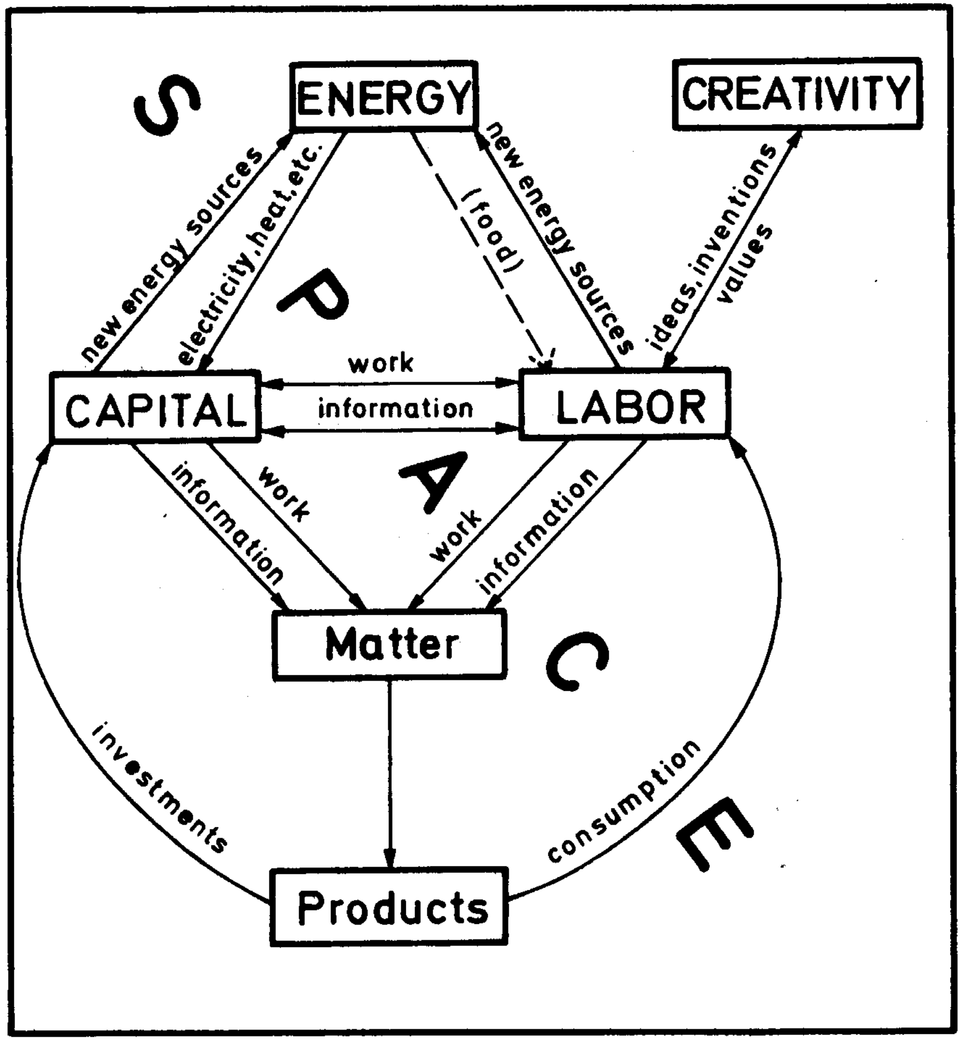
Program

1. The First and the Second Law of Economics
2. Energy and Economic Growth
3. Productive Powers of Capital, Labor, Energy, and Creativity
4. Economic Equilibrium with Constraints
5. Entropy Production and Emissions
6. Conclusions

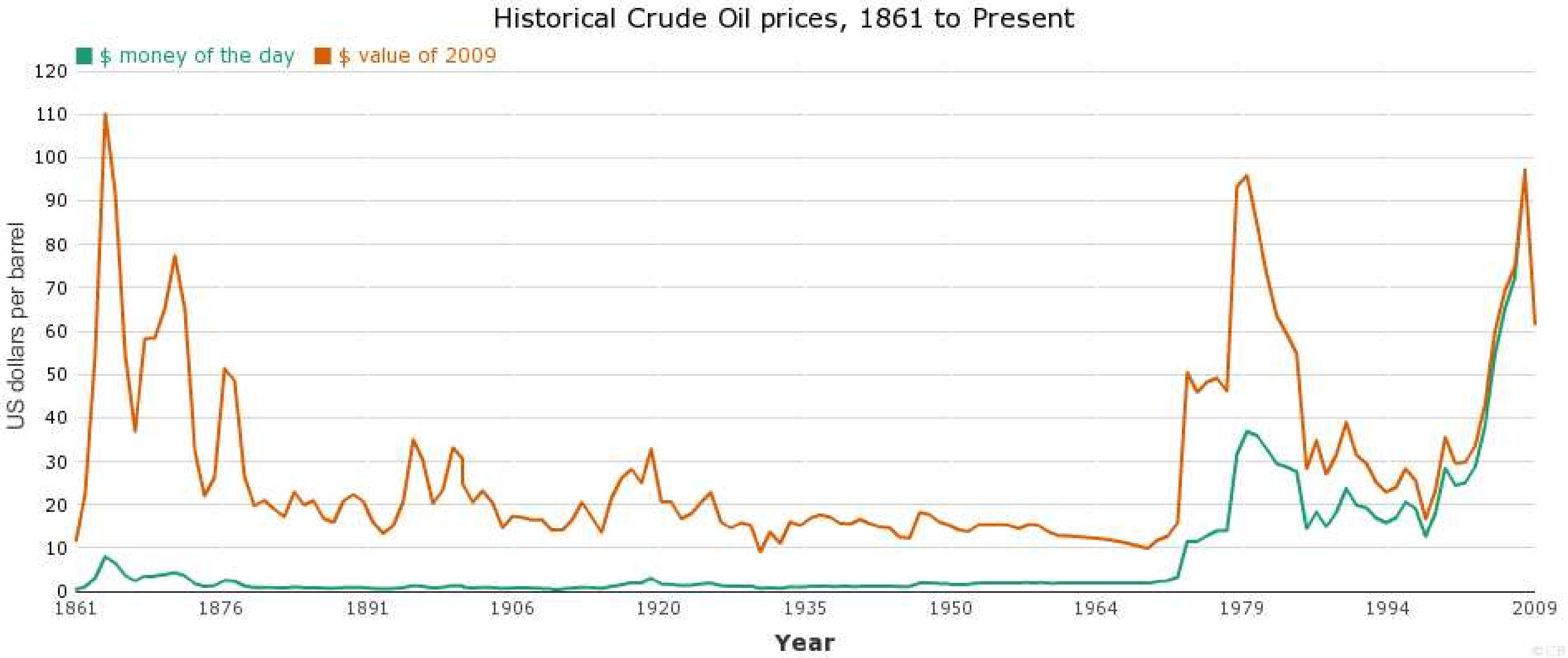
The 1st and the 2nd Law of Economics



Factors of the productive physical basis



Oil price explosions



Development of the price of one barrel of crude oil since 1861 in 2009 US dollar prices (*upper curve*) and in dollar prices of the day (*lower curve*)

Energy and economic growth

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- Energy E (measured, e.g., in Joules/year) activates the capital stock.
- Creativity C: human ideas, inventions and value decisions that affect the output.

KLEC model

Output (value added) and inputs at time t, normalized to their values Q_0, K_0, L_0, E_0 in the base year t_0:

$q(t) = Q(t)/Q_0$ (normalized output),

$k(t) = K(t)/K_0$ (normalized capital stock),

$l(t) = L(t)/L_0$ (normalized labor),

$e(t) = E(t)/E_0$ (normalized energy input).

Creativity causes an explicit time dependence of the

production function $q = q(k, l, e; t)$

that is used to describe mathematically the growth of output.

Growth Equation

Infinitesimal changes of output, dq, capital, dk, labor, de and time, dt are related to each other by the *growth equation* (which is obtained from the total differential of the production function):

$$\frac{\mathrm{d}q}{q} = \alpha \frac{\mathrm{d}k}{k} + \beta \frac{\mathrm{d}l}{l} + \gamma \frac{\mathrm{d}e}{e} + \delta \frac{\mathrm{d}t}{t - t_0} \quad .$$

The **output elasticities**

$$\alpha(k,l,e) \equiv \frac{k}{q}\frac{\partial q}{\partial k}, \quad \beta(k,l,e) \equiv \frac{l}{q}\frac{\partial q}{\partial l}, \quad \gamma(k,l,e) \equiv \frac{e}{q}\frac{\partial q}{\partial e}, \quad \delta \equiv \frac{t-t_0}{q}\frac{\partial q}{\partial t}$$

give the weights, with which relative changes of the production factors k, l, e and of time time t contribute to the relative change of output. In this sense they **measure the productive powers** of capital, labor, energy, and creativity.

Diff. equations for output elasticities

Production functions must be twice differentiable and linearly homogeneous in k, l and e at any fixed time t so that $\alpha + \beta + \gamma = 1$ and

$$\begin{aligned} k\frac{\partial \alpha}{\partial k} + l\frac{\partial \alpha}{\partial l} + e\frac{\partial \alpha}{\partial e} &= 0, \\ k\frac{\partial \beta}{\partial k} + l\frac{\partial \beta}{\partial l} + e\frac{\partial \beta}{\partial e} &= 0, \\ l\frac{\partial \alpha}{\partial l} &= k\frac{\partial \beta}{\partial k}. \end{aligned}$$

The most general solutions of these equations are:

$$\alpha = A(l/k, e/k), \qquad \beta = \int \frac{l}{k}\frac{\partial A}{\partial l}\mathrm{d}k + J(l/e).$$

Output elasticities

Special solutions of the three coupled differential equations:

- Trivial solutions: constants $\alpha_0, \beta_0, \gamma_0 = 1 - \alpha_0 - \beta_0$.
- Simplest non-trivial solutions, satisfying asymptotic technical-economic boundary conditions:

  $\alpha = a\frac{l+e}{k}$

  (Law of diminishing returns),

  $\beta = a(c\frac{l}{e} - \frac{l}{k})$

  (Substitution of labor by energy and capital as automation increases),

  $\gamma = 1 - \alpha - \beta$

  (At a given point in time the weights with which capital, labor and energy contribute to the growth of output add up to 100 %).

Production Functions

Insert the output elasticities into the growth equation and integrate.

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Using the constants $\alpha_0, \beta_0, \gamma_0$ one obtains the energy-dependent Cobb-Douglas production function $q_{CDE} = q_0 k^{\alpha_0} l^{\beta_0} e^{\gamma_0}$.
Neoclassical cost-share weighting:
$\alpha_0 \approx 0.25, \quad \beta_0 \approx 0.70, \quad \gamma_0 \approx 0.05 \rightarrow$ Solow residual.

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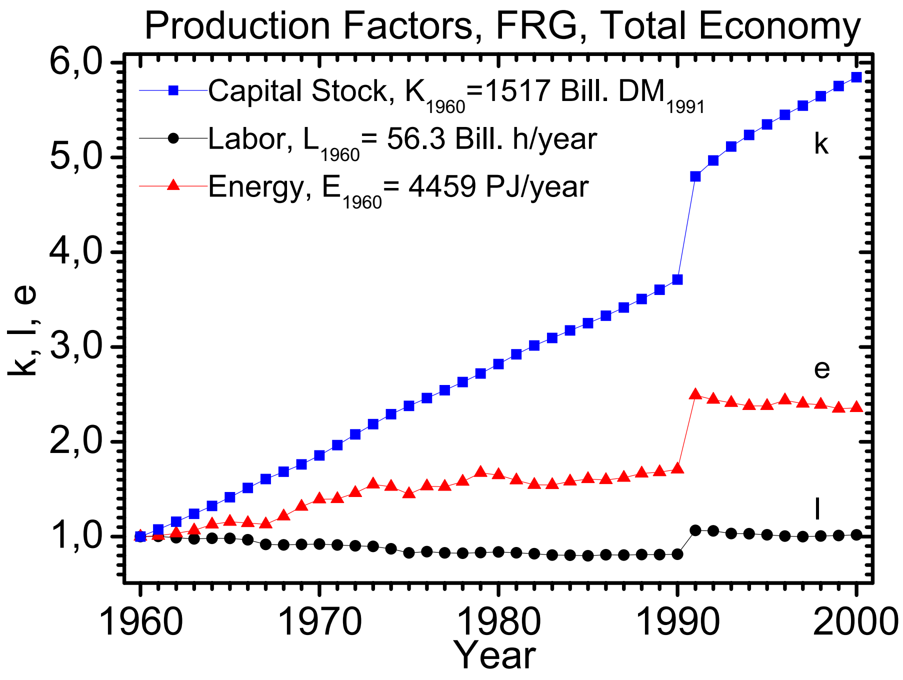
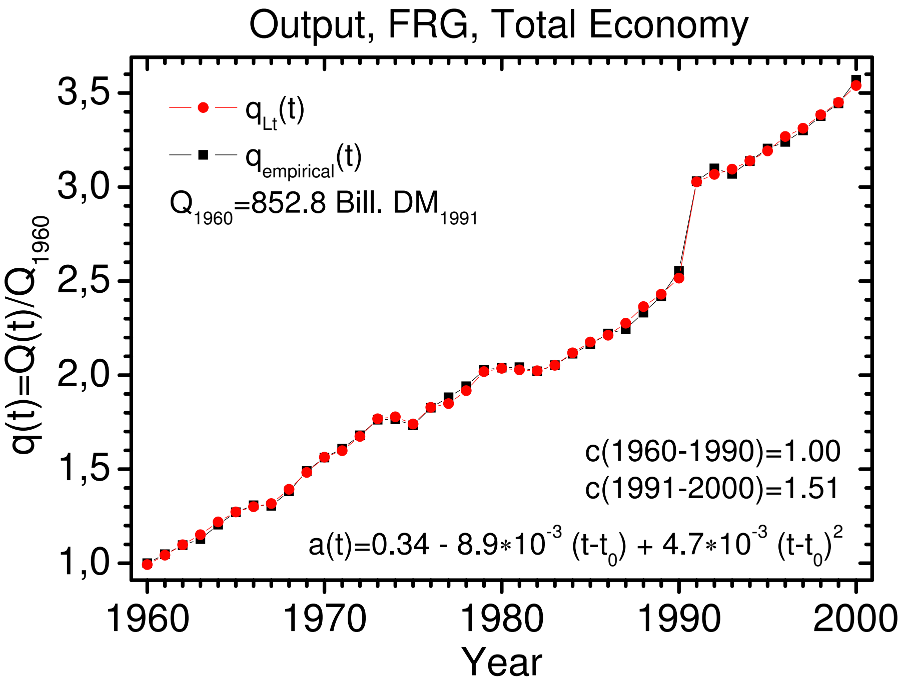
Using the non-trivial output elasticities one obtains the **time-dependent LINEX production function**:

$$q_{Lt}(t) = q_0 e \exp\left[a(t)(2 - \frac{l+e}{k}) + a(t)c(t)(\frac{l}{e} - 1)\right].$$

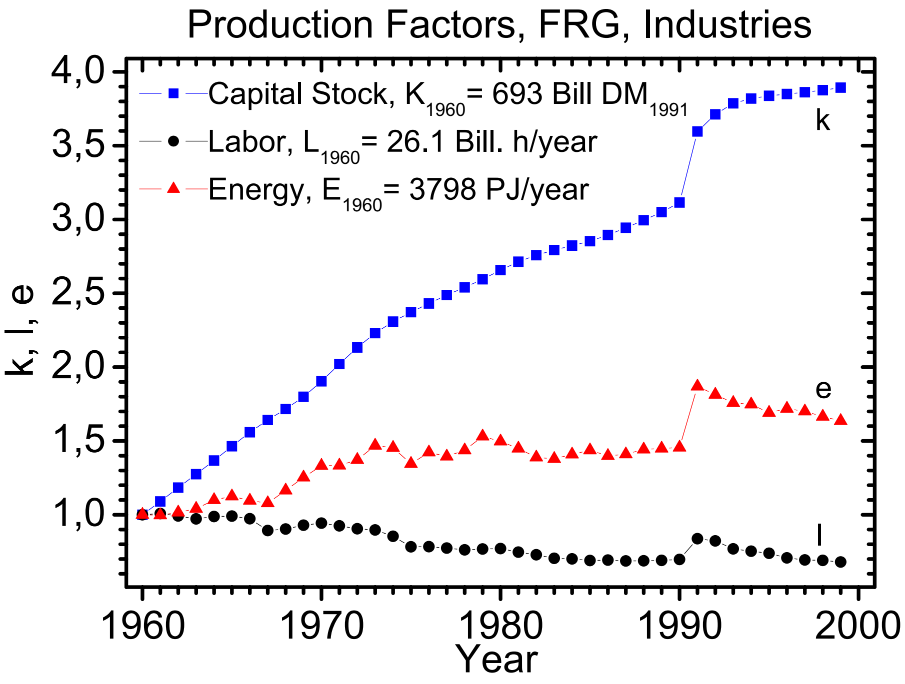
$a(t)$ = capital-efficiency parameter, $c(t)$ = energy-demand parameter, modeled by logistics or taylor series, determined by nonlinear (Levenberg-Marquardt) OLS fitting of $q_{Lt}(t)$ to $q_{empirical}(t)$, subject to the constraints: $\alpha \geq 0, \beta \geq 0, \gamma \geq 0$.

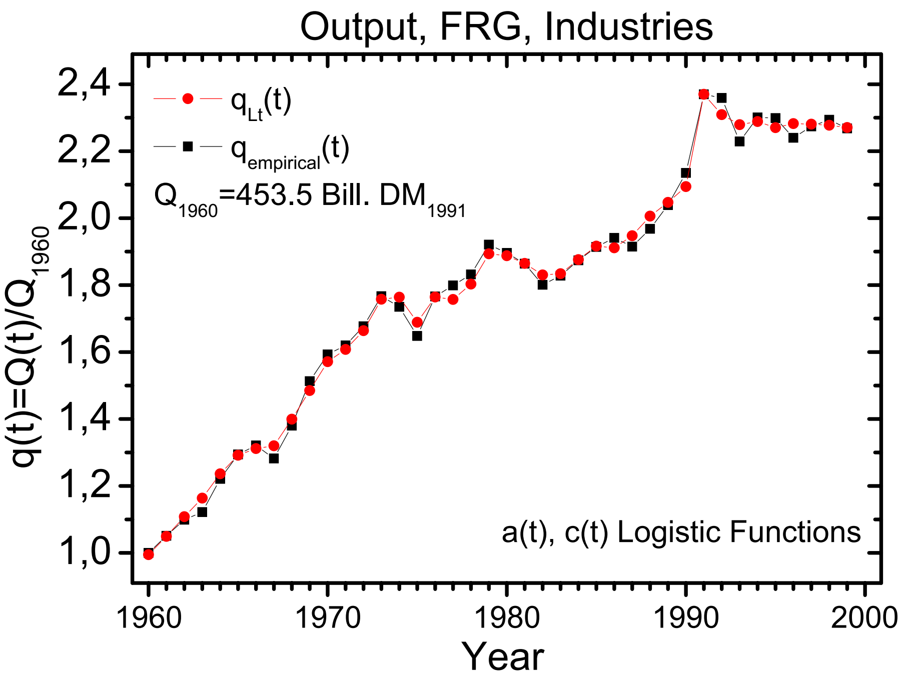
Germany, Total Economy



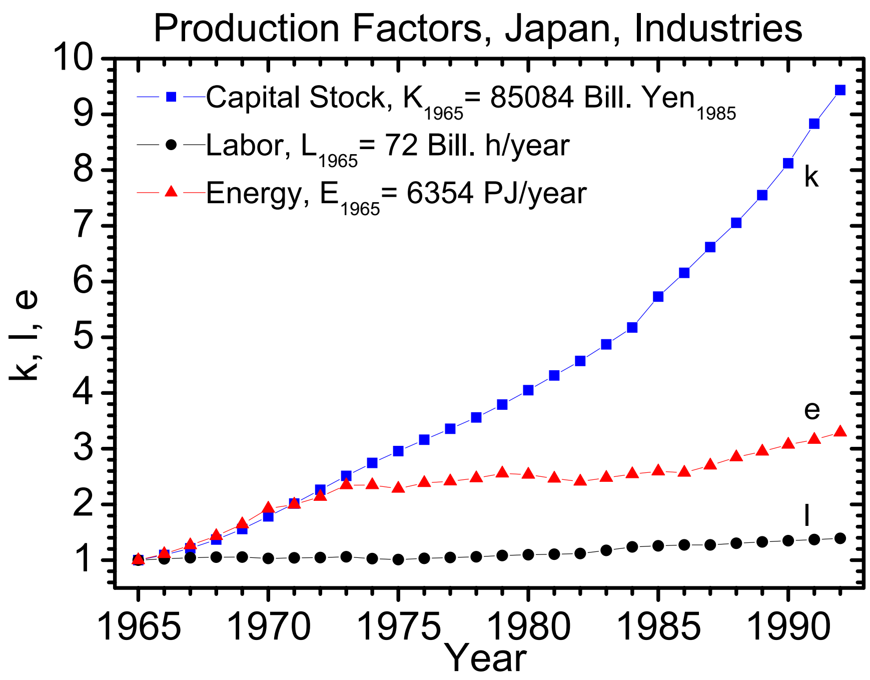


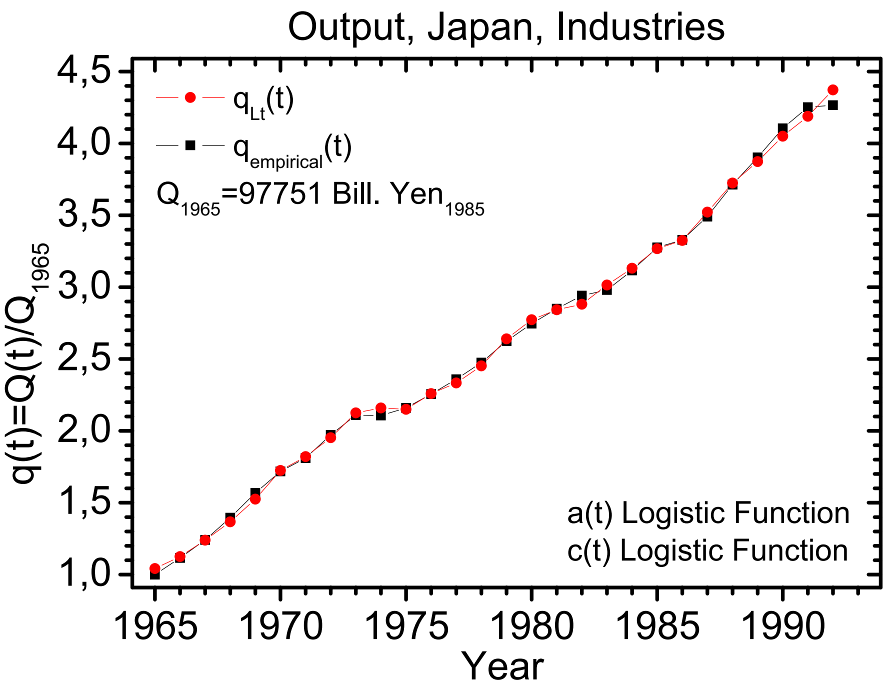
Germany, Warenprod. Gewerbe



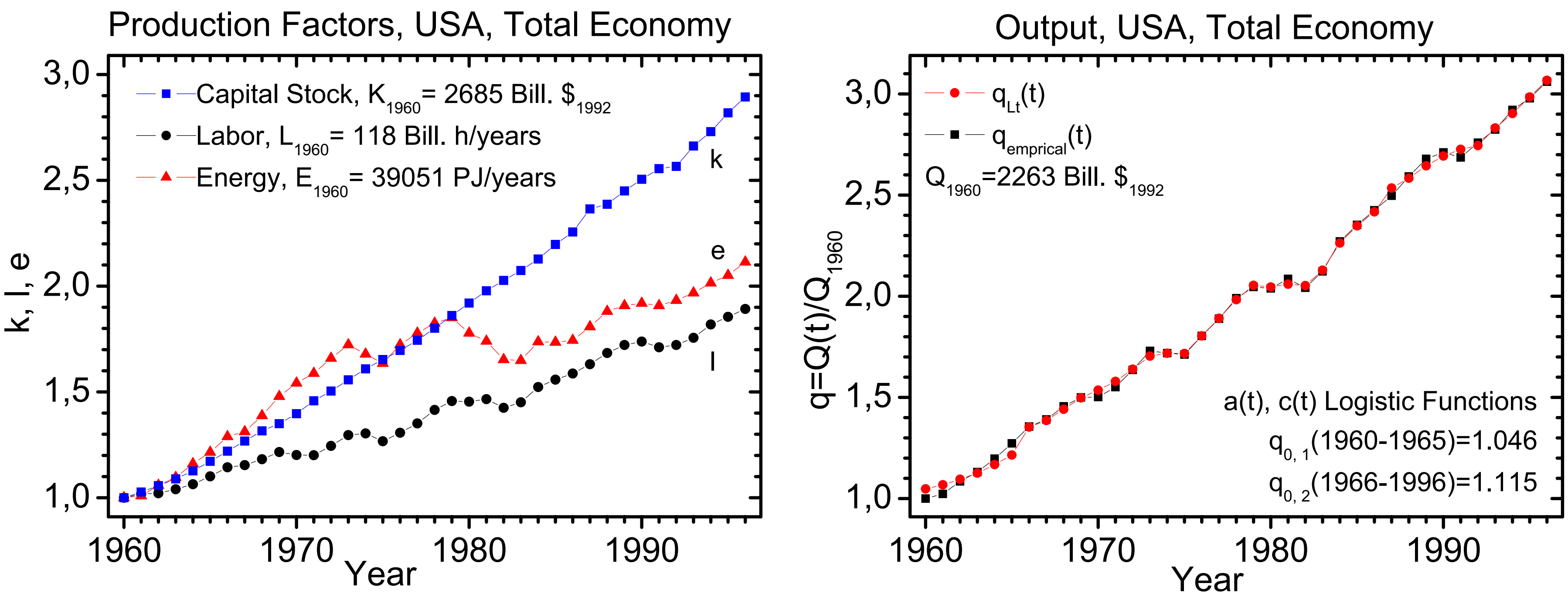


Japan, Industries ≈ Total Economy

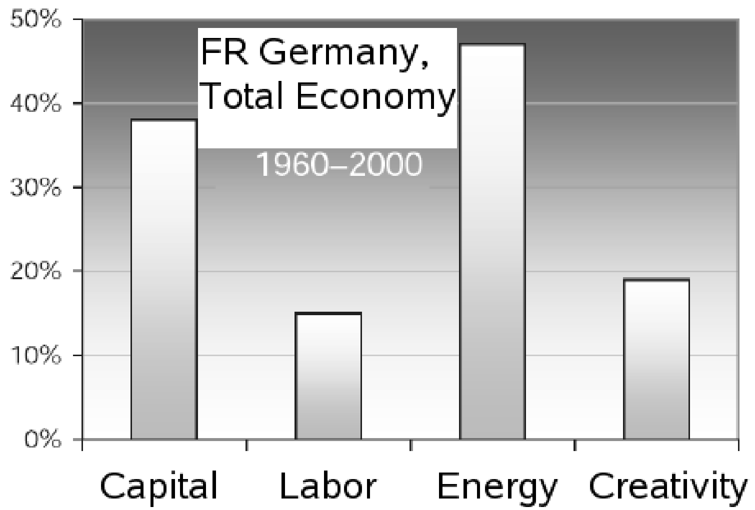


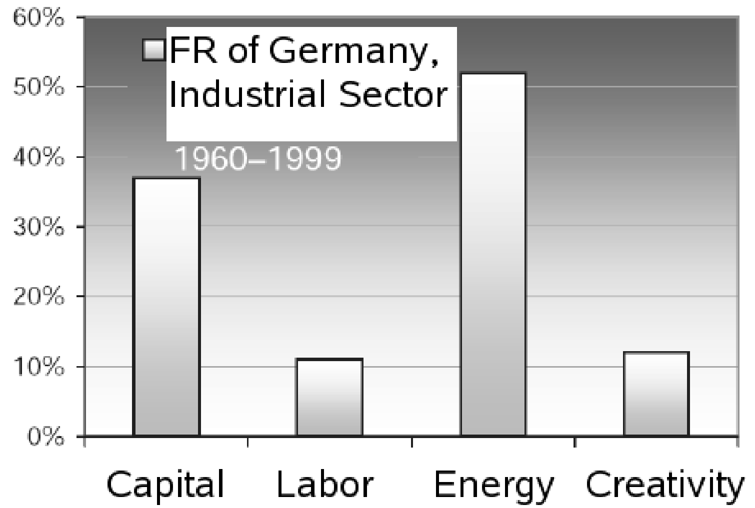


USA, Total Economy



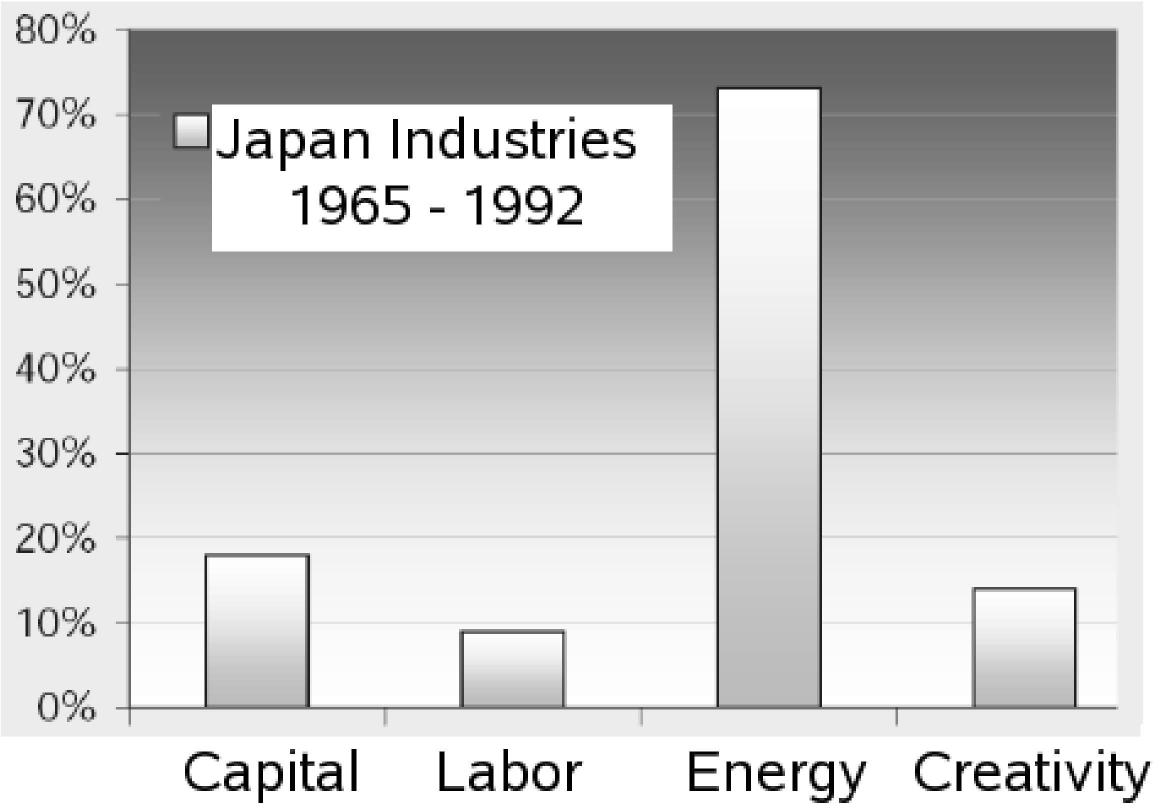
Productive Powers: Germany





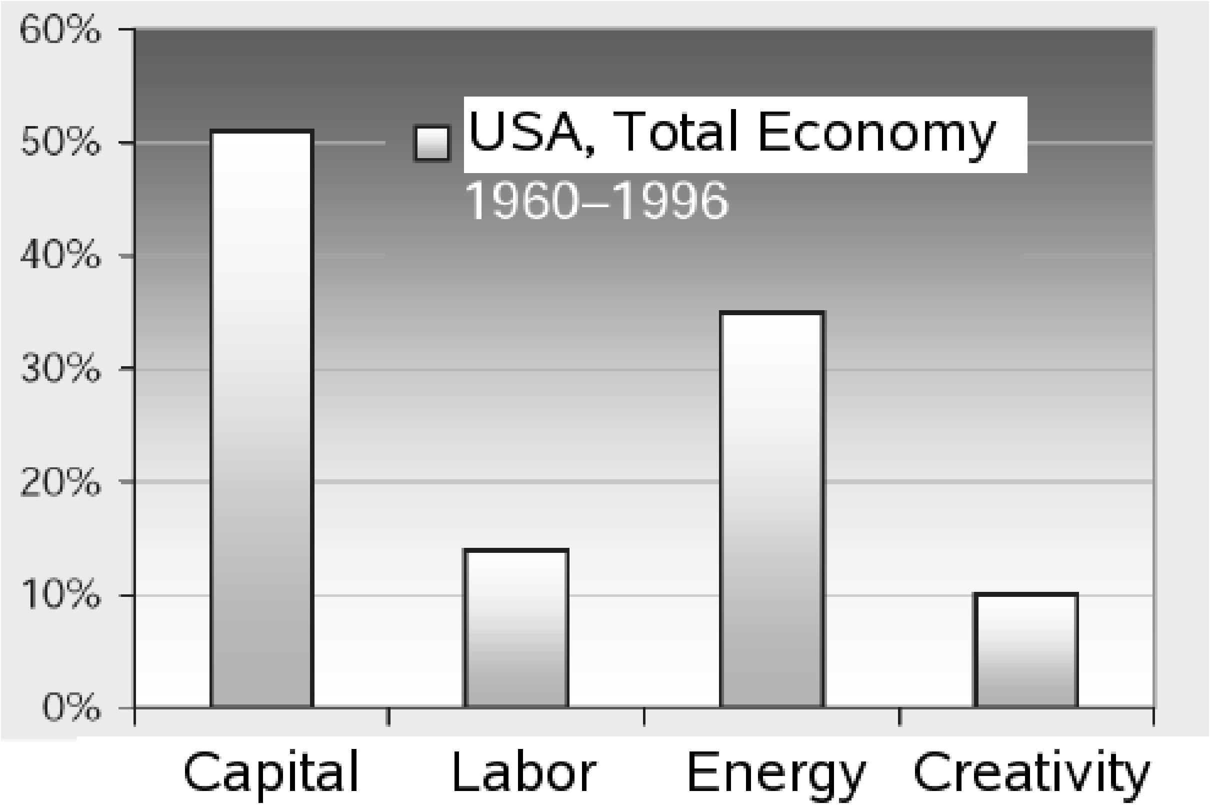
Time-averaged output elasticities (productive powers) in the total economy of the Federal Republic of Germany (top) and in Germany's industrial sector "Warenproduzierendes Gewerbe" (bottom)

Productive Powers: Japan



Time-averaged output elasticities in the Japanese sector "Industries", which produces about 90% of Japanese GDP.

Productive Powers: USA



Time-averaged output elasticities in the total US economy.

P P and Stat. Quality Measures

Time-averaged output elasticities (productive powers) of capital ($\bar{\alpha}$), labor ($\bar{\beta}$), energy ($\bar{\gamma}$), and creativity ($\bar{\delta}$)

FR of Germany, Total Economy, 1960-2000 ($R^2 > 0.999, D_W = 1.64$):
$\bar{\alpha} = 0.38(\pm 0.09)$, $\bar{\beta} = 0.15(\pm 0.05)$, $\bar{\gamma} = 0.47(\pm 0.1)$, $\bar{\delta} = 0.19(\pm 0.2)$.
FR of Germany, Industries, 1960-1999 ($R^2 = 0.996, D_W = 1.90$):
$\bar{\alpha} = 0.37(\pm 0.09)$, $\bar{\beta} = 0.11(\pm 0.07)$, $\bar{\gamma} = 0.52(\pm 0.09)$, $\bar{\delta} = 0.12^*(\pm 0.13)$.
Japan, Industries, 1965-1992 ($R^2 = 0.999, D_W = 1.71$):
$\bar{\alpha} = 0.18(\pm 0.07)$, $\bar{\beta} = 0.09(\pm 0.09)$, $\bar{\gamma} = 0.73(\pm 0.16)$, $\bar{\delta} = 0.14(\pm 0.19)$.
USA, Total Economy, 1960-1996 ($R^2 = 0.999, D_W = 1.46$)
$\bar{\alpha} = 0.51(\pm 0.15)$, $\bar{\beta} = 0.14(\pm 0.14)$, $\bar{\gamma} = 0.35(\pm 0.11)$, $\bar{\delta} = 0.10(\pm 0.17)$.

Factor cost shares (OECD average) are for
capital: 0.25, labor: 0.70, energy: 0.05

Economic Equilibrium with Constraints

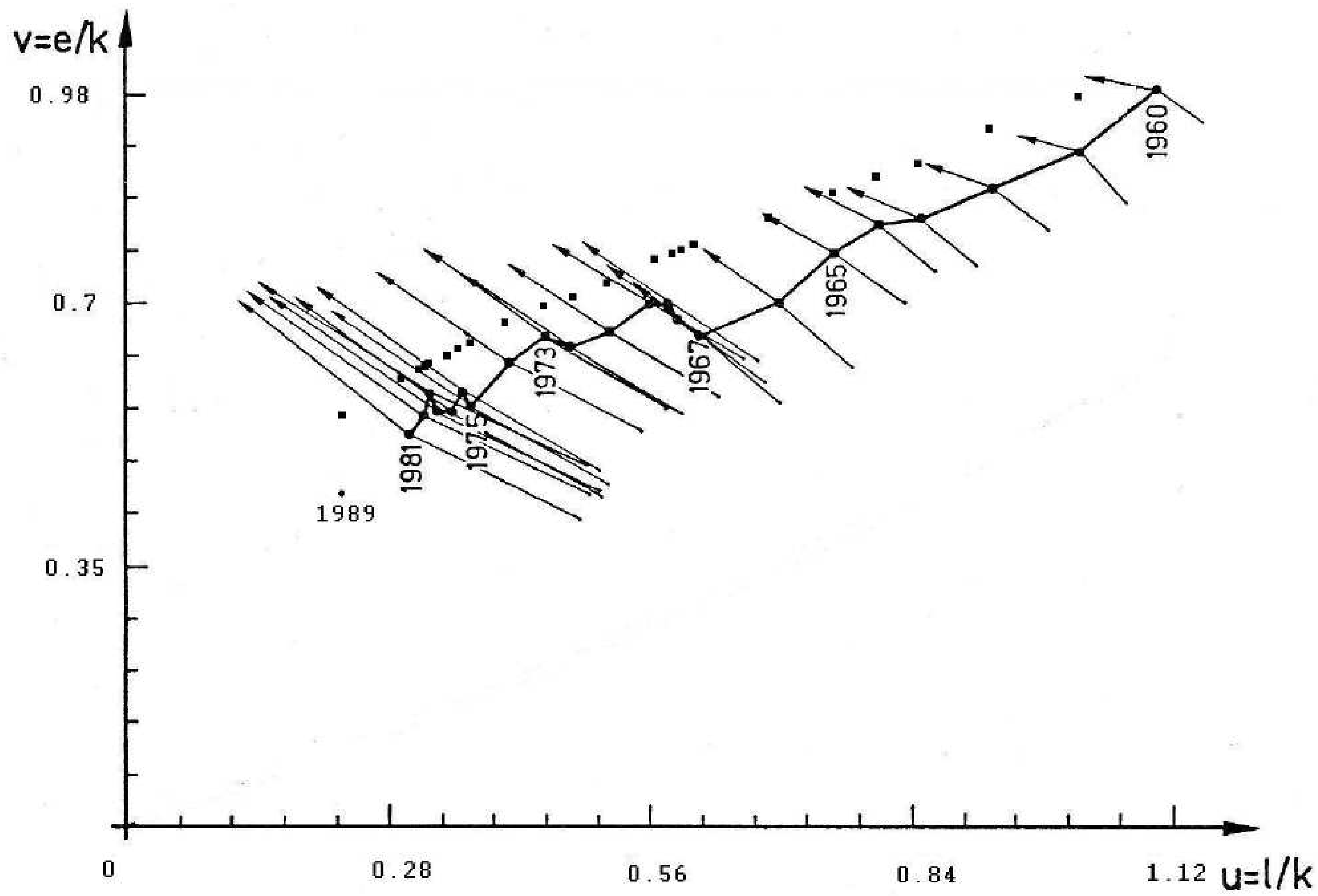
N factors of production $X_1 \ldots X_i \ldots X_N$, subject to constraints labeled by a and described by $f_a(X_1 \ldots X_i \ldots X_N, t) = 0$. Optimization of profit (or time-integrated utility) yields N equilibrium conditions for the X_i:

$$\epsilon_i \equiv \frac{X_i}{Y}\frac{\partial Y}{\partial X_i} = \frac{X_i[p_i + s_i]}{\sum_{i=1}^N X_i[p_i + s_i]}, \qquad s_i \equiv -\sum_a \frac{\mu_a}{\mu}\frac{\partial f_a}{\partial X_i}.$$

ϵ_i = output elasticity (OE) of Faktor X_i, p_i= market price of unit of X_i; $s_i =$ shadow price of X_i. μ_a/μ = quotients of Lagrange multipliers, depend upon OE. $\longrightarrow$
Output elasticities are NOT equal to factor cost shares.

$N = 3 : X_1$ **= capital** K, X_2 **= labor** L, X_3 **= energy** E.
Technological constraints on factor combinations:
1. degree of capacity utilization ≤ 1,
2. degree of automation $\leq \rho_T(t) \leq 1$.

Shadow price barrier



Shadow price barrier and cost gradients along the path of the German industrial sector “Warenproduzierendes Gewerbe” in the cost mountain between the years 1960 and 1989, projected onto the $\frac{l}{k} - \frac{e}{k}$ plane.

Energy and Entropy

- First Law of Thermodynamics: Energy is conserved. It consists of Exergy + Anergy.
  Exergy: valuable part of energy, can be converted into work.
  Anergy: useless part of energy, e.g. heat at temperature T_0 of the environment.

- Second Law of Thermodynamics: Entropy-production density in real-life non-equilibrium systems containing N different sorts of particles k is inevitable and given by:

  $$\sigma_{S,dis}(\vec{r},t) = \vec{j}_Q \vec{\nabla}(1/T) + \sum_{k=1}^{N} \vec{j}_k[-\vec{\nabla}(\mu_k/T) + \vec{f}_k/T] > 0 \quad .$$

  $\vec{j}_Q$ = heat-current density, $\vec{\nabla}$ = gradient, T = temperature, $\vec{j}_k$ = particle (diffusion) current density, μ_k= chemical potential, $\vec{f}_k$ = external force on particle k.

Entropy production in energy conversion processes decreases exergy ("energy consumption") and is associated with emissions of heat and particles. It changes the composition of and the energy flows through the biosphere. If these changes are too rapid so that individuals and societies cannot adapt to them, they are perceived as environmental pollution.

Conclusions 1: Social problems

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The consequences are: Routine jobs get lost in high-wage countries and profits increase for the owners of the energy sources and the masters of the energy conversion devices. In addition, climate-destabilizing emissions grow with the increasing use of fossil energies.

Conclusions 2 : Climate-change problems

- Fossil fuels satisfy about 80% of present world energy demand. Greenhouse-gas emissions must be reduced drastically, by up to 80% until the year 2050, if the increase of the surface temperature of the earth should not exceed 2°C. Non-fossil fuels must replace coal, oil, and gas in time, otherwise there will be severe economic recessions. (Whether CCS will work, remains to be seen.)
- Germany has decided to phase out fossil and nuclear fuels rapidly. Hopefully, the world will not learn sad lessons from Germany's "Energiewende" experiment.
- "Haste makes waste".

Conclusions 3: Peak-oil research

Conventional oil satisfies about 34% of present world energy demand. A first step to getting a feeling for post-peak economies might involve:

- Build a three-sector model of the economy that consists of 1) Agriculture, 2) Transportation, 3) All the Rest.
- Describe the outputs of 1), 2), and 3) by appropriate, twice-differentiable production functions in capital, labor, and energy, whose output elasticities are estimated econometrically.
- Model how the outputs of 1) and 2) act as inputs to 3).
- Analyze how reductions of the outputs of 1) and 2), e.g. because of reductions of oil consumption that are enforced by Peak Oil and/or climate change, affect the output of 3).
- Compute scenarios where renewably generated electricity and/or hydrogen substitute for conventional oil in 1) and 2).

Conclusions 4: Energy Taxes

In order to fight increasing unemployment (and state indebtedness) and stimulate energy conservation and emission mitigation the disequilibrium between the productive powers and cost shares of labor and energy should be reduced by:

- shifting the burden of taxes and levies from labor to energy so that these factors' cost shares come closer to the factors' productive powers; $\longrightarrow$ **tax and levy shares:**
  labor 10-20%, capital 30-40%, energy 40-50%.
- Increase of tax per energy unit according to progress in energy conservation in order to keep revenues constant.
- Border tax adjustments according to the energy required for production and transportation of the border-crossing goods prevent competitive disadvantages in relation to not-energy-taxing countries.

No recessions like that due to oil price shocks: the wealth created by energy is not transferred abroad but only redistributed within the country. BBC World Service Poll (2007): People will accept higher energy taxes, if the total tax bill stayed the same.