Why exergy economics is right and the neoclassical duality of quantities and prices is wrong

Reiner Kümmel, Tobias Winkler

Institute for Theoretical Physics and Astrophysics, University of Würzburg, Germany

in cooperation with Florian Weiser and Dietmar Lindenberger

Institute of Energy Economics, University of Cologne, Germany

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Program

1. Energy, entropy, and exergy
2. Energy and economic growth
3. How technological constraints destroy the neoclassical cost share theorem
4. Summary

Details in:
R. K., “The Second Law of Economics: Energy, Entropy, and the Origins of Wealth”. Springer, New York, Dordrecht, Heidelberg, London, 2011;
R. K., D. Lindenberger, F. Weiser, “The economic power of energy and the need to integrate it with energy policy”, Energy Policy 86, 833-843 (2015).

Energy, entropy, and exergy

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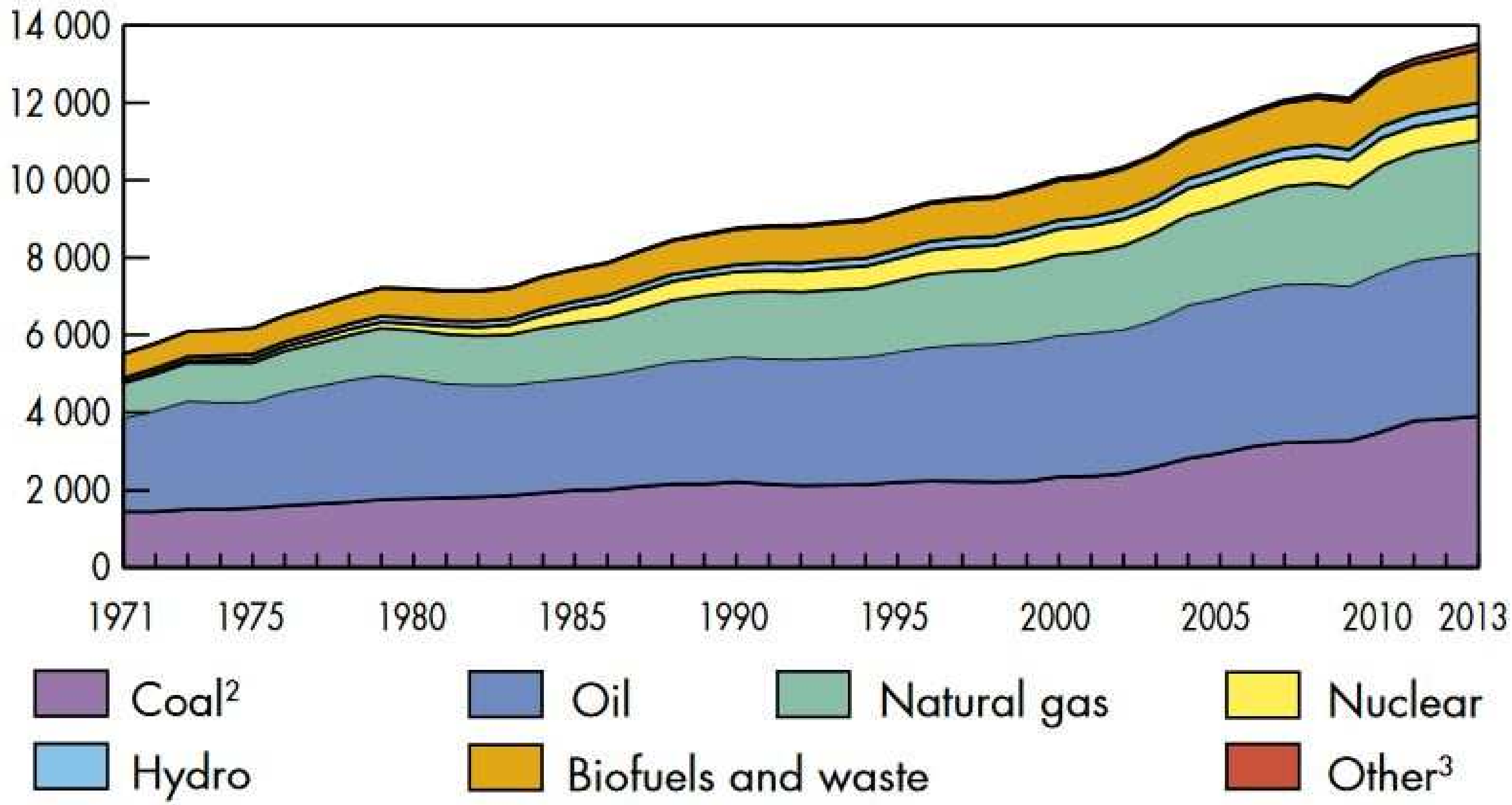
- Second Law: unavoidable entropy production
  1) destroys exergy, enhances useless anergy: the technologies of energy conversion determine, how much exergy one gets from primary energy $\rightarrow$ limits to improvements of energy efficiency!
  2) results in polluting emissions of particles (NO_X, SO_2, greenhouse gases) and heat: entropy production density in a non-equilibrium system of N different sorts of particles k:
  $\sigma_{S,dis}(\vec{r},t) = \sum_{k=1}^{N} \vec{j}_k[-\vec{\nabla}(\mu_k/T) + \vec{f}_k/T] + \vec{j}_Q \vec{\nabla}(1/T) > 0.$
  $\vec{j}_k$ = particle current density, $\vec{j}_Q$ = heat current density,
  ($\vec{\nabla}$: gradient, T = temperature, μ_k= chemical potentials, $\vec{f}_k$ = external forces.)

Global consumption of primary (en/ex)ergy

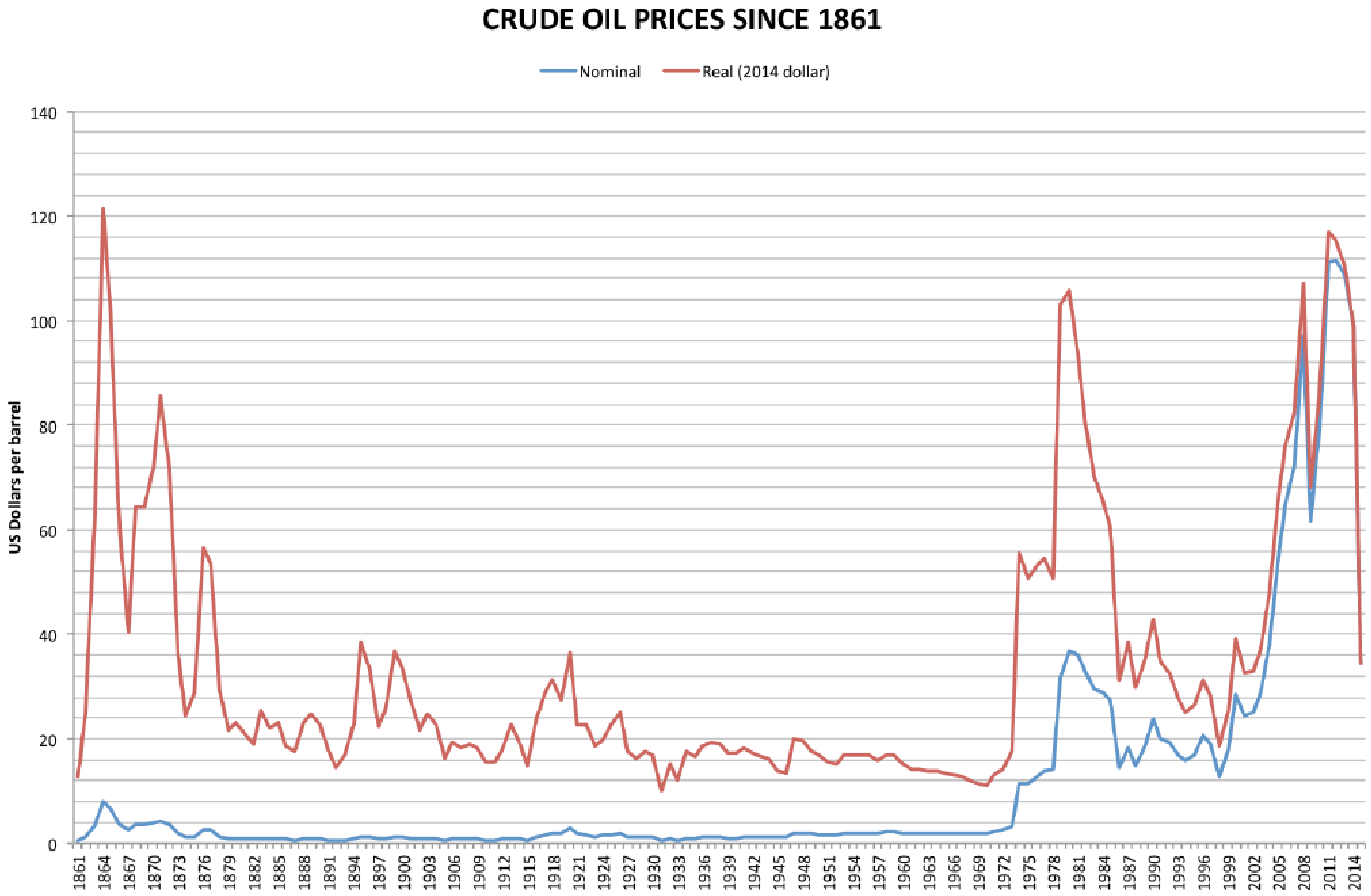
World

World[1] total primary energy supply (TPES) from 1971 to 2013 by fuel (Mtoe)



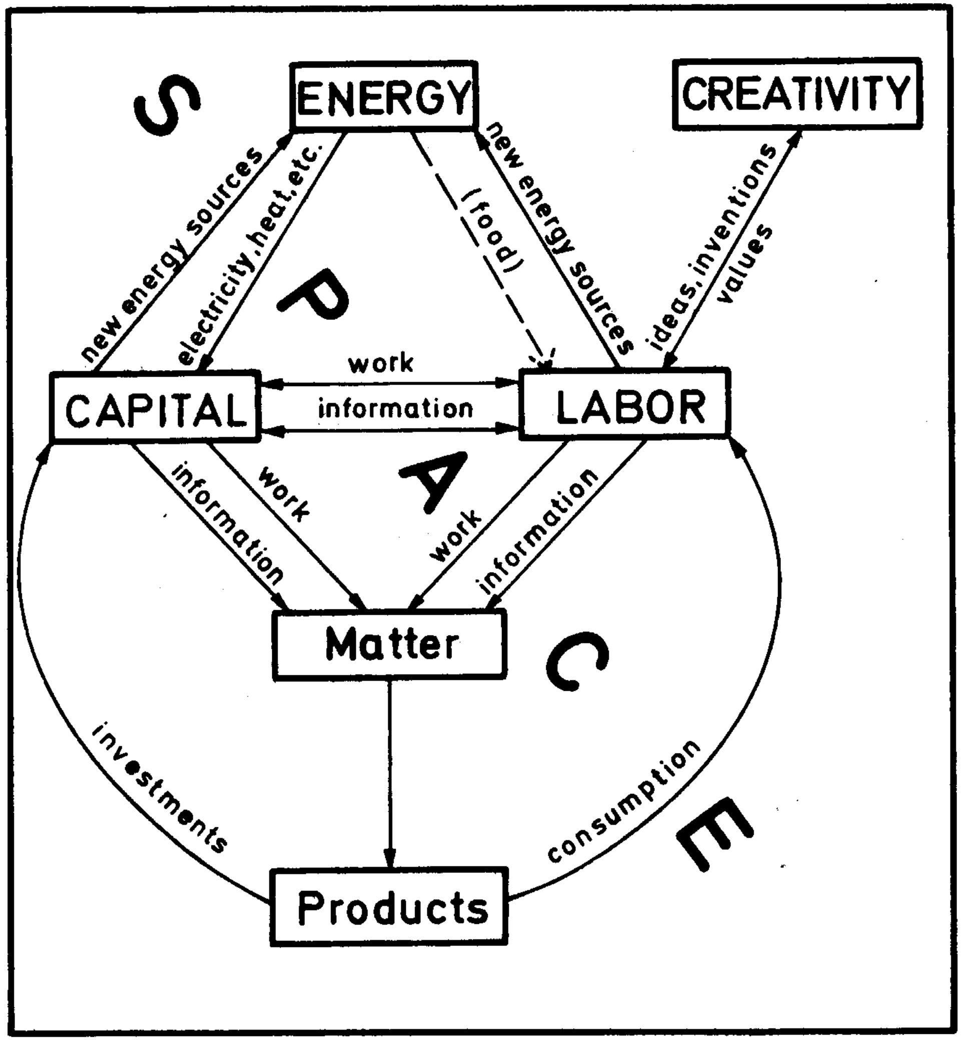
Source: International Energy Agency “KeyWorld Statistics 2015”

Oil price shocks



Development of the price of one barrel of crude oil since 1861 in inflation-corrected US_{2014} (*upper curve*) and in dollar prices of the day (*lower curve*).

Pre-analytic vision



Capital (stock) = all energy-conversion devices and information processors, and all buildings and installations necessary for their protection and operation.

From: “The Impact of Energy on Industrial Growth”, Energy 7, 189-203 (1982).

KLEC model

Structural Change and Economic Dynamics **13** 415-433 (2002)
Journal of Non-Equilibrium Thermodynamics **35** 145-179 (2010)
New Journal of Physics **16** 125008 (2014)
Energy Policy **86** 833-843 (2015)

Output (value added) and inputs at time t, normalized to their quantities Y_0, K_0, L_0, E_0 in the base year t_0:

$y(t) = Y(t)/Y_0$ (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 $y = y(k, l, e; t)$,

which is a **state function**, i.e. it depends only on the actual magnitudes of k, l, e at time t, and not on the history of the system.

Growth equation

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

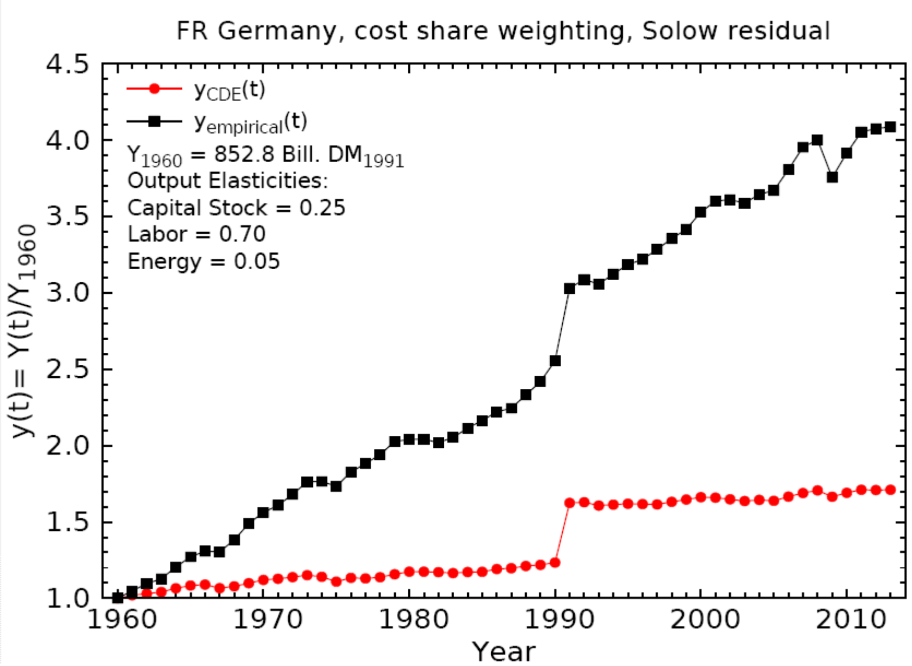
$$\frac{\mathrm{d}y}{y} = \alpha\frac{\mathrm{d}k}{k} + \beta\frac{\mathrm{d}l}{l} + \gamma\frac{\mathrm{d}e}{e} + \delta\frac{\mathrm{d}t}{t - t_0} \quad .$$

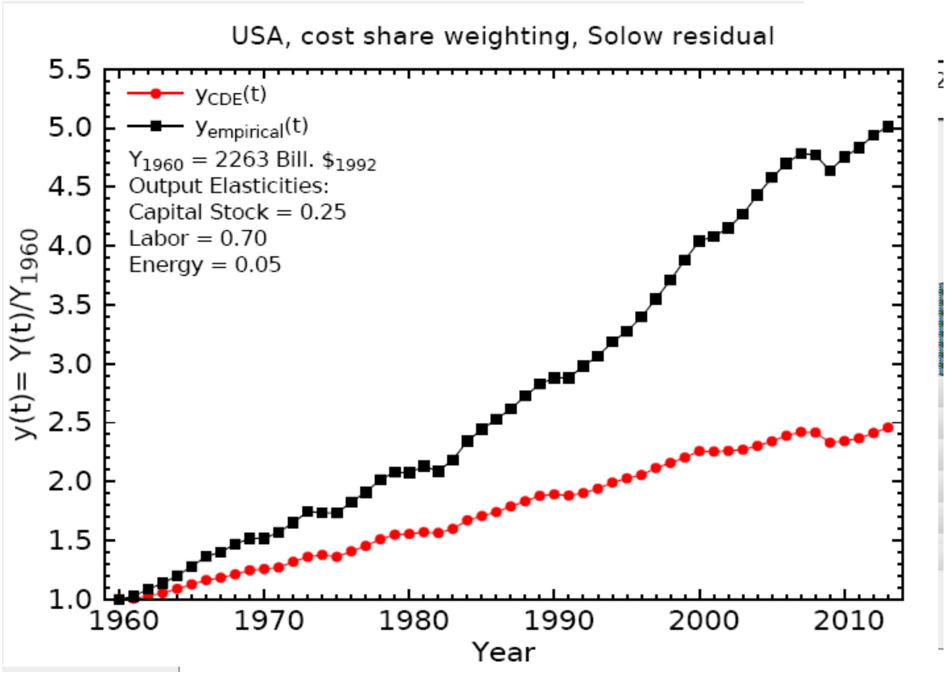
The **output elasticities** (productive powers)

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

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.
Textbook economics: $\alpha \approx 0.25$, $\beta \approx 0.7$, $\gamma \approx 0.05$ (from unconstrained optimization) + technological progress

Solow Residual in FR Germany and USA





Difference between empirical output (black) and theoret. output (red) ($\equiv$ **Solow Residual**) at cost-share weighting of production factors in the energy-dependent Cobb-Douglas production function is attributed to **“technological progress”** by textbook economics.

Diff. equations for output elasticities

Standard requirement on production functions (PF) is twice differentiability with respect to $k, l, e \rightarrow$ second-order mixed derivatives of PF must be equal. Furthermore: $\alpha + \beta + \gamma = 1$ at any *fixed* time $t \rightarrow$

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

$$l\frac{\partial \alpha}{\partial l} = k\frac{\partial \beta}{\partial k}.$$

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:

- 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: $\alpha \rightarrow 0$, if $(l+e)/k \rightarrow 0$),
  $\beta = a(c\frac{l}{e} - \frac{l}{k})$
  (Substitution of capital and energy for labor as automation increases: $\beta \rightarrow 0$, if $k \rightarrow k_m$ and $e \rightarrow ck_m$),
  $\gamma = 1 - \alpha - \beta$
  (At a given point in time the weights with which capital, labor and energy contribute to the growth of output add up to 100 %).

The output elasticities of neoclassical production functions, e.g. CES functions, are solutions, too; see: “Energy and the State of Nations”, Energy **36** 6010-6018 (2011)

Production functions

The production function is the integral of the growth equation:

$$y(k, l, e; t) = y_0(t) \exp\left\{ \int_{k_0, l_0, e_0}^{k, l, e} \left[\alpha \frac{\mathrm{d}k}{k} + \beta \frac{\mathrm{d}l}{l} + \gamma \frac{\mathrm{d}e}{e} \right] \mathrm{d}s \right\}.$$

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The constants $\alpha_0, \beta_0, \gamma_0$ yield the energy-dependent Cobb-Douglas production function

$$y_{CDE} = y_0 k^{\alpha_0} l^{\beta_0} e^{\gamma_0}.$$

Neoclassical cost-share weighting: $\alpha_0 \approx 0.25, \quad \beta_0 \approx 0.70, \quad \gamma_0 \approx 0.05 \longrightarrow$ Solow residual.

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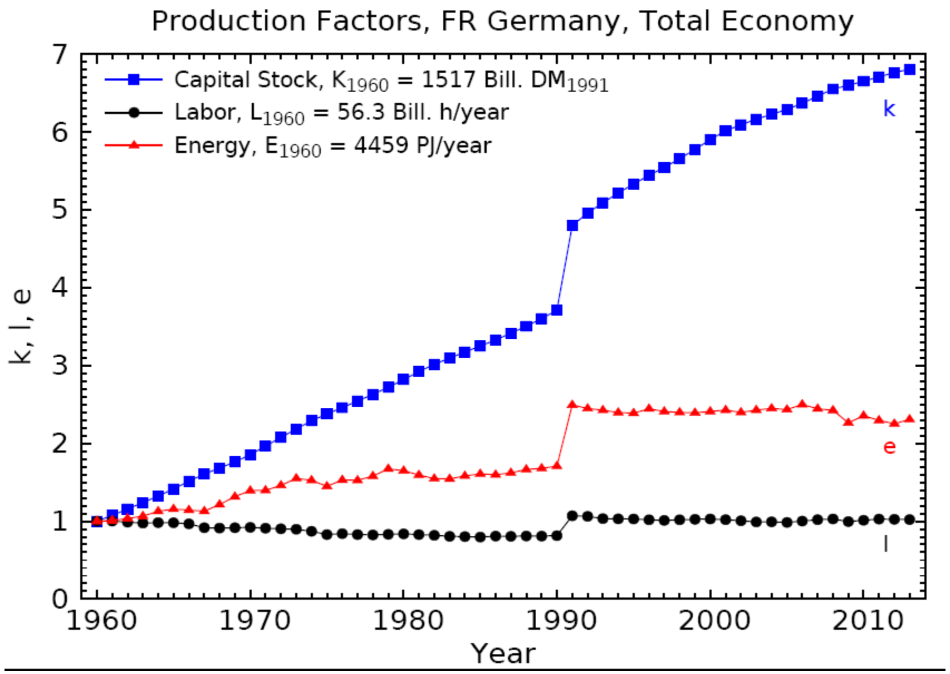
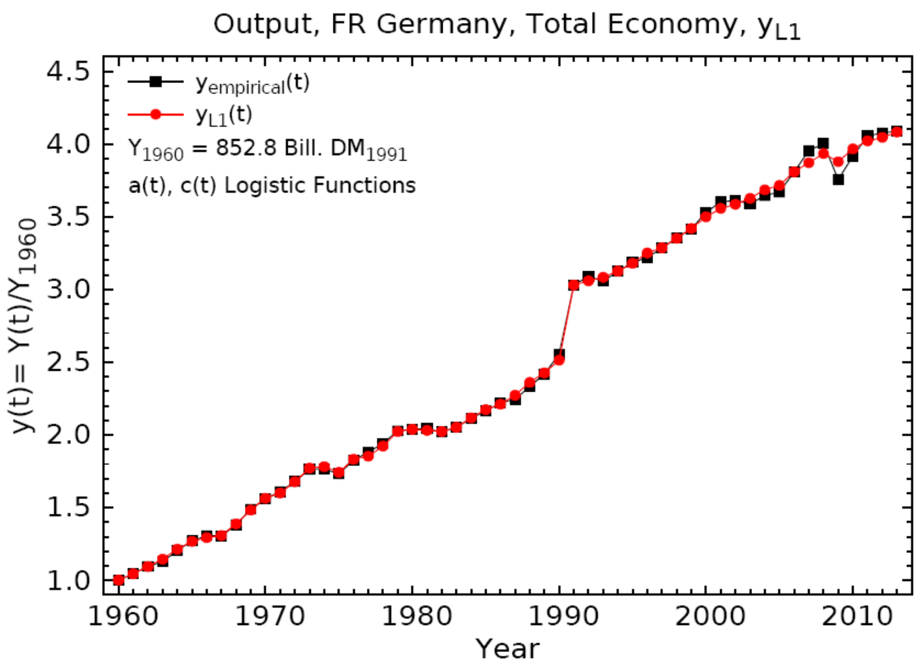
The non-trivial $\alpha = a\frac{l+e}{k}$, $\beta = a(c\frac{l}{e} - \frac{l}{k})$, $\gamma = 1-\alpha-\beta$ yield the **time-dependent LinEx production function**:

$$y_{L1}(t) = y_0(t) e \exp\left[a(t)(2-\frac{l+e}{k}) + a(t)c(t)(\frac{l}{e}-1)\right].$$

$a(t)$ = capital-effectiveness parameter, $c(t)$ = energy-demand parameter, modeled by logistics or taylor series, determined by nonlinear (Levenberg-Marquardt) OLS fitting of $y_{L1}(t)$ to $y_{empirical}(t)$, subject to the restrictions: $\alpha \geq 0, \beta \geq 0, \gamma \geq 0$.

FR Germany, Total Economy



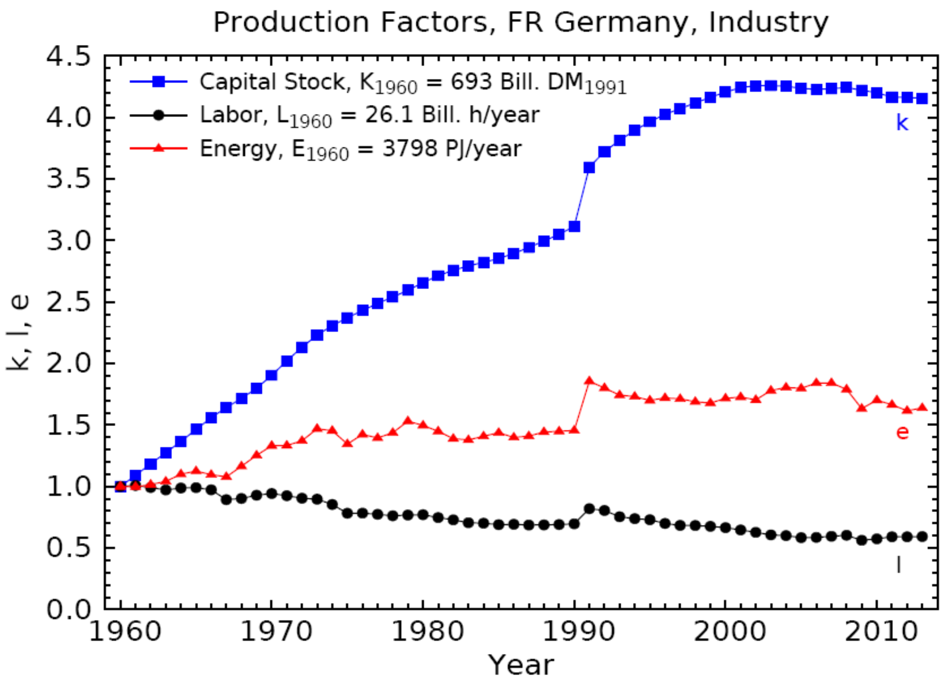


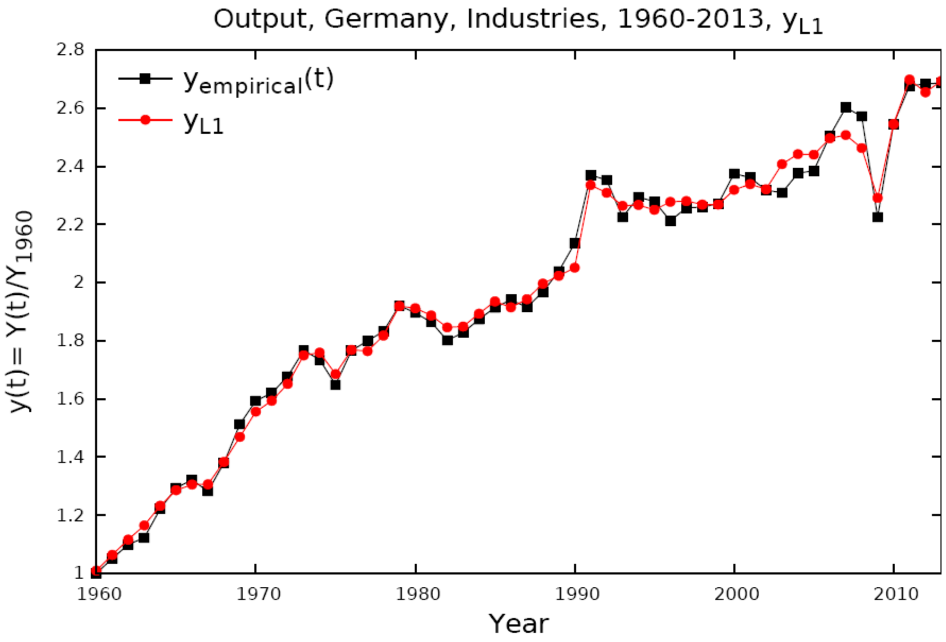
Left: Empirical time series of capital, labor, and (primary) energy. Right: Growth of output; black: empirical, red: computed with LinEx function

$$y_{L1}(t) = y_0(t) e \exp\left[a(t)\left(2 - \frac{l+e}{k}\right) + a(t)c(t)\left(\frac{l}{e} - 1\right)\right].$$

The technology parameters (a, c) become time-dependent, when creativity acts. If time series of exergy inputs are available, (a, c) may be constant.

FR Germany, Industry





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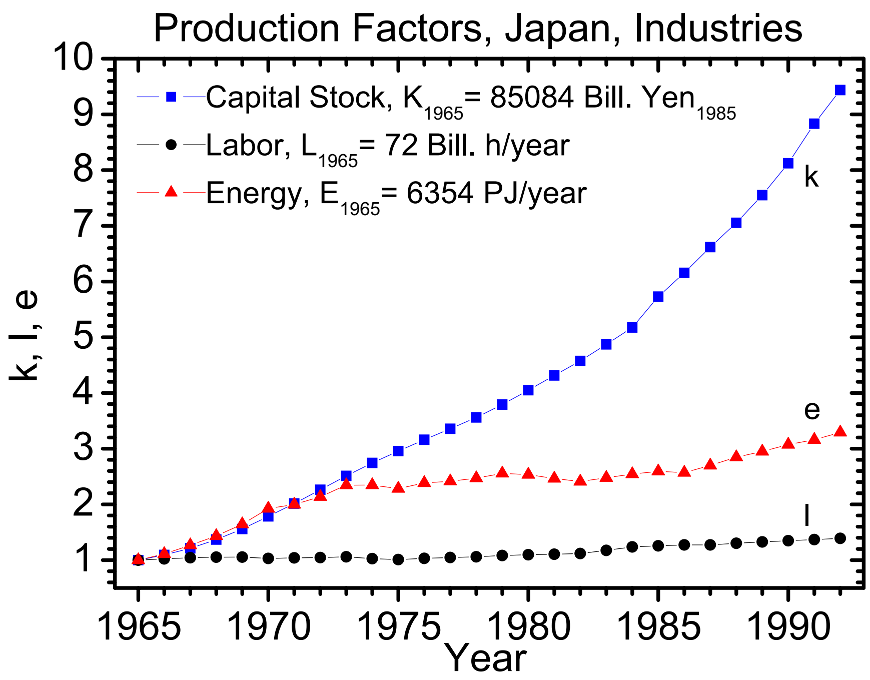
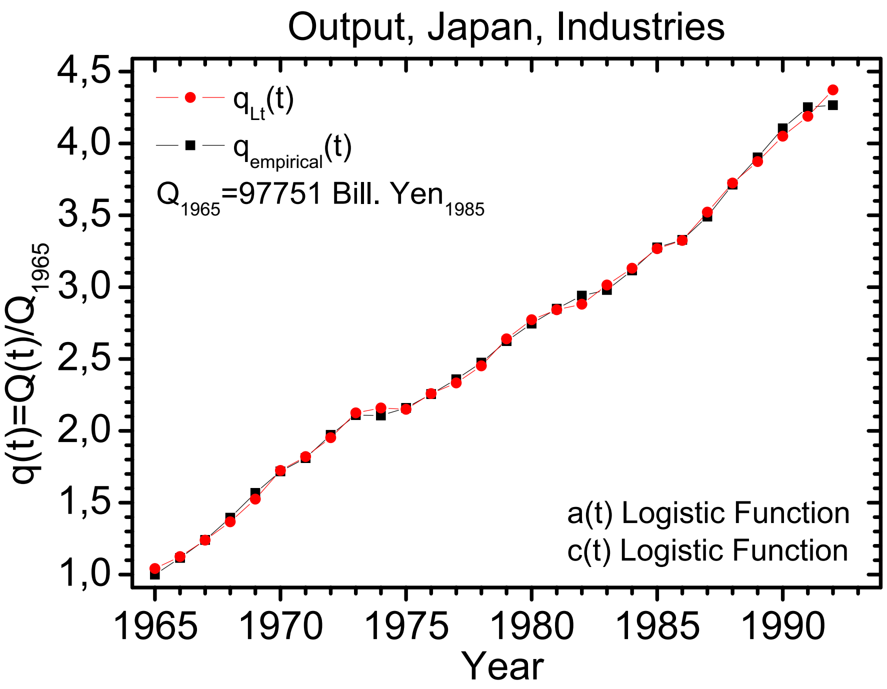
Japan, Industries ≈ Total Economy





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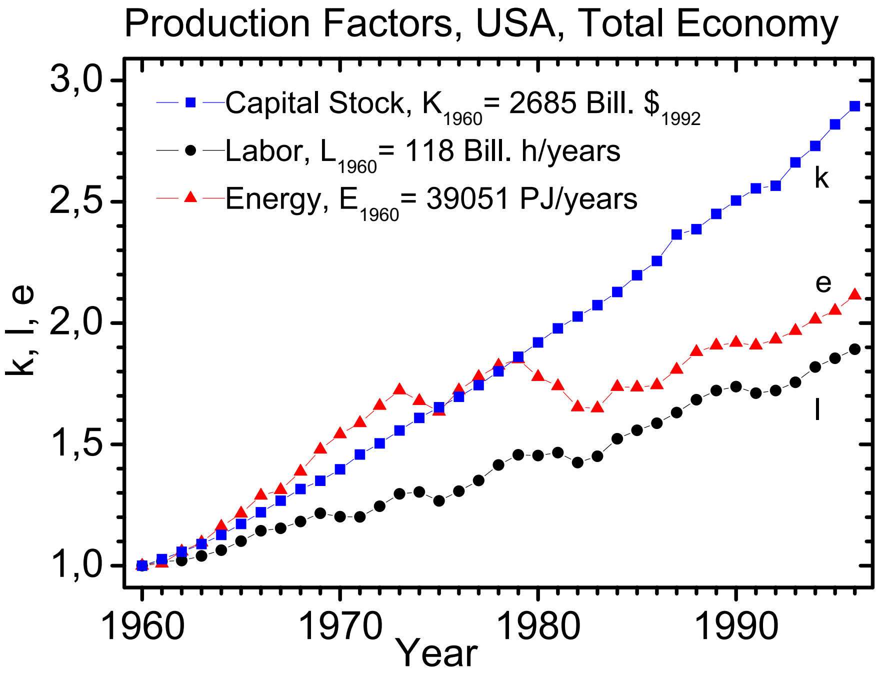
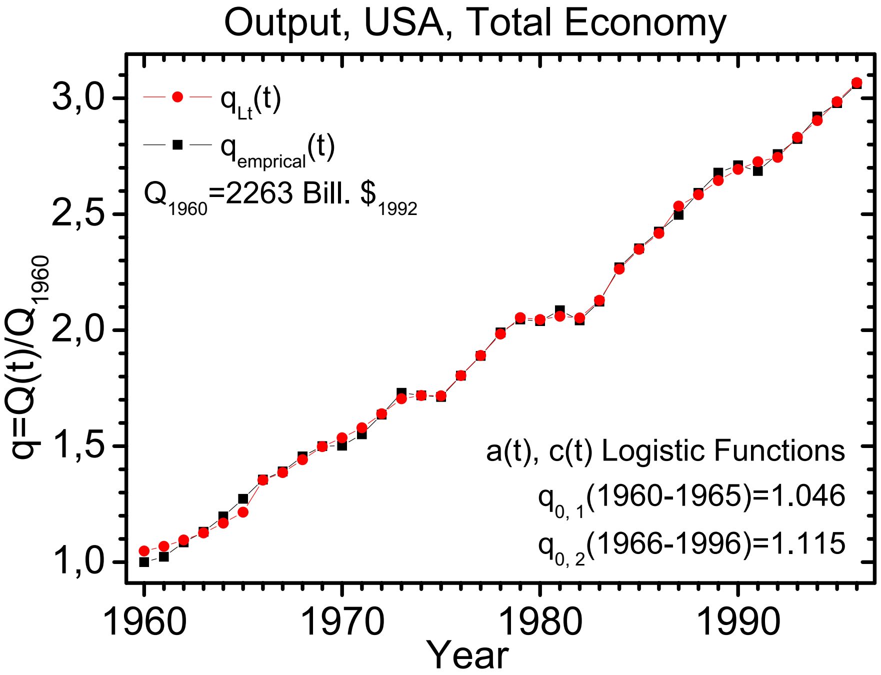
USA, Total Economy





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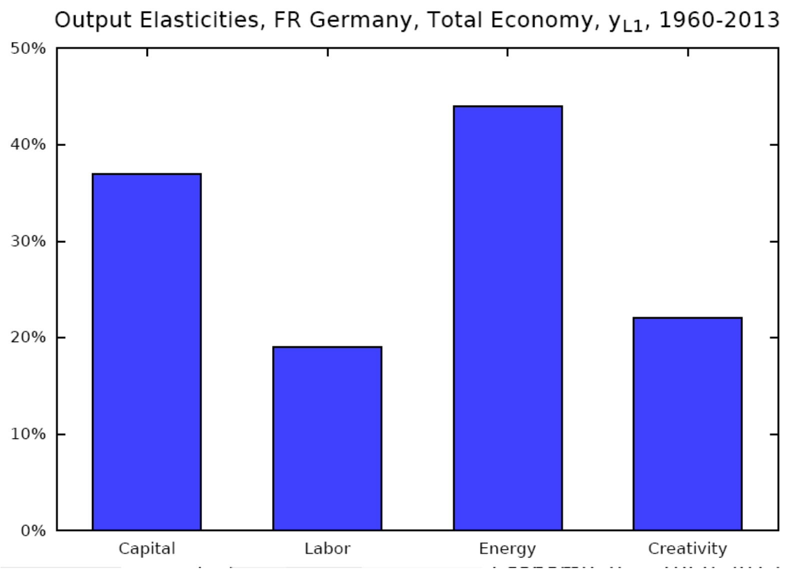
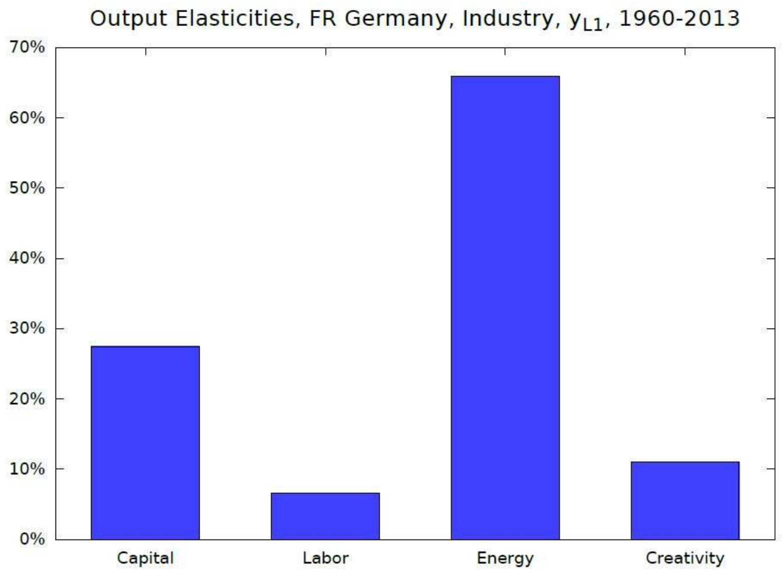
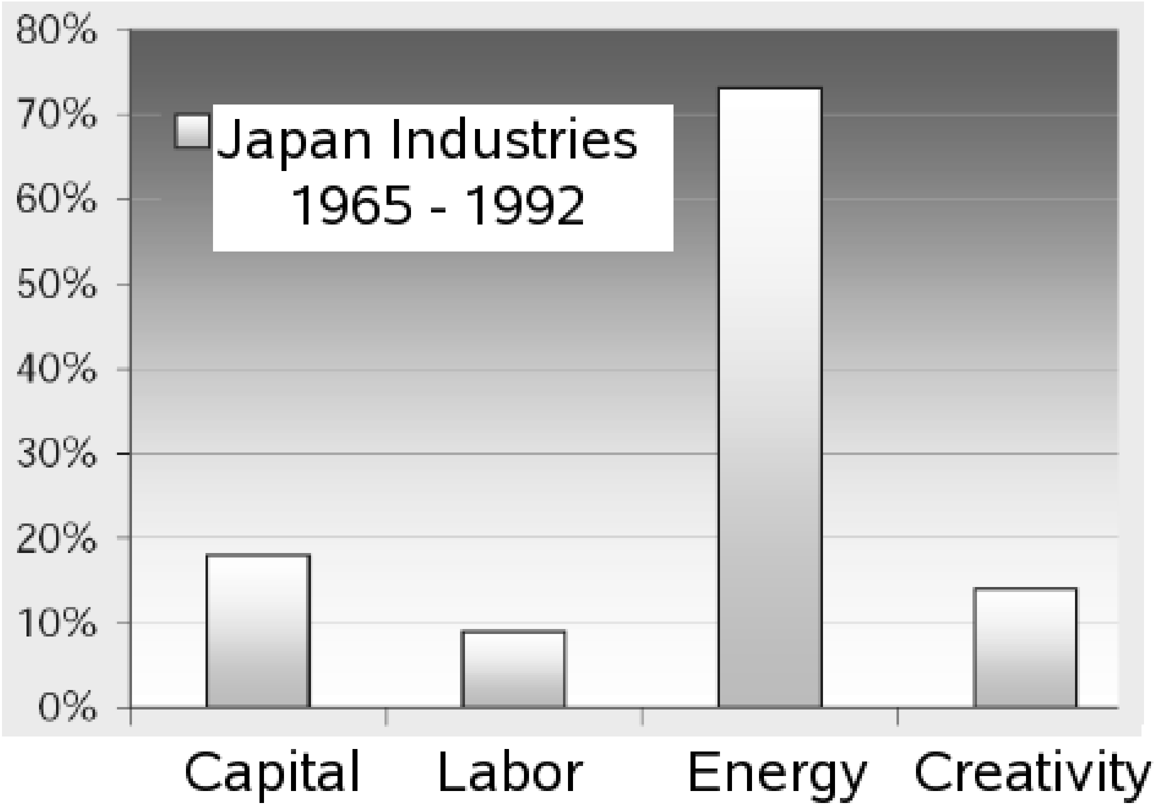
Output elasticities: FR Germany





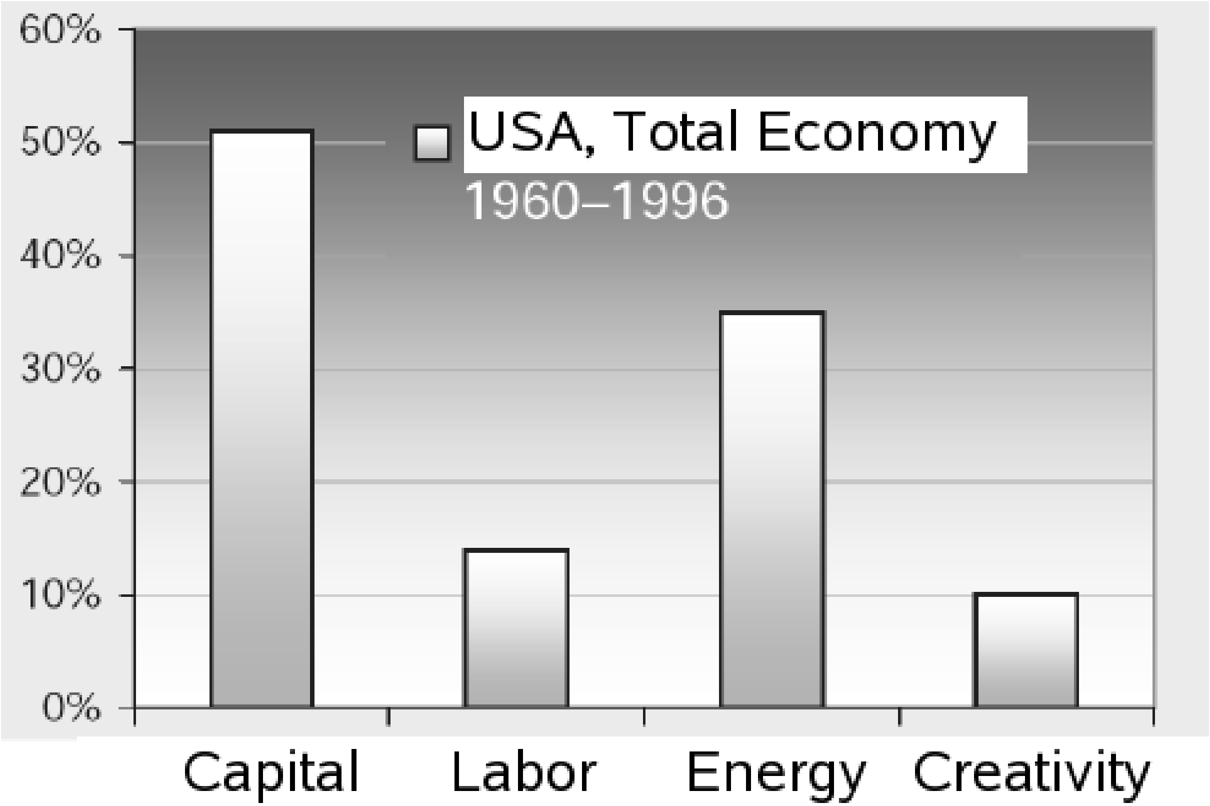
Time-averaged output elasticities in the total economy (top) and in the industrial sector (bottom) of the FR Germany; creativity without reunification peak.

Output elasticities: Japan



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

Output elasticities: USA



Time-averaged output elasticities in the total US economy.

Profit optimization, constraints, duality

Production factors $X_1 \equiv K, X_2 \equiv L, X_3 \equiv E$. Exogeneously given prices per factor unit $(p_1, p_2, p_3) \equiv \mathbf{p}$. Total factor cost is $\mathbf{p(t)} \cdot \mathbf{X(t)} = \sum_{i=1}^{3} p_i(t) X_i(t)$. Technological constraints $f_\eta(\mathbf{X}, t) = 0 = f_\rho(\mathbf{X}, t)$. Economic equilibrium: Maximize profit function

$$G(\mathbf{X}, \mathbf{p}, t) \equiv Y(\mathbf{X}, t) - \mathbf{p} \cdot \mathbf{X} \rightarrow$$

$$\vec{\nabla}\left[Y(\mathbf{X}; t) - \sum_{i=1}^{3} p_i(t) X_i(t) + \mu_\eta f_\eta(\mathbf{X}, t) + \mu_\rho f_\rho(\mathbf{X}, t)\right] = 0 \quad ,$$

$$\frac{\partial Y}{\partial X_i} - p_i + \mu_\eta \frac{\partial f_\eta(\mathbf{X}, t)}{\partial X_i} + \mu_\rho \frac{\partial f_\rho(\mathbf{X}, t)}{\partial X_i} = 0, \quad i = 1, 2, 3 \quad .$$

Without constraints $\mu_\eta = 0 = \mu_\rho$. $\rightarrow$ Profit-maximizing equilibrium values **would** be $X_{1M}(\mathbf{p}), X_{2M}(\mathbf{p}), X_{3M}(\mathbf{p})$. With $\mathbf{X}_M(\mathbf{p})$ the profit function **would** turn into the – only price-dependent – Legendre transform of the PF $Y(\mathbf{X}, t)$ (i.e duality of quantities and prices):

$$G(\mathbf{X}_M(\mathbf{p}), \mathbf{p}) = Y(\mathbf{X}_M(\mathbf{p})) - \mathbf{p} \cdot \mathbf{X}_M(\mathbf{p}) \equiv g(\mathbf{p}).$$

Non-existent, because of the technological constraints.

Cost share theorem?

Technological constraints: 1) the degree of capacity utilization $\eta(K, L, E) \leq 1$; 2) degree of automation $\rho(K, L, E) \leq \rho_T(t) \leq 1$. $\rightarrow$ With slack variables $f_\eta(\mathbf{X}, t) = 0$, $f_\rho(\mathbf{X}, t) = 0$.

Optimization of profit yields equilibrium conditions for the X_i:

$$\epsilon_i \equiv \frac{X_i}{Y} \frac{\partial Y}{\partial X_i} = \frac{X_i \left[p_i + s_i\right]}{\sum_{i=1}^{3} X_i \left[p_i + s_i\right]}, \qquad s_i \equiv -\mu_\eta \frac{\partial f_\eta}{\partial X_i} - \mu_\rho \frac{\partial f_\rho}{\partial X_i}.$$

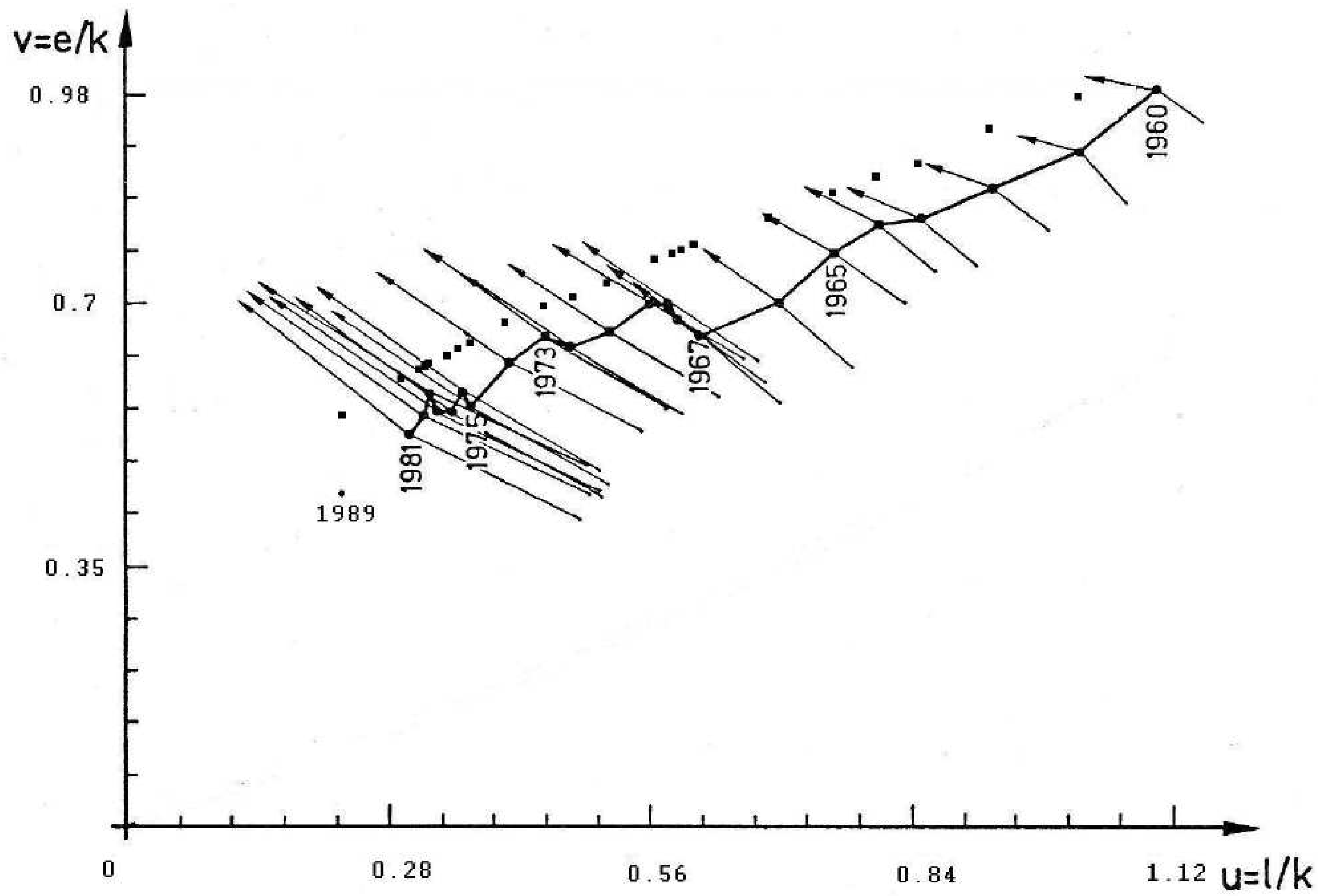
ϵ_i = output elasticity of Faktor X_i, p_i= market price of unit of X_i; $s_i =$ shadow price of X_i. μ_η, μ_ρ are Lagrange multipliers, depend upon ϵ_i.

$\longrightarrow$ Output elasticities are not equal to factor cost shares.

Technological constraints: **Binding, if** the state of the economy were **exclusively** determined by profit maximization $\rightarrow$ a) At least one non-zero component of s_i, b) less than 3 independent factors.

Non-binding, if the real-world state of the economy is **not** exclusively determined by profit maximization $\rightarrow$
a) equilibrium **not** at boundary, b) 3 independent factors.

Path in the cost mountain



Barrier from the limit to capacity utilization, $\eta = 1$, and neg. cost gradients along the path of Germany's industrial sector in the cost mountain between 1960 and 1989, projected onto the $\frac{l}{k} - \frac{e}{k}$ plane.

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- Barriers from technological constraints prevent industrial economies from reaching the state where output elasticities would equal factor cost shares. →No duality of quantities and prices. Real-life economies evolve at some distance from the barriers, observing also "soft" constraints due to entrepreneurial preference for flexibility according to customer demand, and social and legal obligations as well.

Change of market's legal framework

In order to fight increasing unemployment (and state indebtedness) and stimulate energy conservation and emission mitigation the disequilibrium between the output elasticities 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' output elasticities; $\longrightarrow$ **tax and levy shares:**
  labor 10-20%, capital 30-40%, energy 40-50%,
- increasing the tax per energy unit according to progress in energy conservation so that revenues remain constant.
- Border tax adjustments according to the energy required for production and transportation of border-crossing goods prevent competitive disadvantages in relation to not-energy-taxing economies.

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.