Economics 216:
The Macroeconomics of Development

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Lecture 3
Accounting for Economic Growth: Methodologies

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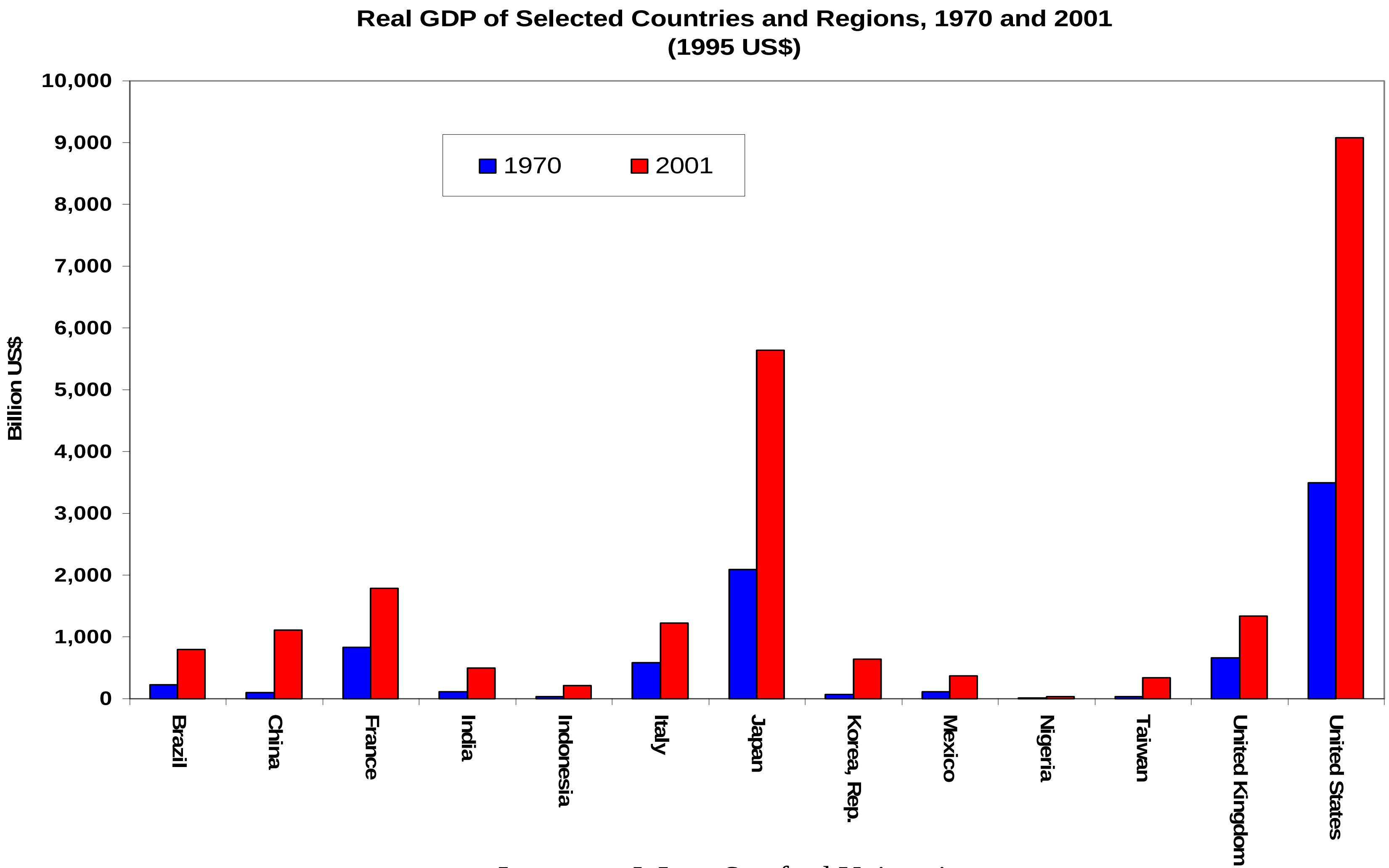
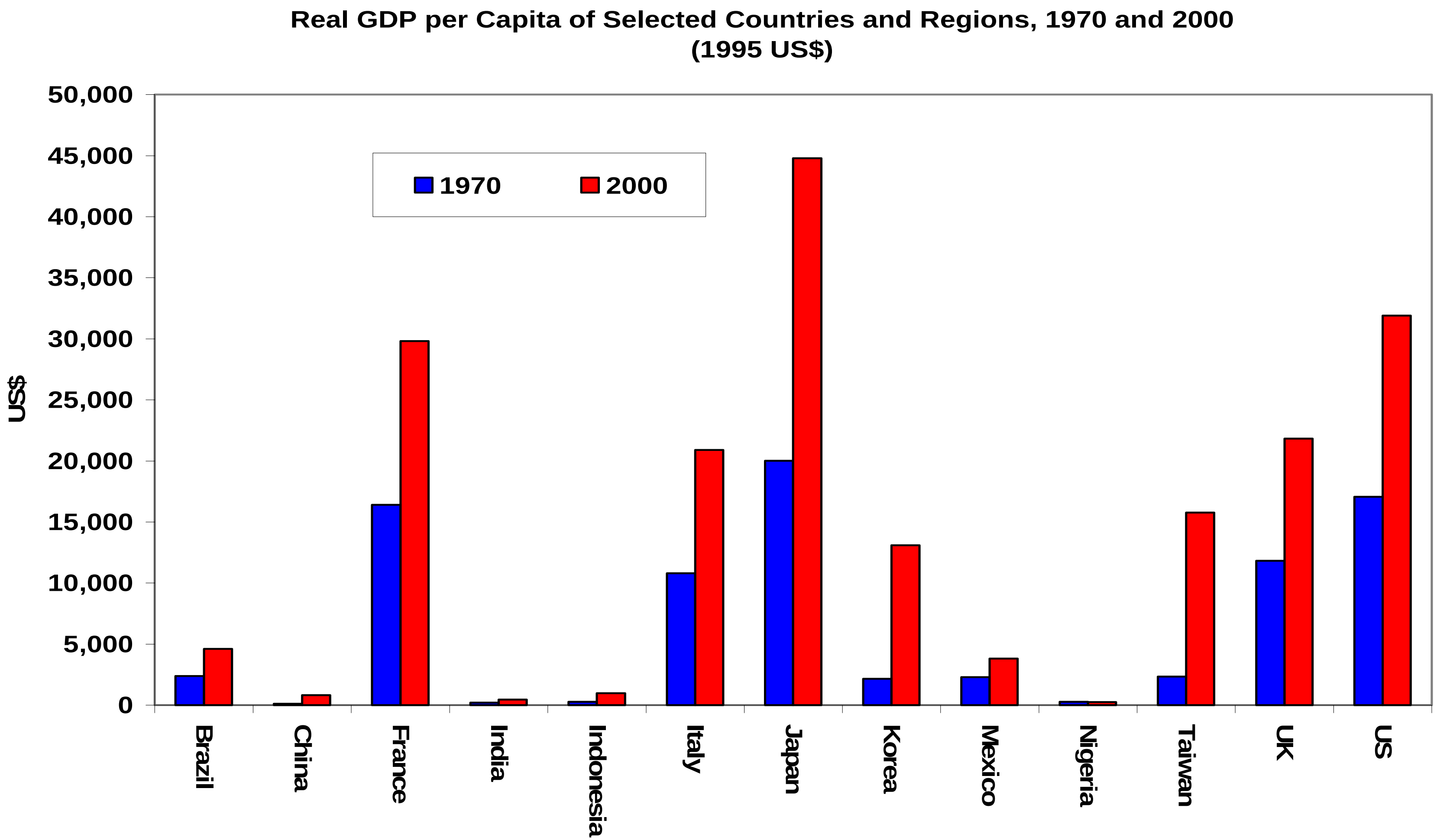
Real GDP of Selected Countries and Regions, 1970 and 2001



Real GDP per Capita of Selected Countries and Regions, 1970 and 2001



What Are the Sources of Long-Term Economic Growth?

- Great dispersion in the levels and rates of growth of real GDP and real GDP per capita across economies
- What are the causes of the differences in the levels of measured real GDP and GDP per capita? Can the differences bet explained by differences in the levels of measured inputs such as tangible or physical capital (structure and equipment), labor hours, and land? Can the remaining differences be explained by the differences in the levels of intangible capital (human capital, R&D capital, and natural resource endowments (including geographical location, climate, etc.

Accounting for Economic Growth

- Can the differences in the rates of growth be explained by the differences in the levels and rates of growth of the measured inputs? What are the sources of growth of real GNP over time?
- Growth accounting is a methodology for decomposing the growth of output by its proximate sources:
  - How much of the growth of output can be attributed to the growth of measured inputs, tangible capital and labor (and land—the land input is not normally included as a source of growth of output because it is fixed in quantity)? and
  - How much of the growth of output can be attributed to technical progress (also known as growth in total factor productivity, multifactor productivity, "the residual," or "a measure of our ignorance") or improvements in productive efficiency over time.
- **TECHNICAL PROGRESS (GROWTH IN TOTAL FACTOR PRODUCTIVITY)
= GROWTH IN OUTPUT HOLDING ALL <u>MEASURED</u> INPUTS CONSTANT**
- How much of the growth in real output is due to "working harder"? How much is due to "working smarter"?

Accounting for Economic Growth

- Simon Kuznets (1966), Nobel Laureate in Economics, observed that "the direct contribution of man-hours and capital accumulation would hardly account for more than a tenth of the rate of growth in per capita product--and probably less." (p. 81)
- Moses Abramovitz (1956) and Robert Solow (1957), another Nobel Laureate in Economics, similarly found that the growth of output cannot be adequately explained by the growth of inputs
- Edward Denison (1962), under the assumption that the degree of returns to scale is 1.1, found less technical progress

Accounting for Economic Growth

- Griliches and Jorgenson (1966), Jorgenson, Gollop and Fraumeni (1987) and Jorgenson and his associates found even less technical progress by adjusting capital and labor inputs for quality improvements
- Boskin and Lau (1990), applying the meta-production function approach to data on constant-price capital stocks and labor hours, found that technical progress has been the most important source of growth for the developed countries (the Group-of-Five (G-5) Countries—France, West Germany, Japan, United Kingdom and the United States) in the postwar period

The Concept of a Production Function

- Definition:
  - A production function is a rule which gives the quantity of output, Y , for a given quantity of input, X , denoted:

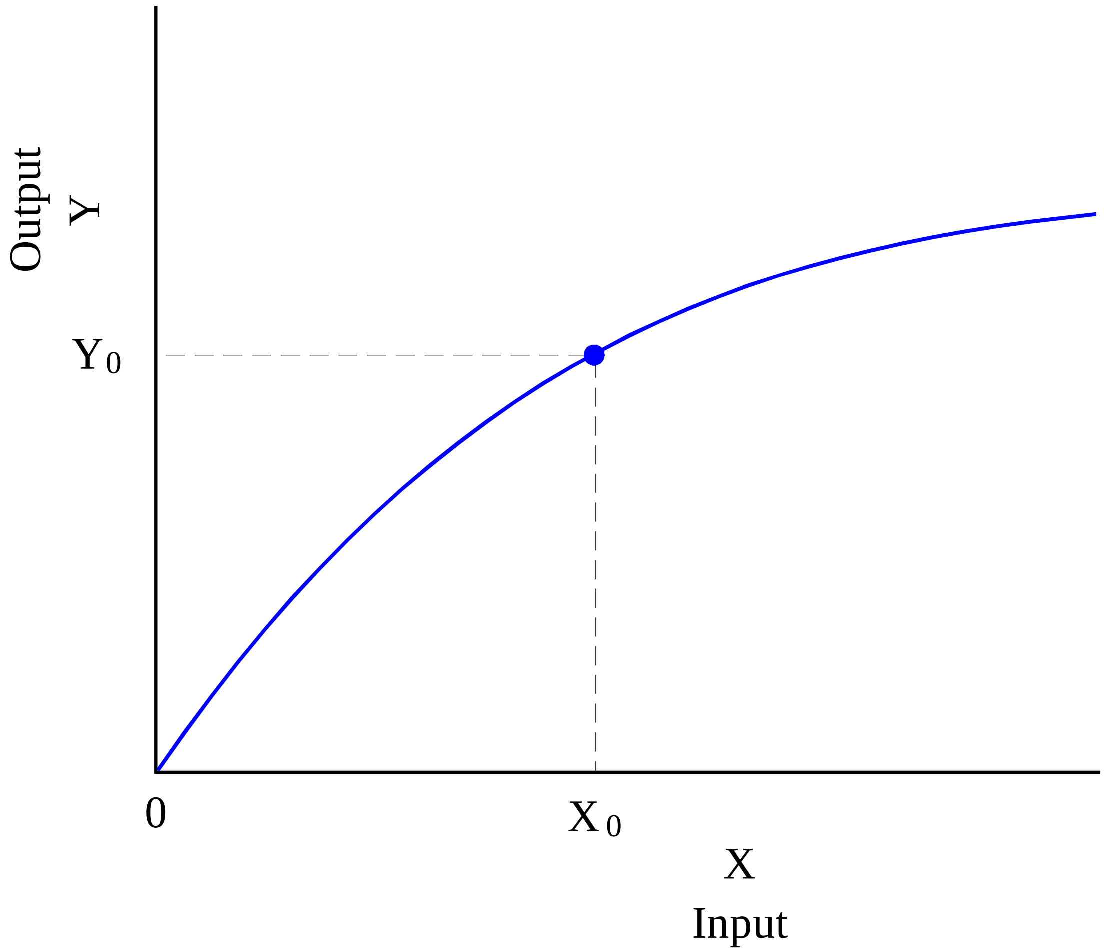
$$Y = F(X)$$

The Point of Departure: The Concept of a Production Function

- Definition:
  - A production function is a rule which gives the quantity of output, Y , for a given vector of quantities of inputs, X , denoted:

$$Y = F(X)$$

The Single-Output, Single-Input Case



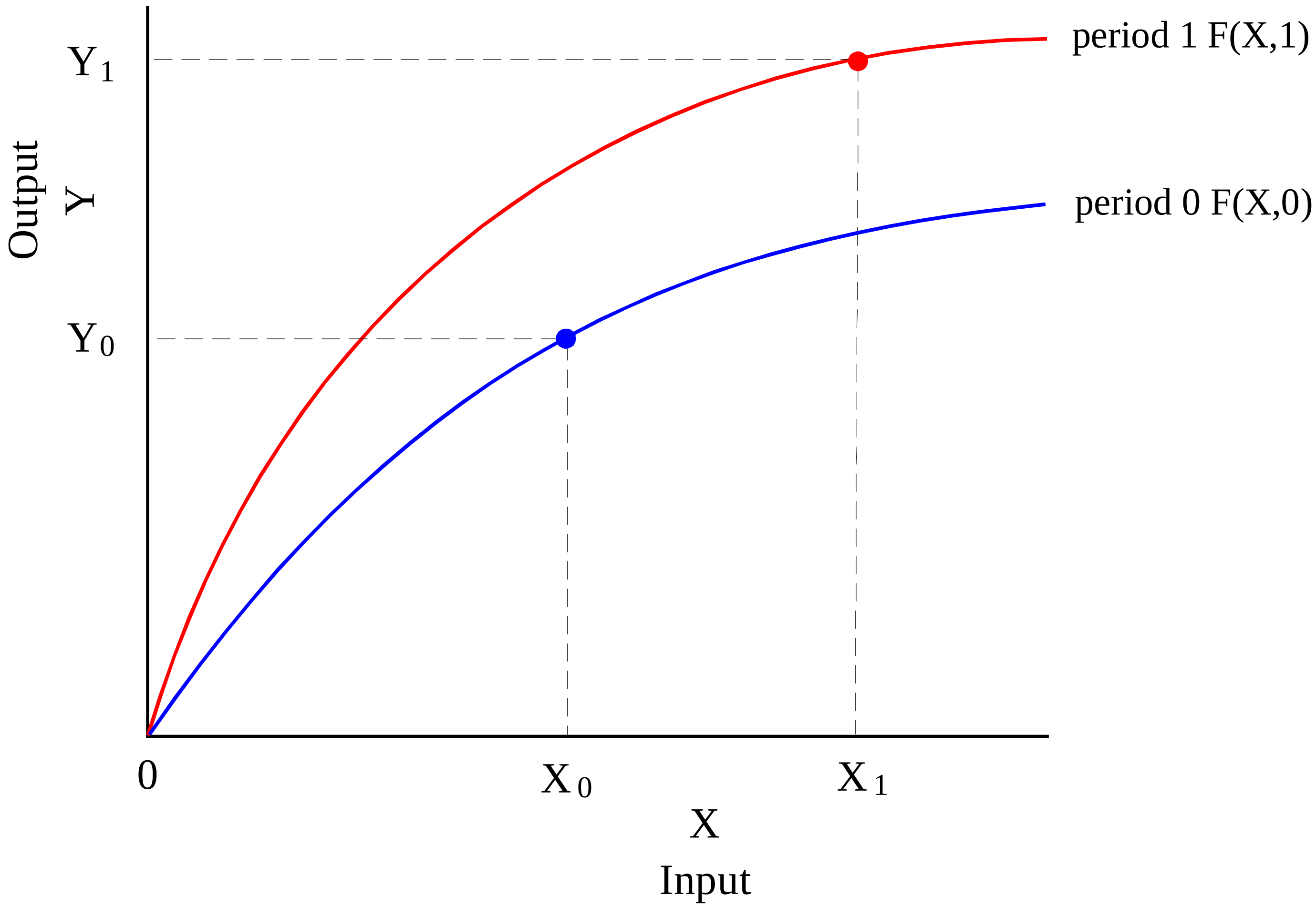
The Economist's Concept of Technical Progress

- A production function may change over time. Thus:
  - $Y = F(X, t)$
- Definition:
  - There is technical progress between period 0 and period 1 if given the same quantity of input, X_0 , the quantity of output in period 1, Y_1 , is greater than the quantity of output in period 0, Y_0 , i.e.,

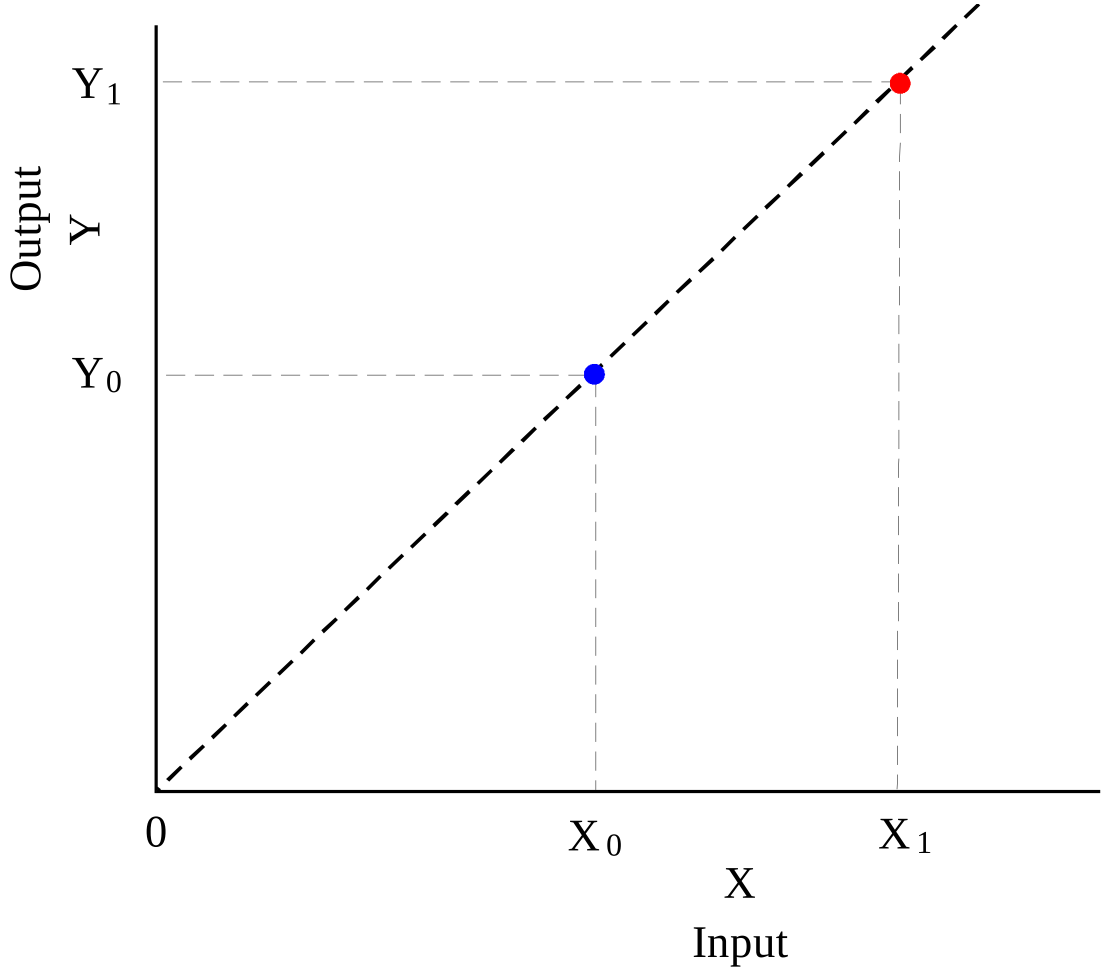
$$F(X_0, 1) \geq F(X_0, 0)$$

- TECHNICAL PROGRESS = THE GROWTH OF OUTPUT HOLDING MEASURED INPUTS CONSTANT

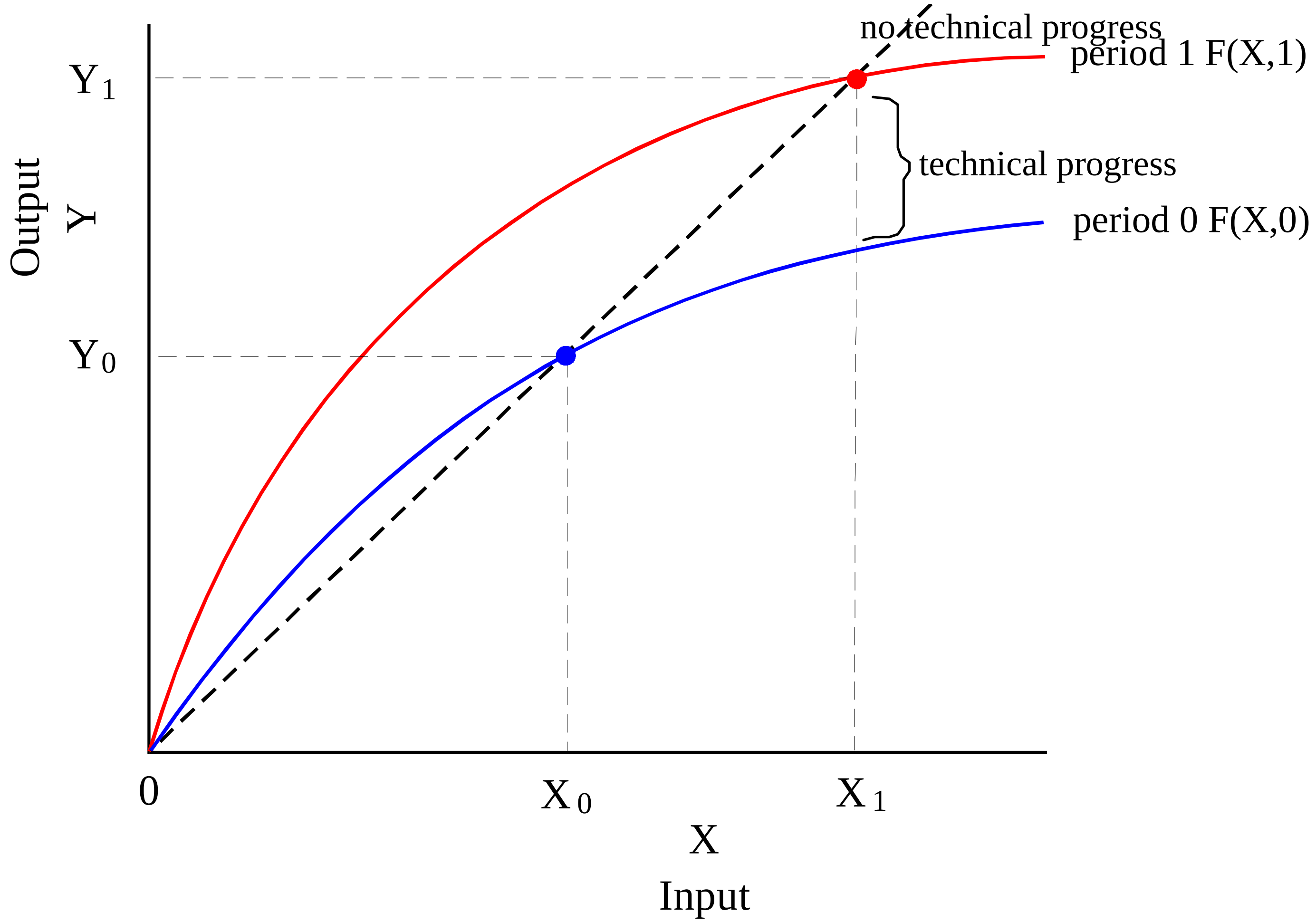
Technical Progress: The Single-Output, Single-Input Case



The Case of No Technical Progress



Under-Identification of Technical Progress from a Single Time-Series of Empirical Data



Interpretation of Technical Progress (Growth of Total Factor Productivity)

- Not "Manna from Heaven"
- Growth in unmeasured Intangible Capital (Human Capital, R&D Capital, Goodwill (Advertising and Market Development), Information System, Software, Business methods and Models, etc.)
- Growth in other omitted and unmeasured inputs (Land, Natural Resources, Water Resources, Environment, etc.)
- The effects of improvements in technical and allocative efficiency over time, e.g., learning-by-doing
- "Residual" or "Measure of Our Ignorance"

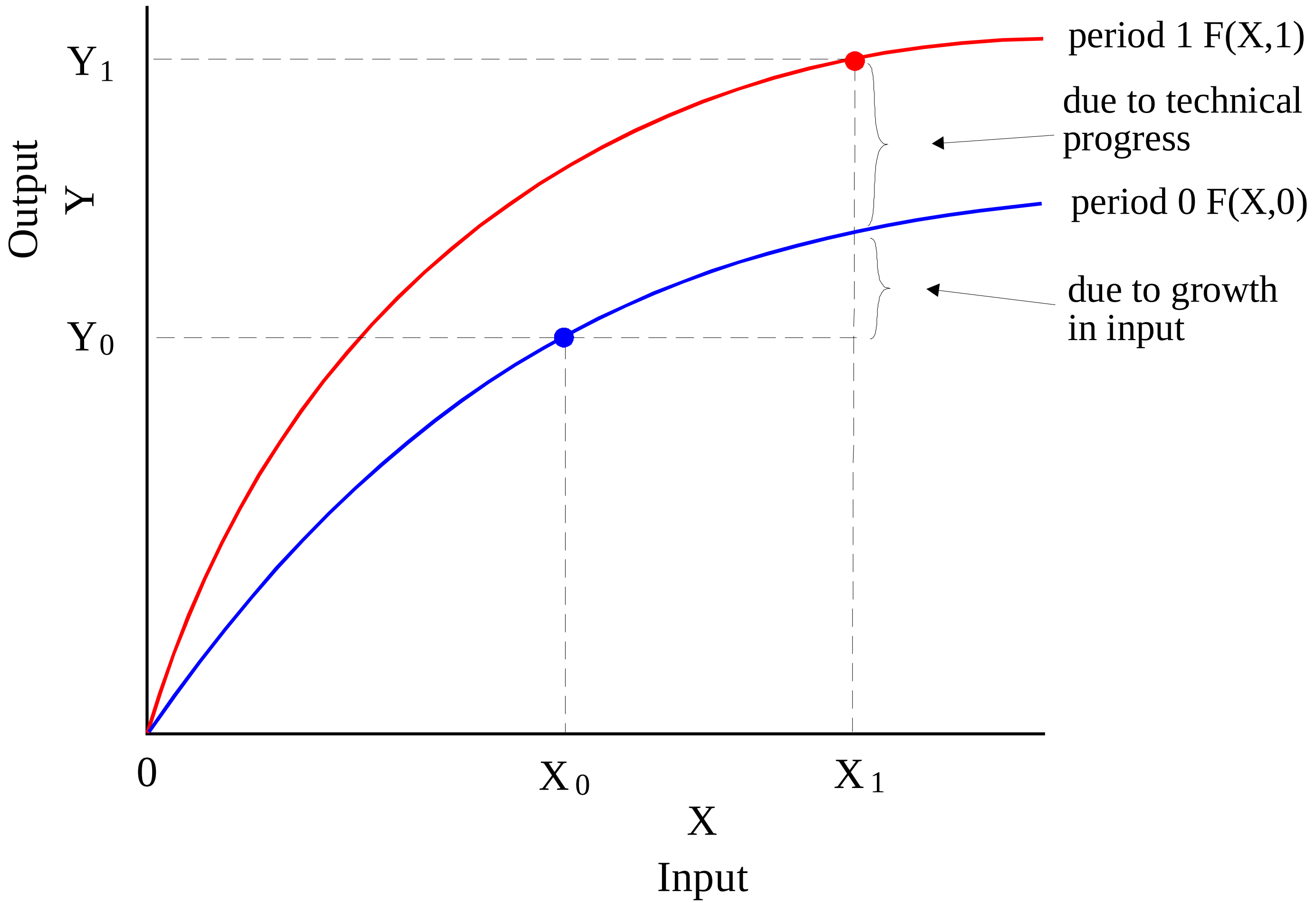
The Inputs of Production

- Measured Inputs
  - Tangible Capital
  - Labor
  - Land (possible)
- Technical Progress or Growth in Total Factor Productivity
  - Intangible Capital (Human Capital, R&D Capital, Goodwill (Advertising and Market Development), Information System, Software, etc.)
  - Other Omitted and Unmeasured Inputs (Land, Natural Resources, Water Resources, Environment, etc.)
  - Improvements in Technical and Allocative Efficiency over time
- Human Capital and R&D capital may be explicitly distinguished as measured inputs in the production function to the extent that they can be separately measured.

Decomposition of the Growth of Output

- If the production function is known, the growth of output can be decomposed into:
  - (1) The growth of output due to the growth of measured inputs (movement along a production function) and
  - (2) Technical progress (shift in the production function)
- The growth of output due to the growth of inputs can be further decomposed into the growth of output due to tangible capital, labor (and any other measured inputs)
- One central question of growth accounting is: What is the relative importance of the "measured inputs" versus "technical progress" or growth in total factor productivity (TFP) as sources of economic growth?

Decomposition of the Growth of Output



Contribution of the Growth of Input

- The rate of growth of output between period 0 and period 1 due to the growth of inputs can be estimated as:

$$(F(X_1,0) - F(X_0,0)) / F(X_0,0)$$

- or as: $$(F(X_1,1) - F(X_0,1)) / F(X_0,1)$$
- The two are not the same except under neutrality of technical progress.
- A natural estimate is the (geometric) mean of the two estimates (the geometric mean is defined as the the square root of the product of the two estimates)

Definition of Neutrality

- Technical progress is said to be neutral if
  - $F(X, t) = A(t)\,F(X), \;\; for\ all\ X, t$

Contribution of Technical Progress

- The growth of output due to technical progress can be estimated as: $(F(X_0,1)-F(X_0,0))/F(X_0,0)$
- or as: $(F(X_1,1)-F(X_1,0))/F(X_1,0)$
- The two are not the same except under neutrality of technical progress.
- A natural estimate is again the (geometric) mean of the two estimates.

The Point of Departure: An Aggregate Production Function

- Each country has an aggregate production function:

$$Y_{it} = F_i(K_{it}, L_{it}, t), i = 1, \ldots, n; t = 0, \ldots, T$$

- In general, $F_i(.)$ is not necessarily the same across countries, hence the subscript i

Decreasing, Constant or Increasing Returns to Scale?

- Constant returns to scale imply that the production function is homogeneous of degree one:

  $$\mathbf{F(\lambda X_t, t) = \lambda\, F(X_t, t), \text{ all } X_t, t}$$

  The hypothesis of constant returns to scale is traditionally assumed at the aggregate level (except Denison, who assumes the degree of returns to scale is 1.1)
- A problem of identification from a single time-series of empirical data
  - The confounding of economies of scale and technical progress for a growing economy
  - The higher the assumed degree of returns to scale, the lower the estimated technical progress (and vice versa)

Decreasing, Constant or Increasing Returns to Scale?

- Theoretical arguments for Constant Returns at the aggregate level
  - Replicability
- Theoretical arguments for Decreasing Returns
  - Omitted inputs--land, natural resources, human capital, R&D capital, other forms of intangible capital

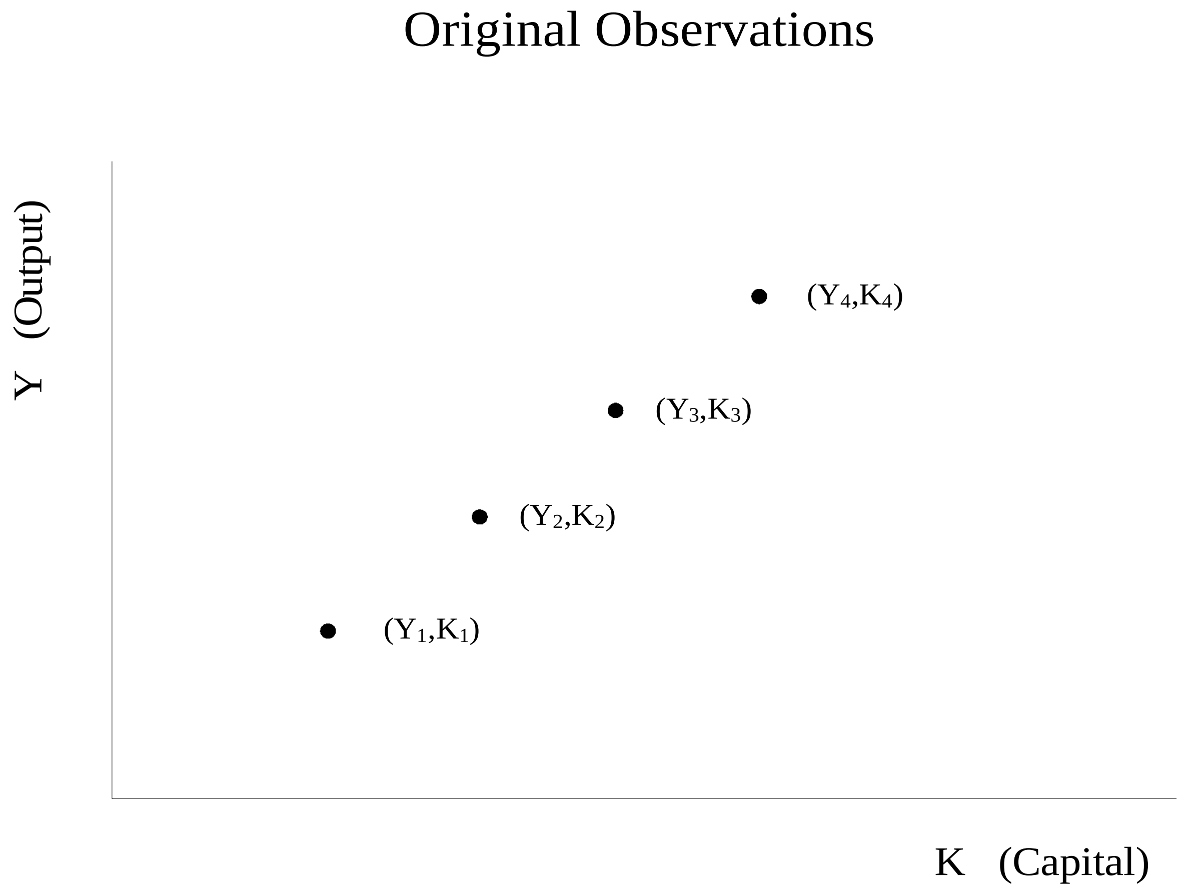
Decreasing, Constant or Increasing Returns to Scale?

- Theoretical arguments for Increasing Returns
  - Economies of scale at the microeconomic level (but replicability of efficient-scale units)
  - Increasing returns in the production of new knowledge--high fixed costs and low marginal costs (but diminishing returns of the utilization of knowledge to aggregate production)
  - Scale permits the full realization of the economies of specialization
  - Existence of coordination externalities (but likely to be a one-time rather than continuing effect)
  - Network externalities (offset by congestion costs, also replicability of efficient-scale networks)

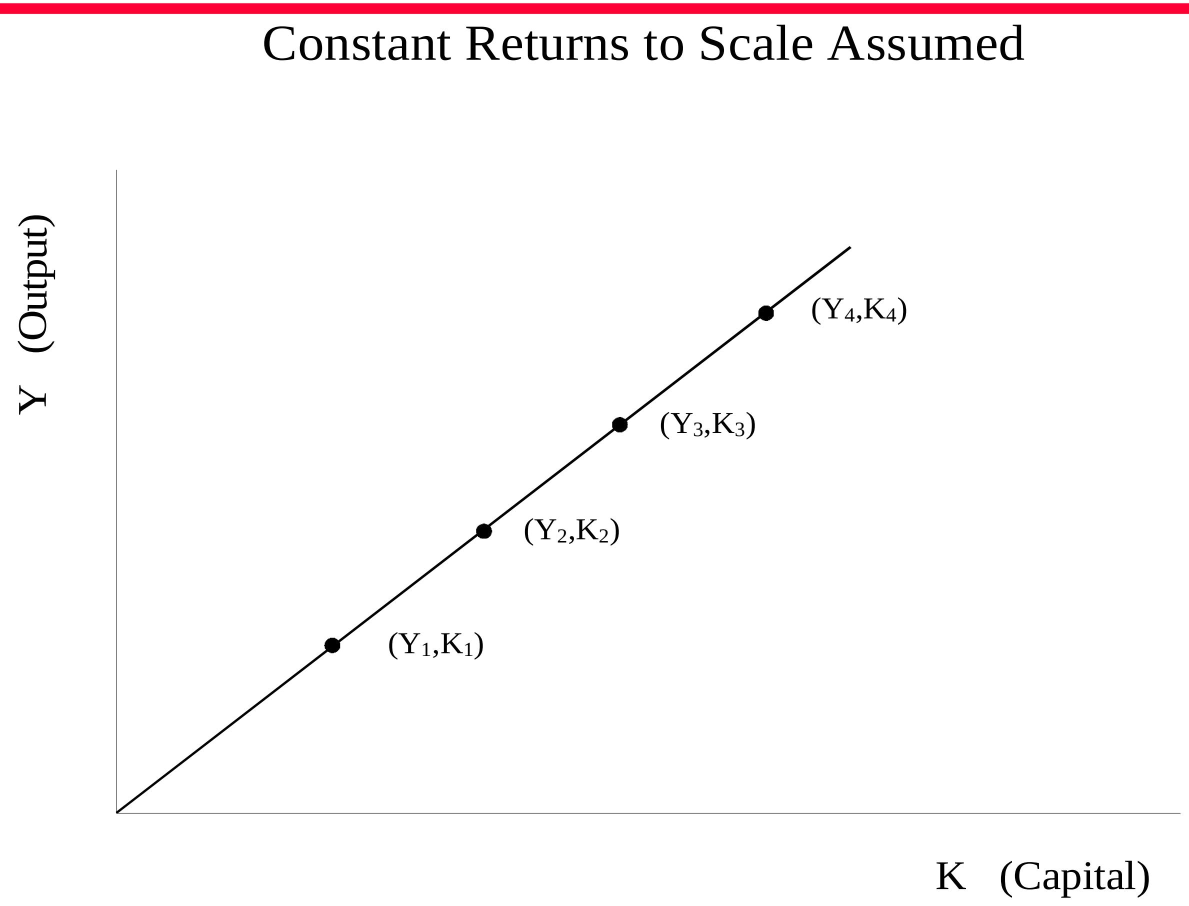
Difficulties in the Measurement of Technical Progress (Total Factor Productivity)

- (1) The confounding of economies of scale and technical progress
  - Solution: pooling time-series data across different countries--at any given time there are different scales in operation; the same scale can be observed at different times
- (2) The under-identification of the biases of scale effects and technical progress
  - Bias in scale effects--as output is expanded under conditions of constant prices of inputs, the demands for different inputs are increased at differential rates
  - Bias in technical progress--over time, again under constant prices, the demands of different inputs per unit output decreases at different rates
  - Solution: econometric estimation with flexible functional forms

Original Observations

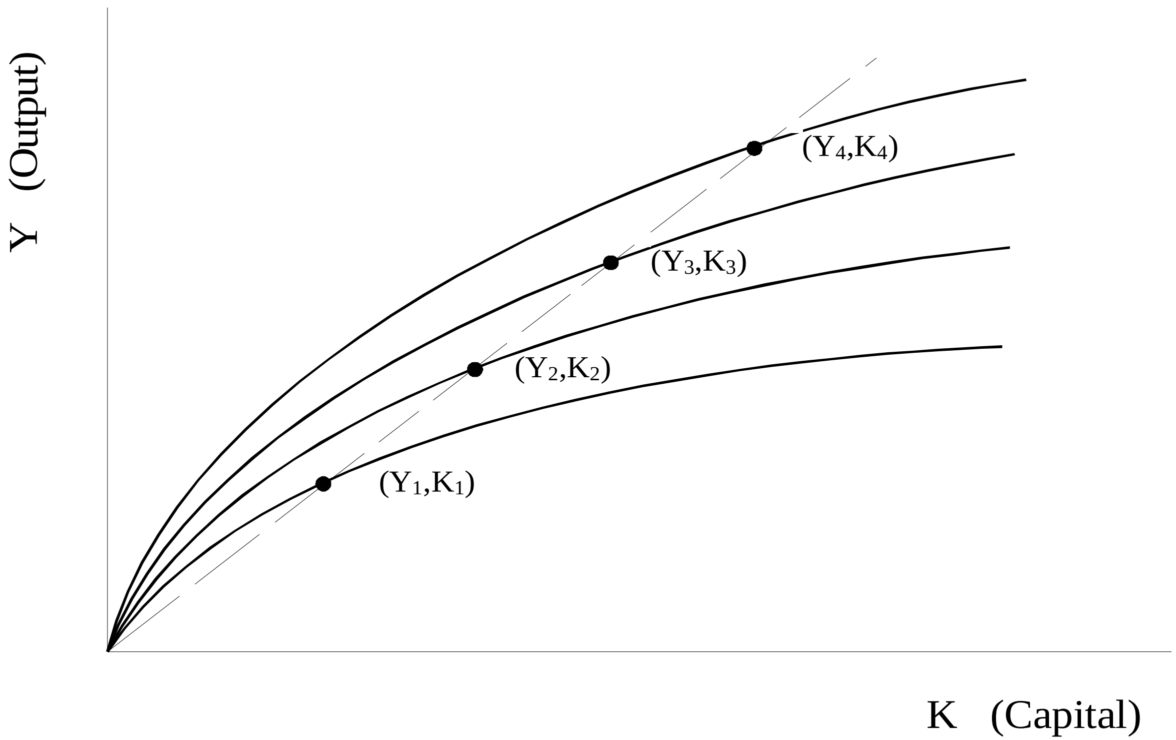


Constant Returns to Scale Assumed Result: No Technical Progress

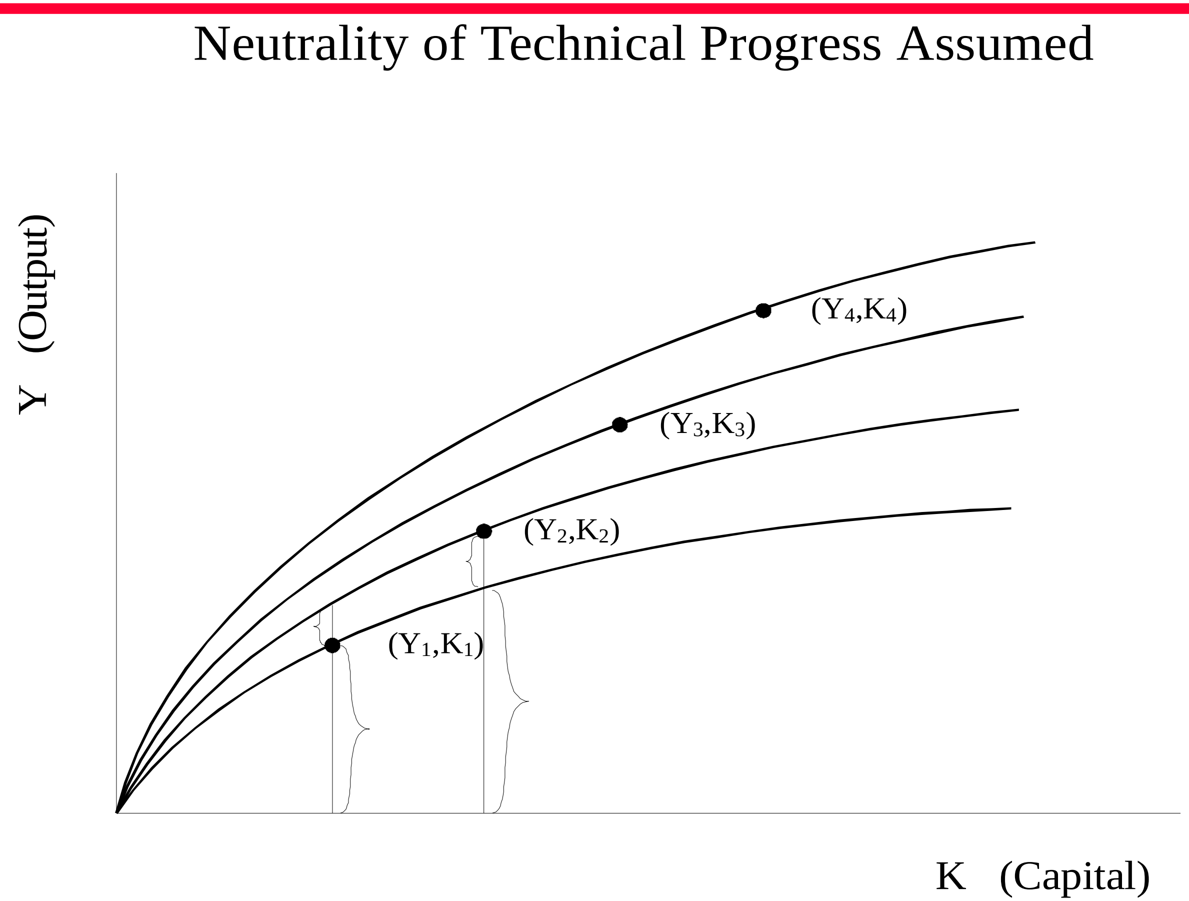


Decreasing Returns Assumed
Result: Technical Progress

Decreasing Returns to Scale Assumed

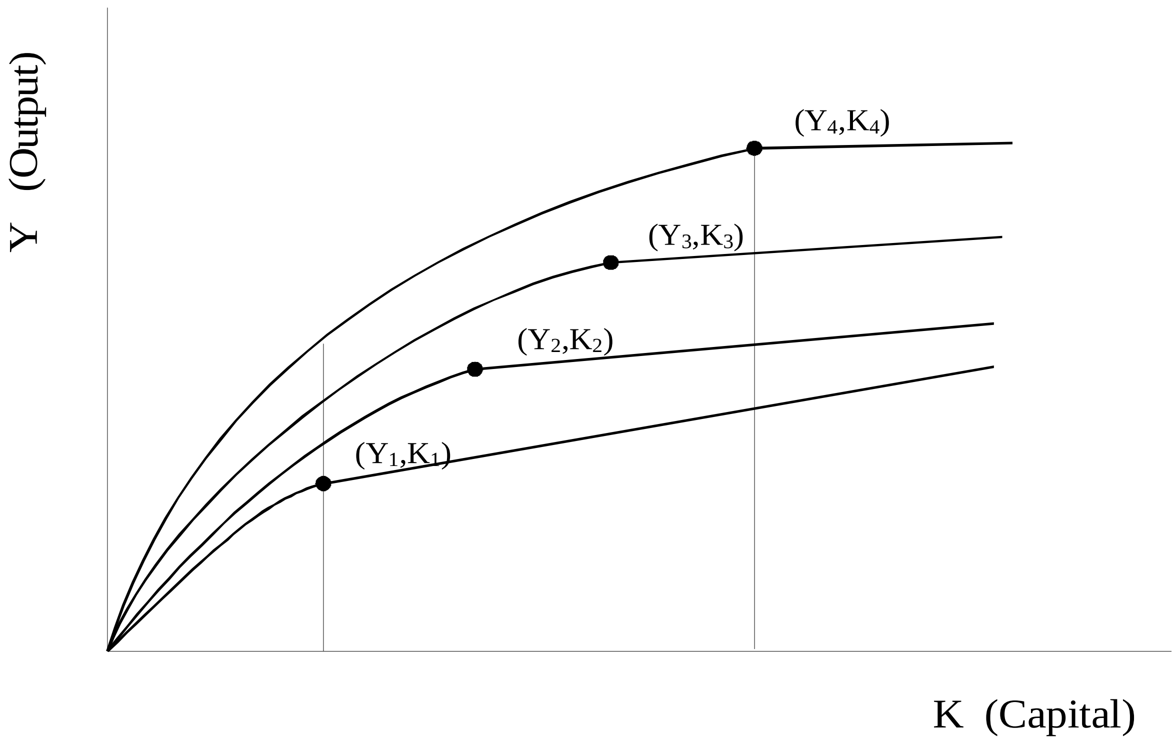


Neutrality of Technical Progress Assumed: Uniform Shifts of the Production Function

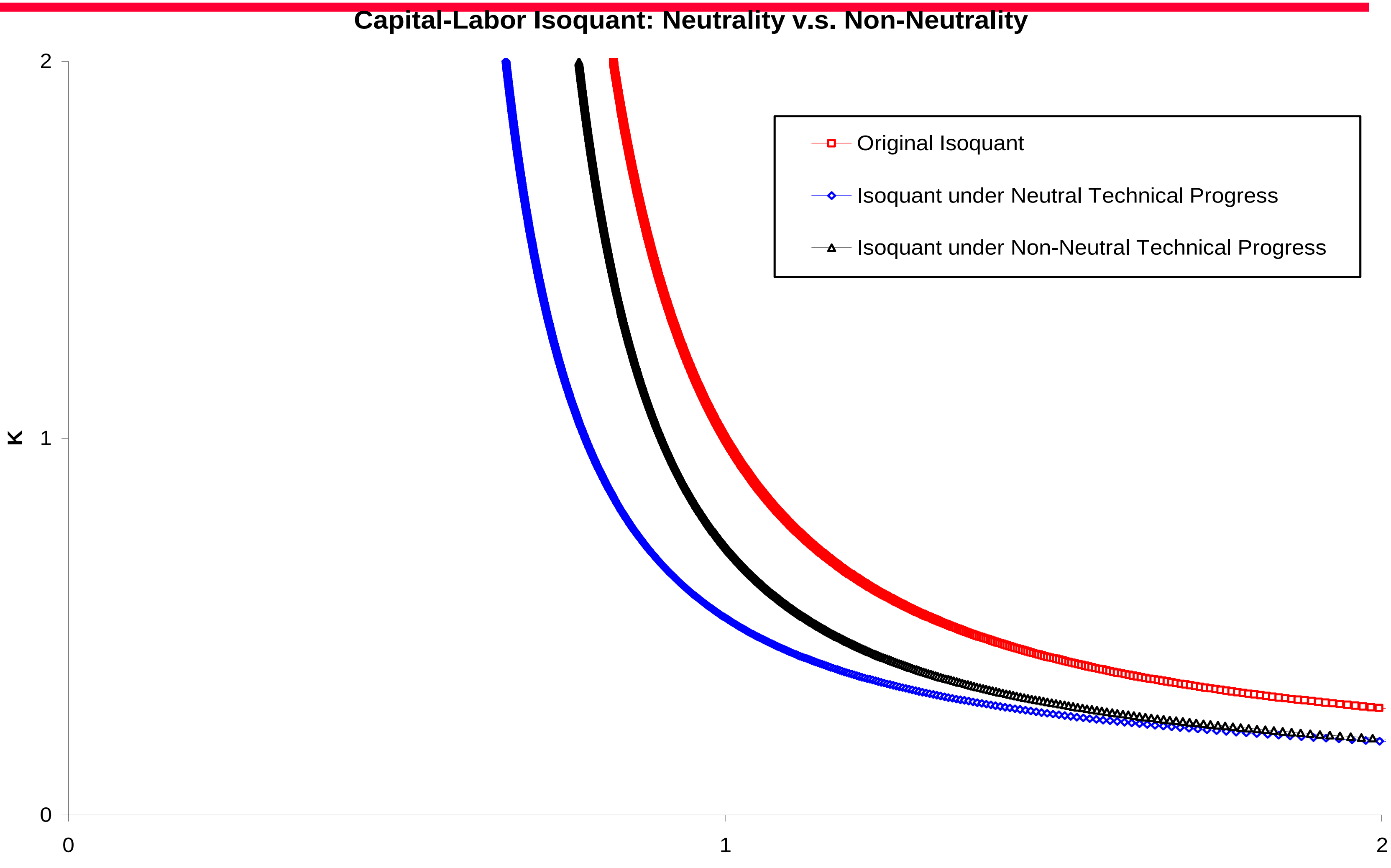


Neutrality of Technical Progress Not Assumed: Non-Uniform Shifts of the Production Function

Neutrality of Technical Progress Not Assumed

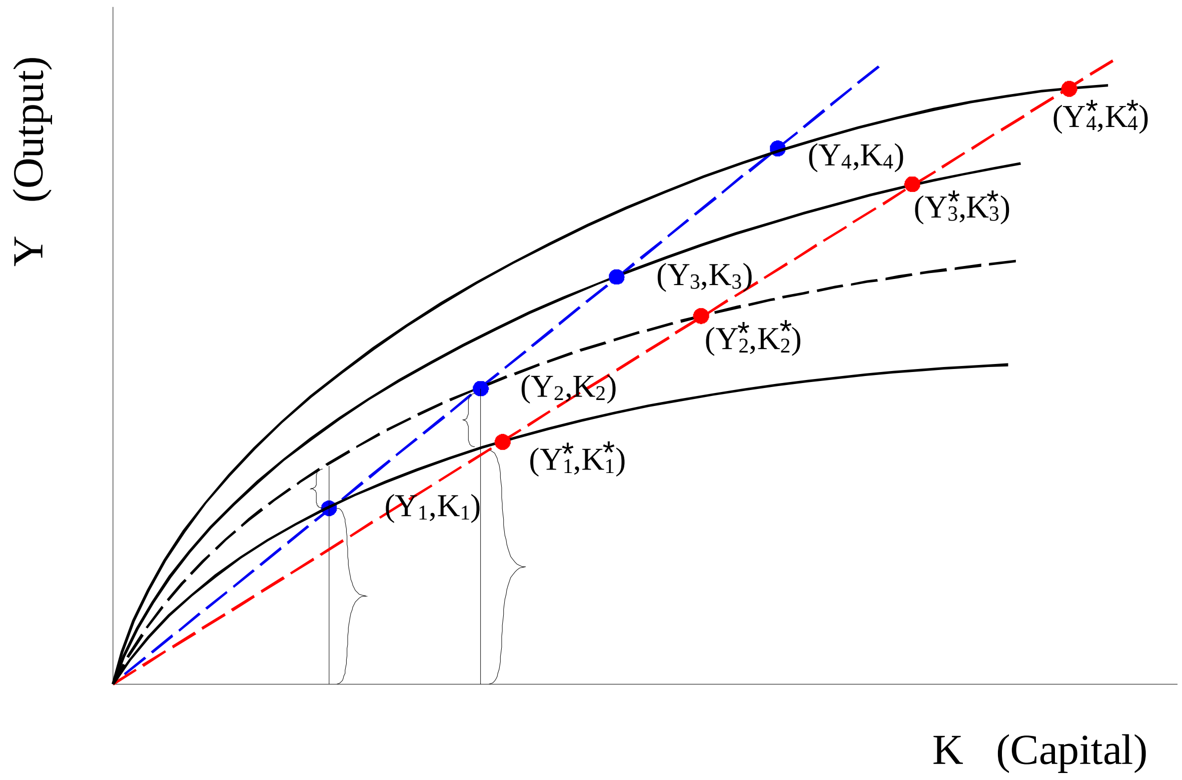


Neutrality of Technical Progress: Uniform Shift of the Isoquant



Identification of Scale Effects and Technical Progress through Pooling Across Countries

Identification through Pooling



Two Leading Alternative Approaches to Growth Accounting

- (1) Econometric Estimation of the Aggregate Production Function

  E.g., the Cobb-Douglas production function

$$Y_t = A_0 e^{\gamma t} K_t^{\alpha} L_t^{\beta}$$

or, taking natural logarithms

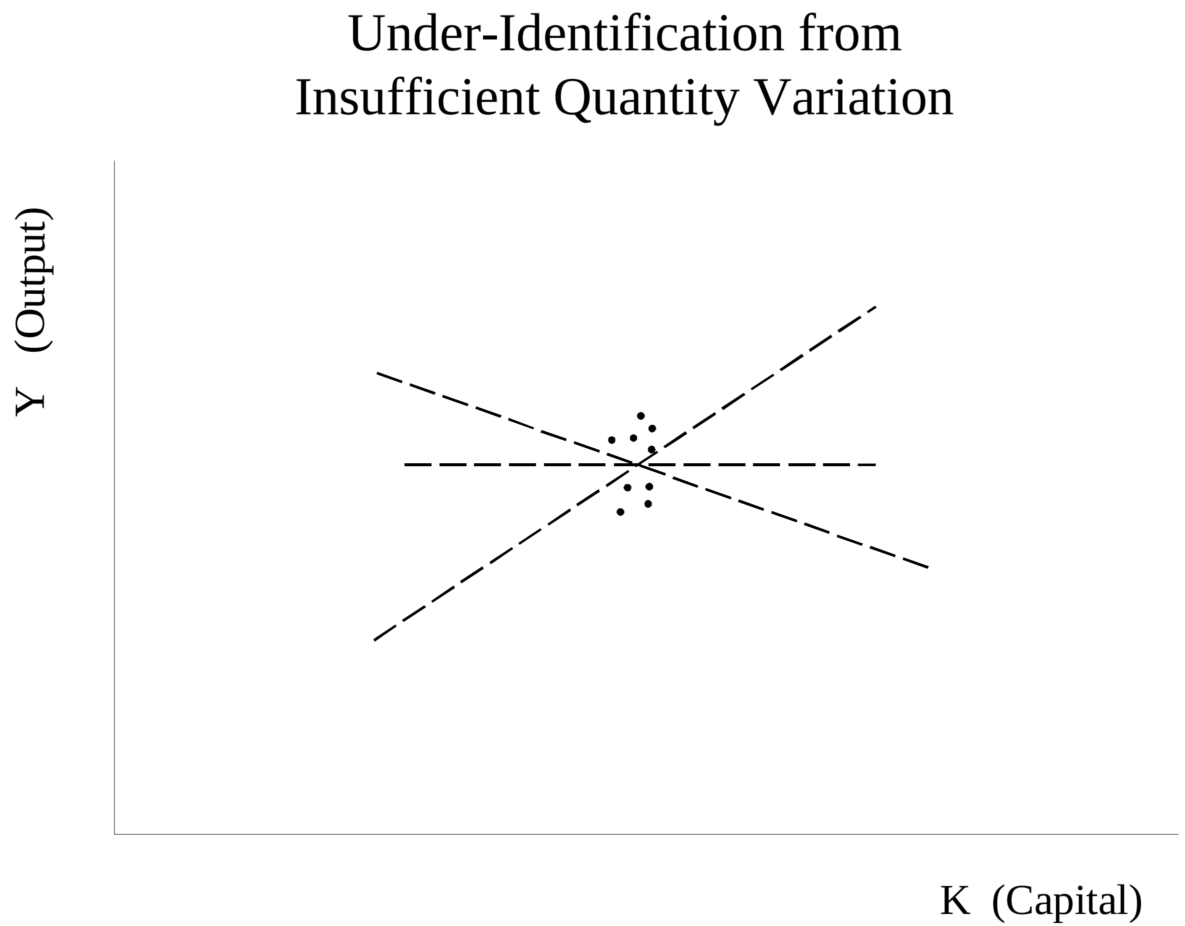
$$\ln Y_t = \ln A_0 + \alpha \ln K_t + \beta \ln L_t + \gamma t$$

- (2) Traditional Growth-Accounting Formula
- **Are Differences in Empirical Results Due to Differences in Methodologies or Assumptions or Both?**

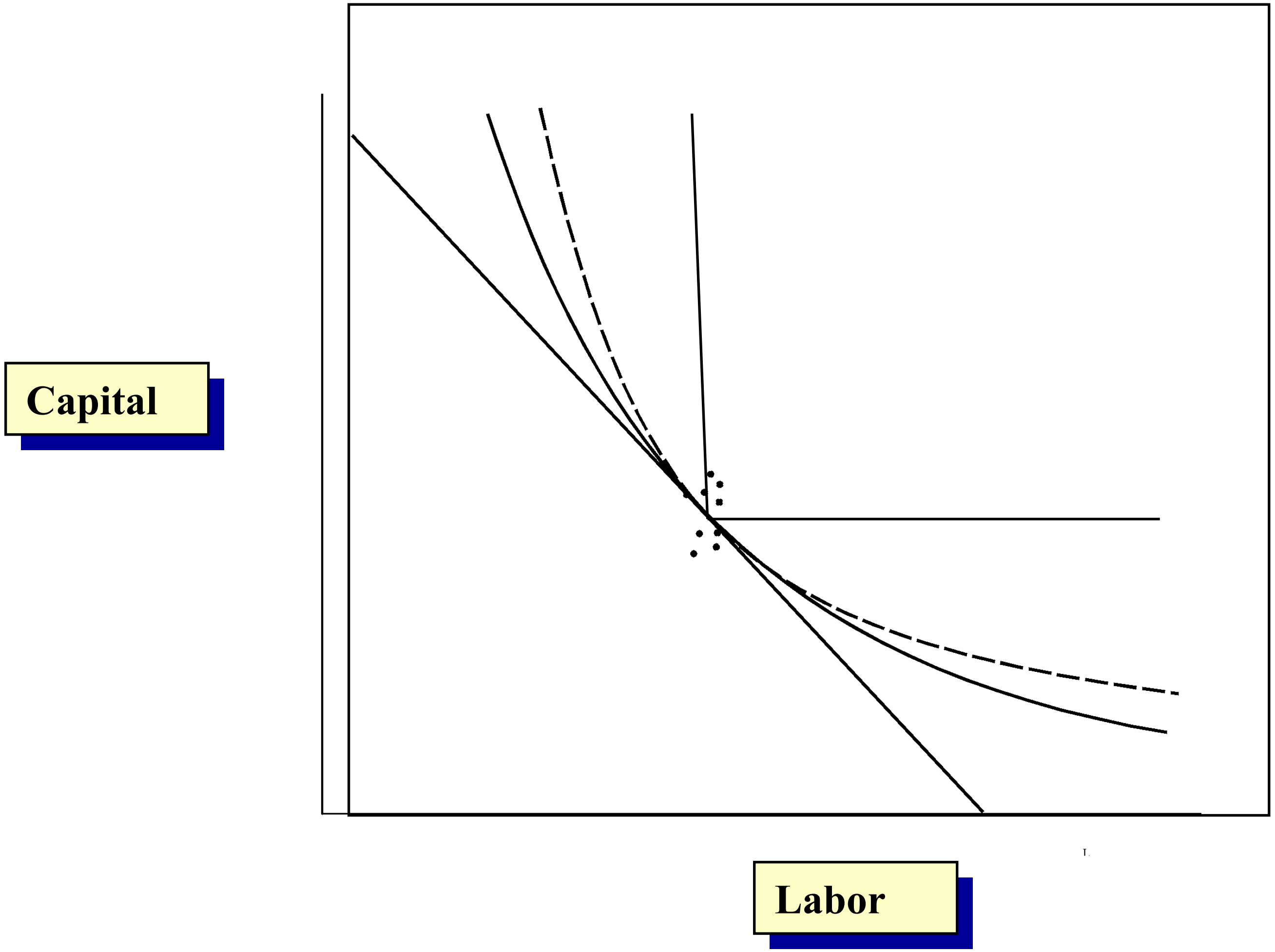
Potential Problems of the Econometric Approach

- Insufficient Quantity Variation
  - multicollinearity
  - restricted range of variation
  - approximate constancy of factor ratios
- Insufficient Relative-Price Variation
- Implications:
  - imprecision
  - unreliability
  - under-identification
  - restricted domain of applicability and confidence

Under-Identification from Insufficient Quantity Variation



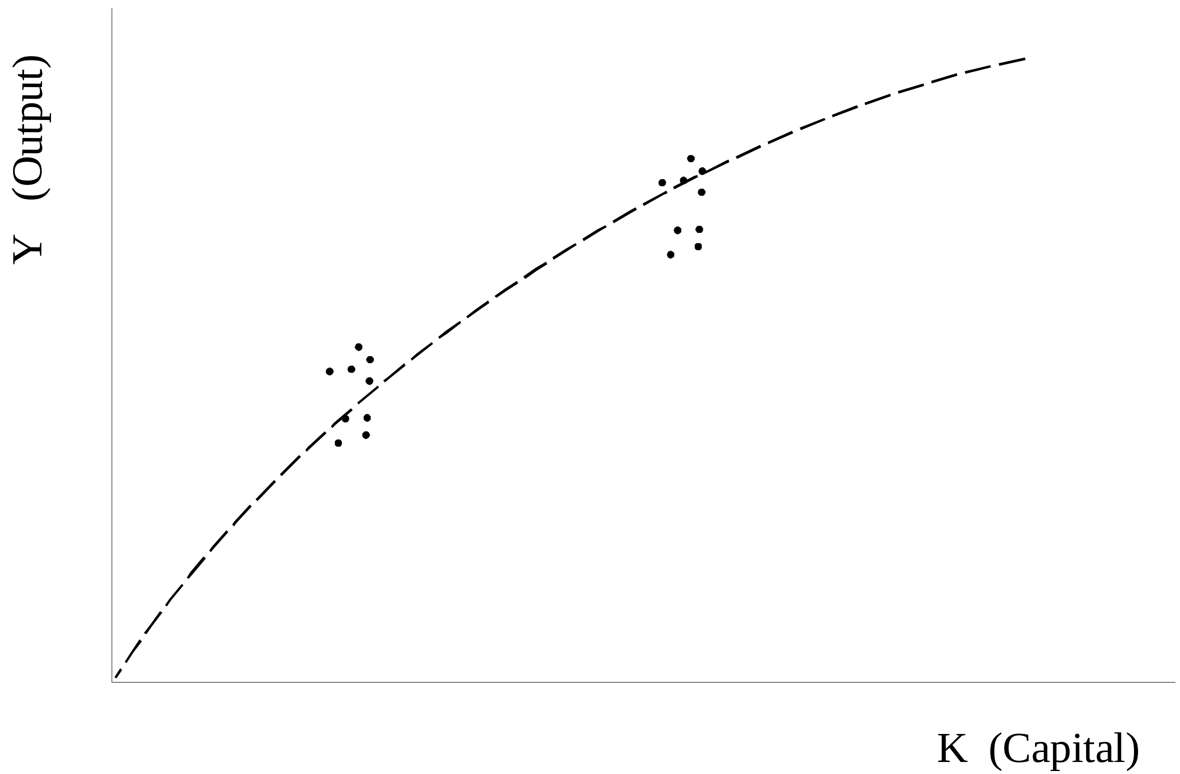
Under-Identification of Isoquant from Insufficient Relative-Price Variation



Alternative isoquants that fit the same data equally well.

Solution:
Pooling Across Countries

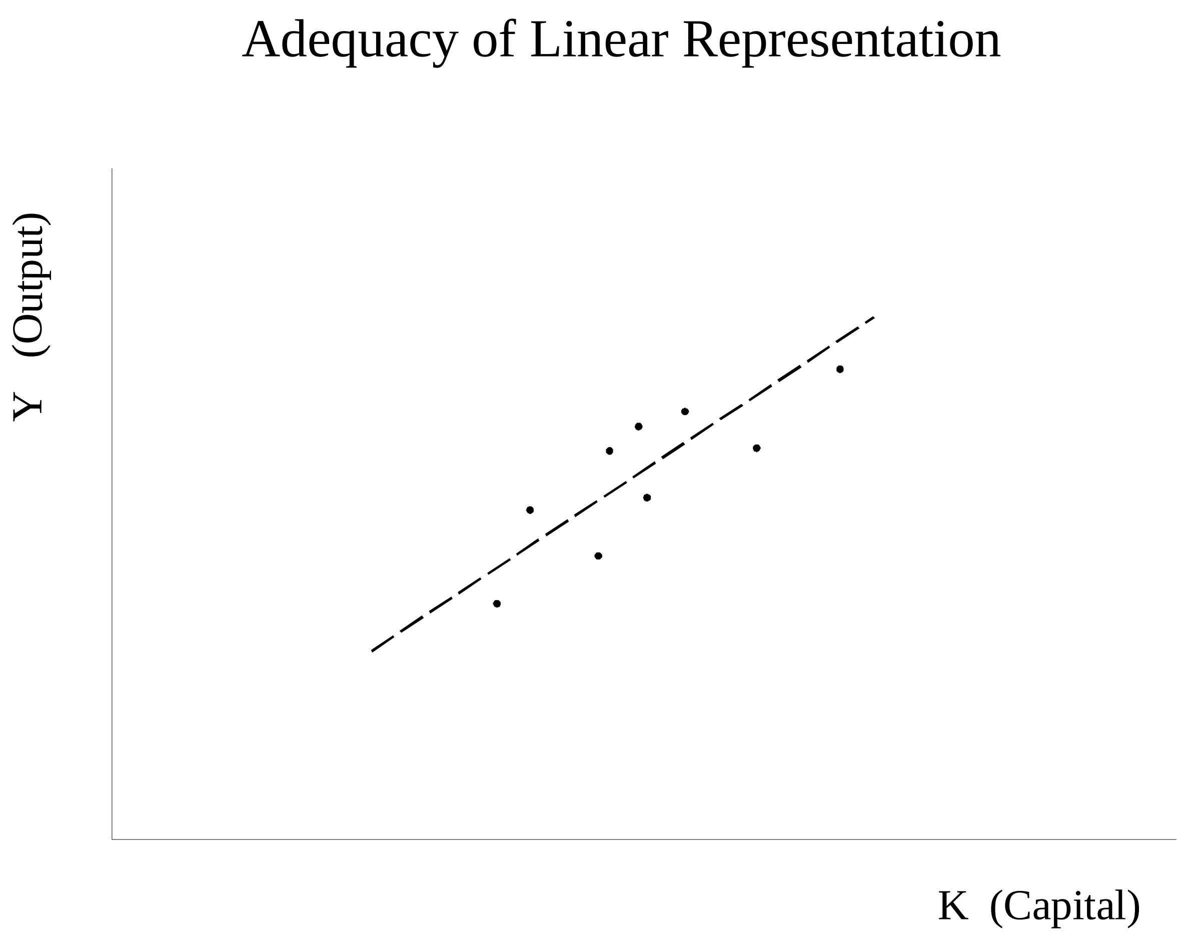
The Effect of Pooling



Problems Arising from Pooling

- Extensiveness of the Domain of the Variables
  - Solution: Use of a flexible functional form
- The Assumption of Identical Production Functions
  - Solution: The meta-production function approach
- Non-Comparability of Data
  - Solution: The meta-production function approach

Adequacy of Linear Representation



Inadequacy of Linear Representation

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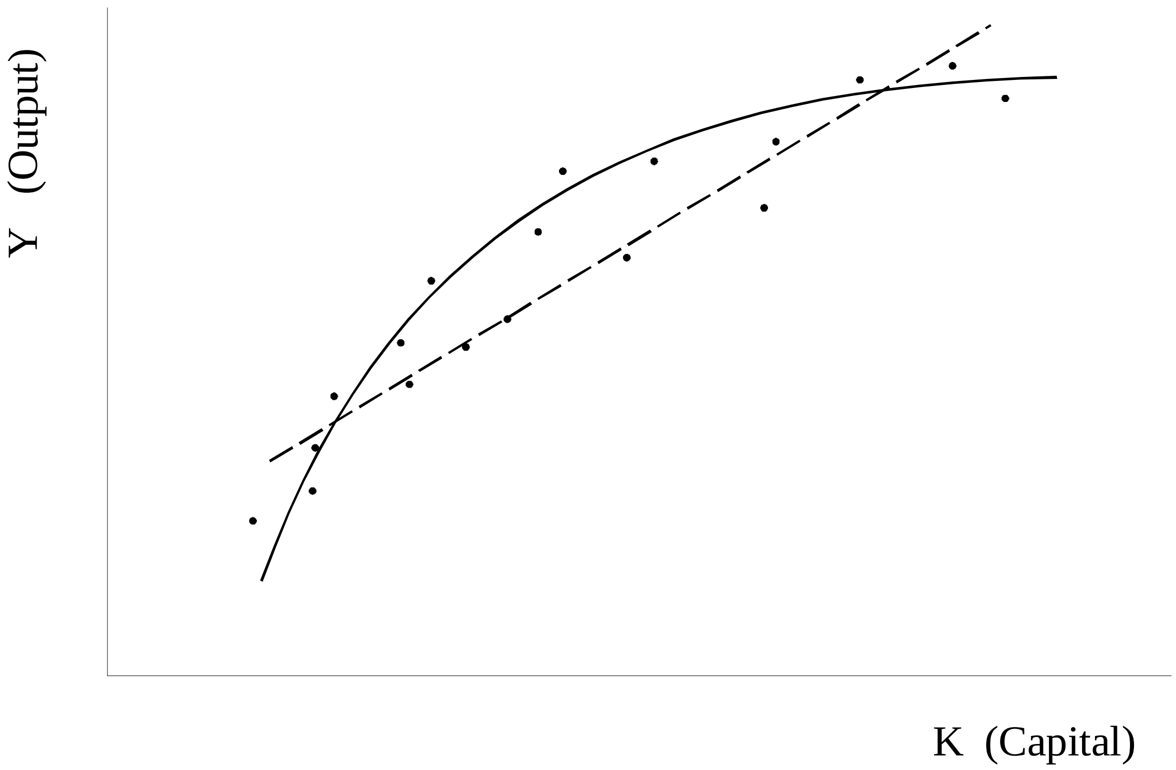


The Traditional Growth-Accounting Formula: The Concept of a Production Elasticity

$$\varepsilon_{X_i} = \frac{\Delta Y}{Y} / \frac{\Delta X_i}{X_i} = \frac{\partial Y}{\partial X_i} / \frac{Y}{X_i} = \frac{\partial \ln Y}{\partial \ln X_i}$$

- The production elasticity of an input is the % increase in output in response to a 1% increase in the input, <u>holding all other inputs constant</u>. It typically lies between 0 and 1.
- The % increase in output attributable to an increase in input is approximately equal to the product of the production elasticity and the actual % increase in the input.

Decomposition of the Change in Output

Differentiating logarithmically with respect to time the production function

$$\mathrm{Y} = F(\mathrm{K}, \mathrm{L}, t),$$

$$\frac{d\ln \mathrm{Y}}{dt} = \frac{\partial \ln F}{\partial \ln \mathrm{K}} \bullet \frac{d\ln \mathrm{K}}{dt} + \frac{\partial \ln F}{\partial \ln \mathrm{L}} \bullet \frac{d\ln \mathrm{L}}{dt} + \frac{\partial \ln F}{\partial t}$$

$$\%\ \Delta \mathrm{Y} = \varepsilon_{\mathrm{K}}\ \%\ \Delta \mathrm{K} + \varepsilon_{\mathrm{L}}\ \%\ \Delta \mathrm{L} + \gamma$$

where $\varepsilon_{\mathrm{K}} = \dfrac{\partial \ln F}{\partial \ln \mathrm{K}}$; $\varepsilon_{\mathrm{L}} = \dfrac{\partial \ln F}{\partial \ln \mathrm{L}}$; and $\gamma = \dfrac{\partial \ln F}{\partial t}$.

The Fundamental Equation of Traditional Growth Accounting Once More

$$\%\Delta Y = \varepsilon_K \%\Delta K + \varepsilon_L \%\Delta L + \gamma$$

The three terms on the right - hand side may be identified as the contributi ons of capital, labor and technical progress respective ly. The percentage contributi on of each is calculated by dividing each term by the left - hand side.

$$\gamma = \%\Delta Y - \varepsilon_K \%\Delta K - \varepsilon_L \%\Delta L$$

The Maximum Contribution of Labor Input to Economic Growth

	Industrialized Economies	Developing Economies
Labor Elasticity	0.6	0.3-0.4
Rate of Growth of Labor	less than 2%	less than 5%
Maximum Contribution	1.2%	2.0%

- ANY TIME THE RATE OF GROWTH OF REAL GDP EXCEEDS 2% p.a. SIGNIFICANTLY, IT MUST BE DUE TO THE GROWTH IN TANGIBLE CAPITAL OR TECHNICAL PROGRESS!

Implementation of the Traditional Growth-Accounting Formula

- The elasticities of output with respect to capital and labor must be separately estimated
- The rate of technical progress depends on K_t and L_t as well as t
- The elasticity of output with respect to labor is equal to the share of labor under instantaneous competitive profit maximization
- The elasticity of output with respect to capital is equal to one minus the elasticity of labor under the further assumption of constant returns to scale

Implementation of the Traditional Growth-Accounting Formula

Under the assumption of instantaneous profit maximization with competitive output and input markets, the value of the marginal product of labor is equal to the wage rate:

$$P\frac{\partial F(K,L,t)}{\partial L}=w$$

Multiplying both sides by L and dividing both sides by P.Y, we obtain:

$$\frac{L}{Y}\cdot\frac{\partial F(K,L,t)}{\partial L}=\frac{wL}{PY}$$

or

$$\frac{\partial \ln F(K,L,t)}{\partial \ln L}=\frac{wL}{PY}$$

In other words, the elasticity of output with respect to labor is equal to the share of labor in the value of total output.

Necessary Assumptions for the Application of the Growth-Accounting Formula

- Instantaneous profit maximization under perfectly competitive output and input markets
  - equality between output elasticity of labor and the share of labor in output
- Constant returns to scale
  - sum of output elasticities is equal to unity
- Neutrality
  - the rates of technical progress can be directly cumulated over time without taking into account the changes in the vector of quantities of inputs

The Implication of Neutrality of Technical Progress

- It may be tempting to estimate the technical progress over T periods by integration or summation with respect to time:

$$\int_0^T \frac{\partial \ln F}{\partial t}(K_t, L_t, t)dt$$

- However, the integration or summation can be rigorously justified if and only if:
  - (1) Technical progress is Hicksian neutral (equivalently output-augmenting); or
  - (2) Capital and labor are constant over time

Necessary Data for the Measurement of Technical Progress

- The Econometric Approach
  - Quantities of Output and Inputs
- The Traditional Growth-Accounting Formula Approach
  - Quantities of Output and Inputs
  - Prices of Outputs and Inputs

Pitfalls of Traditional Growth Accounting (1)

- (1) If returns to scale are increasing, technical progress is over-estimated and the contribution of the inputs is underestimated (and vice versa);
- (2) Nonneutrality prevents simple cumulation over time;
- (3) Constraints to instantaneous adjustments and/or monopolistic or monopsonistic influences may cause production elasticities to deviate from the factor shares, and hence the estimates of technical progress as well as the contributions of inputs using the factor shares may be biased;

Pitfalls of Traditional Growth Accounting (2)

- (4) With more than two fixed or quasi-fixed inputs, their output elasticities cannot be identified even under constant returns

The Meta-Production Function Approach as an Alternative

- Introduced by Hayami (1969) and Hayami & Ruttan (1970, 1985)
- Haymai & Ruttan assume that $F_i(.) = F(.)$:
  - $Y_{it} = F(K_{it}, L_{it}, t), i = 1, \ldots, n; t = 0, \ldots, T$
- Which implies that all countries have identical production functions in terms of <u>measured</u> inputs
- Thus pooling of data across multiple countries is justified

Extension by Boskin, Lau & Yotopoulos

- Extended by Lau & Yotopoulos (1989) and Boskin & Lau (1990) to allow time-varying, country- and commodity-specific differences in efficiency
- Applied by Boskin, Kim, Lau, & Park to the G-5 countries, G-7 countries, the East Asian Newly Industrialized Economies (NIEs) and developing economies in the Asia/Pacific region

The Extended Meta-Production Function Approach: The Basic Assumptions (1)

(1) All countries have the same underlying aggregate production function F(.) in terms of standardized, or "**efficiency-equivalent**", quantities of outputs and inputs, i.e.

(1) $$Y^*_{it} = F(K^*_{it}, L^*_{it}) \ , \ i = 1,...,n.$$

The Extended Meta-Production Function Approach: The Basic Assumptions (2)

(2) The measured quantities of outputs and inputs of the different countries may be converted into the unobservable standardized, or "efficiency-equivalent", units of outputs and inputs by multiplicative country- and output- and input-specific time-varying **augmentation factors**, $A_{ij}(t)$'s, i = 1,...,n; j = output (0), capital (K), and labor (L):

(2) $Y^*_{it} = A_{i0}(t)Y_{it}$;

(3) $K^*_{it} = A_{iK}(t)K_{it}$;

(4) $L^*_{it} = A_{iL}(t)L_{it}$; i = 1, ..., n.

The Extended Meta-Production Function Approach: The Basic Assumptions (2)

- In the empirical implementation, the commodity augmentation factors are assumed to have the constant geometric form with respect to time. Thus:

(5) $Y^*_{it} = A_{i0}\,(1+c_{i0})^t Y_{it}$;

(6) $K^*_{it} = A_{iK}\,(1+c_{iK})^t K_{it}$;

(7) $L^*_{it} = A_{iL}\,(1+c_{iL})^t L_{it}$; $i = 1,\ldots,n$.

A_{i0}'s, A_{ij}'s = augmentation level parameters

c_{i0}'s, c_{ij}'s = augmentation rate parameters

The Extended Meta-Production Function Approach: The Basic Assumptions (2)

- For at least one country, say the ith, the constants A_{i0} and A_{ij}'s can be set identically at unity, reflecting the fact that "efficiency-equivalent" outputs and inputs can be measured only relative to some standard.
- The A_{i0} and A_{ij}'s for the U.S. Are taken to be identically unity.
- Subject to such a normalization, the commodity augmentation level and rate parameters can be estimated simultaneously with the parameters of the aggregate production function.

The Commodity-Augmenting Representation of Technical Progress

One specialization of

$Y = F(K, L, t)$ is

$Y^* \quad = F(K^*, L^*)$, where

Y^*, K^*, and L^* are efficiency-equivalent quantities. Thus, in terms of measured quantities,

$$Y = A_0(t)\, F(A_K(t)K, A_L(t)L).$$

The Meta-Production Function Approach

- It is important to understand that the meta-production function approach assumes that the production function is identical for all countries only in terms of the efficiency-equivalent quantities of outputs and inputs; it is not identical in terms of measured quantities of outputs and inputs
- A useful way to think about what is the same across countries is the following—the isoquants remain the same for all countries and over time with a suitable renumbering of the isoquants and a suitable re-scaling of the axes

The Extended Meta-Production Function Approach: The Basic Assumptions (3)

(3) The aggregate meta-production function is assumed to have a flexible functional form, e.g. the transcendental logarithmic functional form of Christensen, Jorgenson & Lau (1973).

The Extended Meta-Production Function Approach: The Basic Assumptions (3)

- The translog production function, in terms of "efficiency-equivalent" output and inputs, takes the form:

  (8) $\ln Y^*_{it} = \ln Y_0 + a_K \ln K^*_{it} + a_L \ln L^*_{it}$
  $+ B_{KK}(\ln K^*_{it})^2/2 + B_{LL}(\ln L^*_{it})^2/2$
  $+ B_{KL}(\ln K^*_{it})(\ln L^*_{it})$, $i = 1,...,n$.

- By substituting equations (5) through (7) into equation (8), and simplifying, we obtain equation (9), which is written entirely in terms of **observable** variables:

The Estimating Equation

(9) $$\ln Y_{it} = \ln Y_0 + \ln A^*_{i0} + a^*_{Ki} \ln K_{it} + a^*_{Li} \ln L_{it} + c^*_{i0} t + B_{KK}(\ln K_{it})^2/2 + B_{LL}(\ln L_{it})^2/2 + B_{KL}(\ln K_{it})(\ln L_{it}) + (B_{KK}\ln(1+c_{iK}) + B_{KL}\ln(1+c_{iL}))(\ln K_{it})t + (B_{KL}\ln(1+c_{iK}) + B_{LL}\ln(1+c_{iL}))(\ln L_{it})t + (B_{KK}(\ln(1+c_{iK}))^2 + B_{LL}(\ln(1+c_{iL}))^2 + 2B_{KL}\ln(1+c_{iK})\ln(1+c_{iL}))t^2/2,$$

$i = 1,\ldots,n$, where A^*_{i0}, a^*_{Ki}, a^*_{Li}, c^*_{i0} and c_{ij}'s , $j = K, L$ are country-specific constants.

Tests of the Maintained Hypotheses of the Meta-Production Function Approach

- The parameters B_{KK}, B_{KL}, and B_{LL} are independent of i, i.e., of the particular individual country. This provides a basis for testing the maintained hypothesis that there is a single aggregate meta-production function for all the countries.
- The parameter corresponding to the $t^2/2$ term for each country is not independent but is completely determined given B_{KK}, B_{KL}, B_{LL} , c_{iK}, and c_{iL}. This provides a basis for testing the hypothesis that technical progress may be represented in the constant geometric commodity-augmentation form.
- Together, the two hypotheses above constitute the maintained hypotheses of the meta-production function approach.

The Labor Share Equation

- In addition, we also consider the behavior of the share of labor costs in the value of output:

(10) $w_{it}L_{it} / p_{it}Y_{it} = a^*_{Lii} + B_{KLi}(\ln K_{it}) + B_{LLi}(\ln L_{it})$
$+ B_{Lti}t, \; i = 1,...,n.$

Instantaneous Profit Maximization under Competitive Output and Input Markets

- The share of labor costs in the value of output should be equal to the elasticity of output with respect to labor:
(11) $w_{it}L_{it} / p_{it}Y_{it} = a^*_{Li} + B_{KL}(\ln K_{it}) + B_{LL}(\ln L_{it})$
$+(B_{KL}\ln(1+c_{iK}) + B_{LL}\ln(1+c_{iL}))t$, $i = 1,\ldots,n$.
- This provides a basis for testing the hypothesis of profit maximization with respect to labor.

Rates of Growth on Inputs & Outputs of the East Asian NIEs and the G-5 Countries

Table 2.1: Average Annual Rates of Growth of Output and Inputs (percent)

Economy	Period	GDP	Capital Stock	Labor Hours	Human Capital	R&D Capital
Hong Kong	66-90	7.8	9	2.6	2.3	NA
Singapore	65-90	9	10.4	4.3	3.4	15.9
S. Korea	64-90	9	13	3.8	3.7	14.6
Taiwan	64-90	9	12.1	2.9	2.4	14.5
Japan	64-92	5.5	8	0.5	0.8	8.9
France	64-91	3.2	5.2	-0.3	1.3	5
W. Germany	65-91	3	4.4	-0.6	1.1	5.7
U.K.	65-91	2.1	3.8	-0.3	0.9	2.1
U.S.	49-92	3	3.1	1.5	0.8	6.1

Test of Hypotheses: The Meta-Production Function Approach

- The maintained hypotheses of the meta-production function approach
  - “Identical Meta-Production Functions” and
  - “Factor-Augmentation Representation of Technical Progress”
- The different kinds of purely commodity-augmenting technical progress
- The hypothesis of no technical progress

Test Results:
The Meta-Production Function Approach

- The Maintained Hypotheses of the Meta-Production Function Approach
  - “Identical Meta-Production Functions” and
  - “Factor-Augmentation Representation of Technical Progress”
- Cannot be rejected.

Tests of Hypotheses

Tested Hypothesis	Maintained Hypothesis	Assigned Level of Significance	Number of Restrictions	Test Statistics chi-sq/degrees of freedom
I. Single Meta Production Function	Unrestricted	0.01	24	1.11
II. Factor Augmentation	I	0.01	9	0.67
III. Traditional Maintained Hypotheses				
(1) Homogeneity	I+II	0.005	2	19.97
(2) Constant Returns to Scale	I+II	0.005	3	16.02
(3) Neutrality	I+II	0.01	18	4.3
(4) Profit Maximization	I+II	0.01	27	1.96
IV. Identical Augmentation Levels of				
(1) Capital	I+II	0.01	8	1.83
(2) Labor	I+II	0.01	8	1.16
V. Zero Technical Progress				
(1) G-5 Countries	I+II	0.01	15	18.1
(2) East Asian NIEs	I+II	0.01	12	1.23
VI. Purely Capital-Augmenting Tech. Pro.	I+II	0.01	18	1.8

The Maintained Hypotheses of Traditional Growth Accounting

- The Maintained Hypotheses of Traditional Growth Accounting, viz.:
  - Constant Returns to Scale
    - Homogeneity of the production function is implied by constant returns to scale--a production function F(K, L) is homogeneous of degree k if:
      $$F(\kappa K, \kappa L) = \kappa^k F(K, L)$$
    - Constant returns to scale imply k=1; Increasing returns to scale imply k>1; decreasing returns to scale imply k<1
  - Neutrality of Technical Progress
  - Instantaneous Profit Maximization under Competitive Output and Input Markets
- Are all rejected.

Tests of the Maintained Hypotheses of Traditional Growth Accounting

- **Homogeneity**

  $B_{KK} + B_{KL} = 0;$

  $B_{KL} + B_{LL} = 0.$

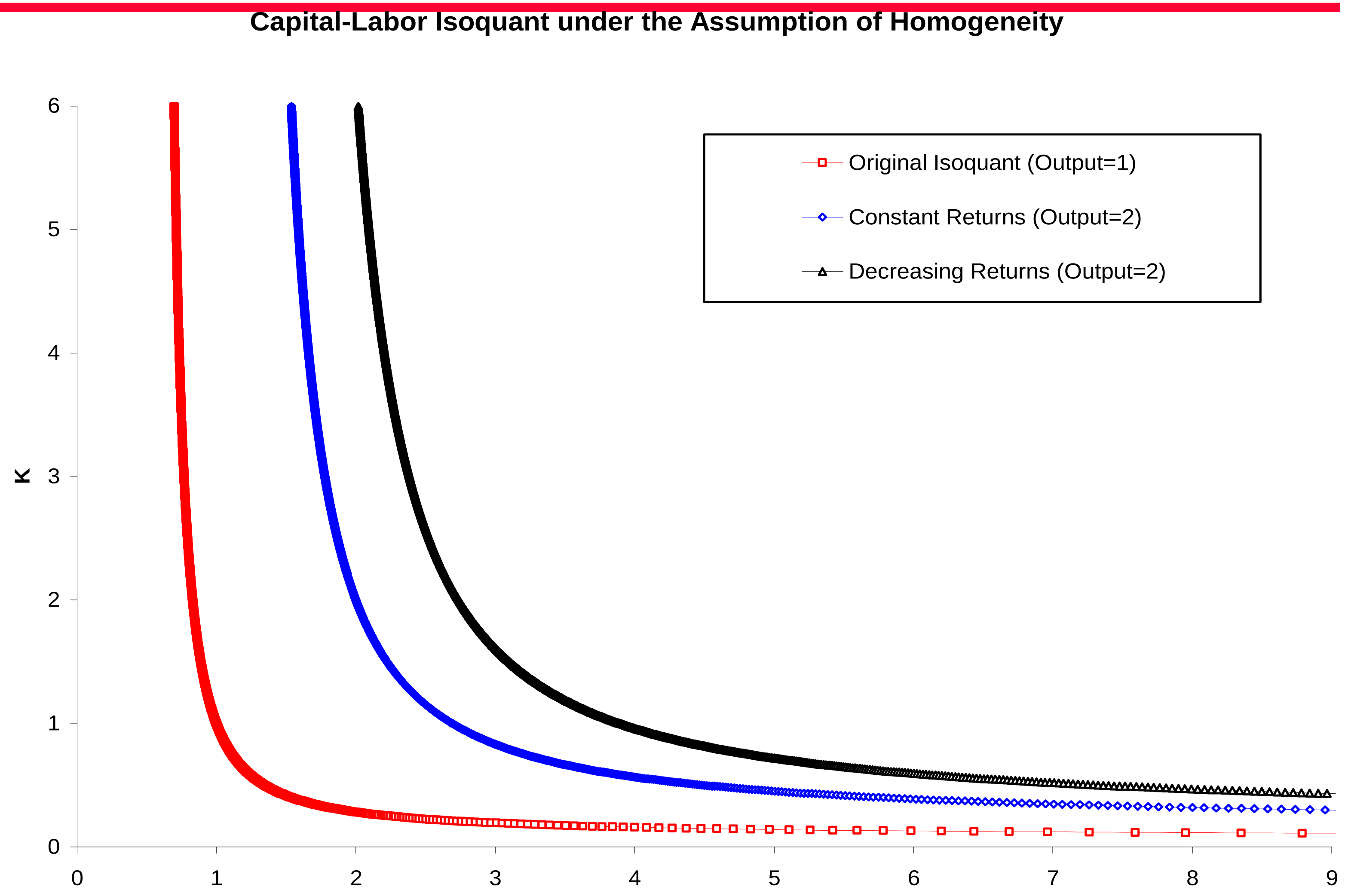
- **Constant returns to scale**

  $a^*_{Ki} + a^*_{Li} = 1.$

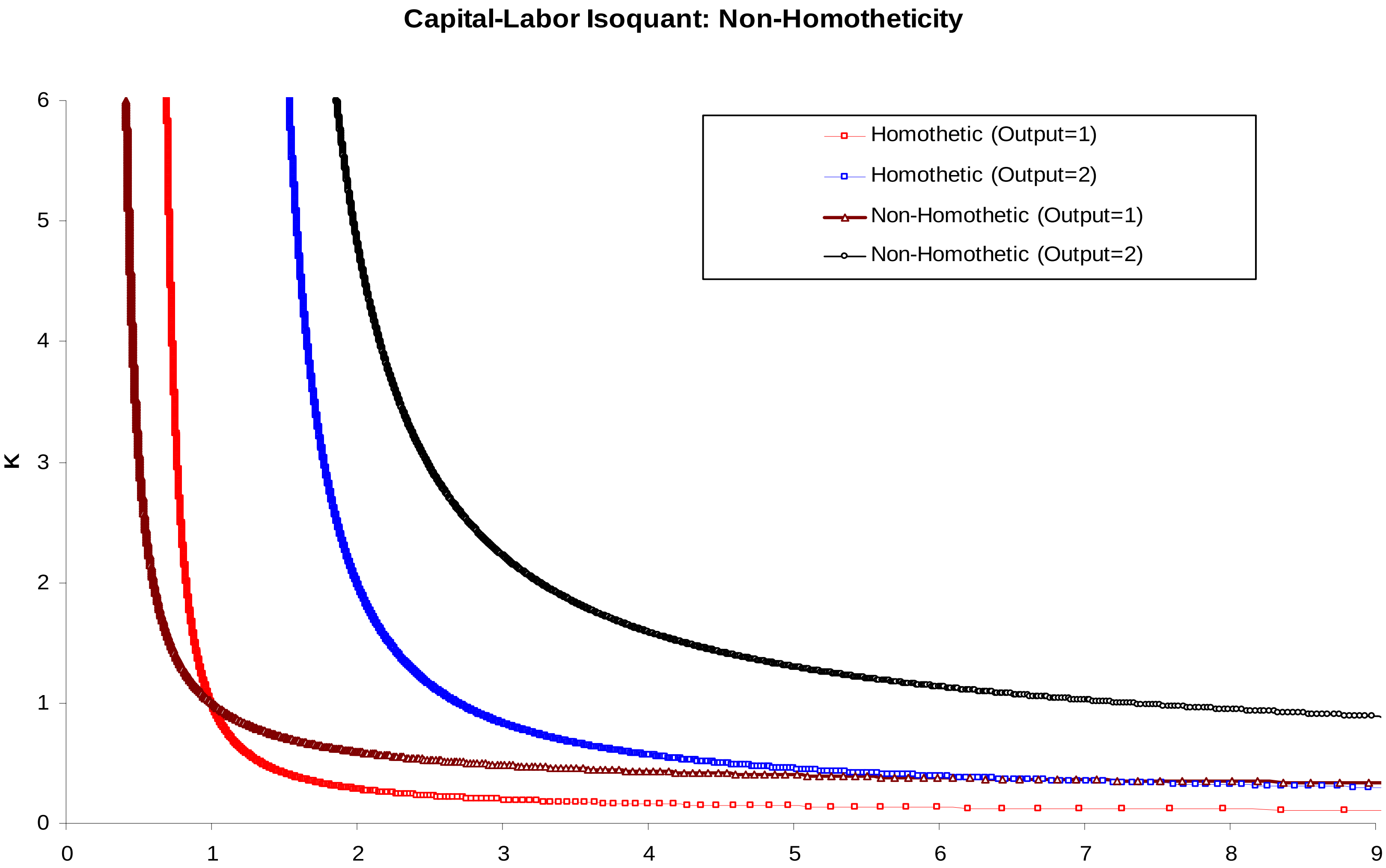
- **Neutrality of technical progress**

  $c_{iK} = 0; c_{iL} = 0.$

Homogeneity and Constant Returns to Scale



Isoquants of Homothetic and Non-Homothetic Production Functions



The Different Kinds of Purely Commodity-Augmenting Technical Progress

$Y = A_0(t)\, F(A_K(t)K,\, A_L(t)L)$

$= A_0(t)F(A_K K,\ A_L L)$, purely output-augmenting (Hicks-neutral)

$= A_0 F(A_K(t)K,\ A_L L)$, purely capital-augmenting (Solow-neutral)

$= A_0 F(A_K K,\ A_L(t)L)$, purely labor-augmenting (Harrod-neutral)

Hypotheses on Augmentation Level and Rate Parameters

- The hypothesis of "Identical Augmentation Level Parameters"
  $A_{iK} = A_K; A_{iL} = A_L$
  cannot be rejected.
- The hypothesis of Purely Output-Augmenting (Hicks-Neutral) Technical Progress $c_{iK} = 0; c_{iL} = 0$
  can be rejected
- The hypothesis of Purely Labor-Augmenting (Harrod-Neutral) Technical Progress $c_{i0} = 0; c_{iK} = 0$
  can be rejected
- The hypothesis of Purely Capital-Augmenting (Solow-Neutral) Technical Progress $c_{i0} = 0; c_{iL} = 0$
  cannot be rejected

The Hypothesis of No Technical Progress

- $c_{i0} = 0; c_{iK} = 0; c_{iL} = 0$
- This hypothesis is rejected for the Group-of-Five Countries.
- This hypothesis cannot be rejected for the East Asian NIEs.

The Estimated Parameters of the Aggregate Meta-Production Function

Table 6.2	Estimated Parameters of the Aggregate Production Function						
Parameter			I+II+IV+V(2)+VI			I+II+IV+VI	
Y_0			0.293	(399.295)		0.331	(318.414)
a_K			0.256	(8.103)		0.245	(7.929)
a_L			0.63	(6.666)		0.524	(5.077)
B_{KK}			-0.074	(-7.445)		-0.058	(-4.919)
B_{LL}			-0.073	(-1.101)		-0.012	(-0.178)
B_{KL}			0.032	(1.324)		0.025	(1.103)
C_{iK}							
	Hong Kong		0			0.062	(2.443)
	Singapore		0			0.045	(1.702)
	South Korea		0			0.026	(1.197)
	Taiwan		0			0.024	(1.523)
	France		0.083	(8.735)		0.1	(6.394)
	West Germany		0.074	(6.761)		0.089	(5.465)
	Japan		0.072	(3.927)		0.098	(3.483)
	UK		0.046	(5.749)		0.056	(5.045)
	United States		0.061	(7.592)		0.067	(6.321)
R-sq			0.753			0.753	
D.W.			1.448			1.473	

The Sources of Economic Growth: Findings of Kim & Lau As Reported by Krugman (1994)

- Using data from the early 1950s to the late 1980s, Kim and Lau (1992, 1994a, 1994b) find, by estimating a meta-production function for the G-5 and the 4 Newly Industrialized Economies (NIEs—Hong Kong, South Korea, Singapore and Taiwan) that:
- (1) No technical progress in the East Asian NIEs but significant technical progress in the industrialized economies (IEs)
- (2) East Asian economic growth has been tangible inputs-driven, with tangible capital accumulation as the most important source of economic growth (the latter applying also to Japan)
  - Working harder as opposed to working smarter
- (3) Technical progress is the most important source of economic growth for the IEs, followed by tangible capital, accounting for over 50% and 30% respectively, with the exception of Japan
  - NOTE THE UNIQUE POSITION OF JAPAN!
- (4) Despite their high rates of economic growth and rapid capital accumulation, the East Asian Newly Industrialized Economies actually experienced a significant decline in productive efficiency relative to the industrialized countries as a group

The Findings of Kim & Lau (1992, 1994a, 1994b) using data from early 50s to late 80s

- (5) Technical progress is purely tangible capital-augmenting and hence complementary to tangible capital, confirming the earlier findings of Boskin and Lau for the Group-of-Five (G-5) Countries
- (6) Technical progress being purely tangible capital-augmenting implies that it is less likely to cause technological unemployment than if it were purely labor-augmenting

Purely Capital-Augmenting Technical Progress

$$Y = A_0(t)\ F(A_K(t)K,\ A_L(t)L)$$

$$= A_0F(A_K(t)K,\ A_LL)$$

$$= A_0F(A_K(1+c_{iK})^tK,\ A_LL)$$

The production function can also be written as:

$$= A_0F(A_K\ e^{c_{iK}.t}K,\ A_LL)$$

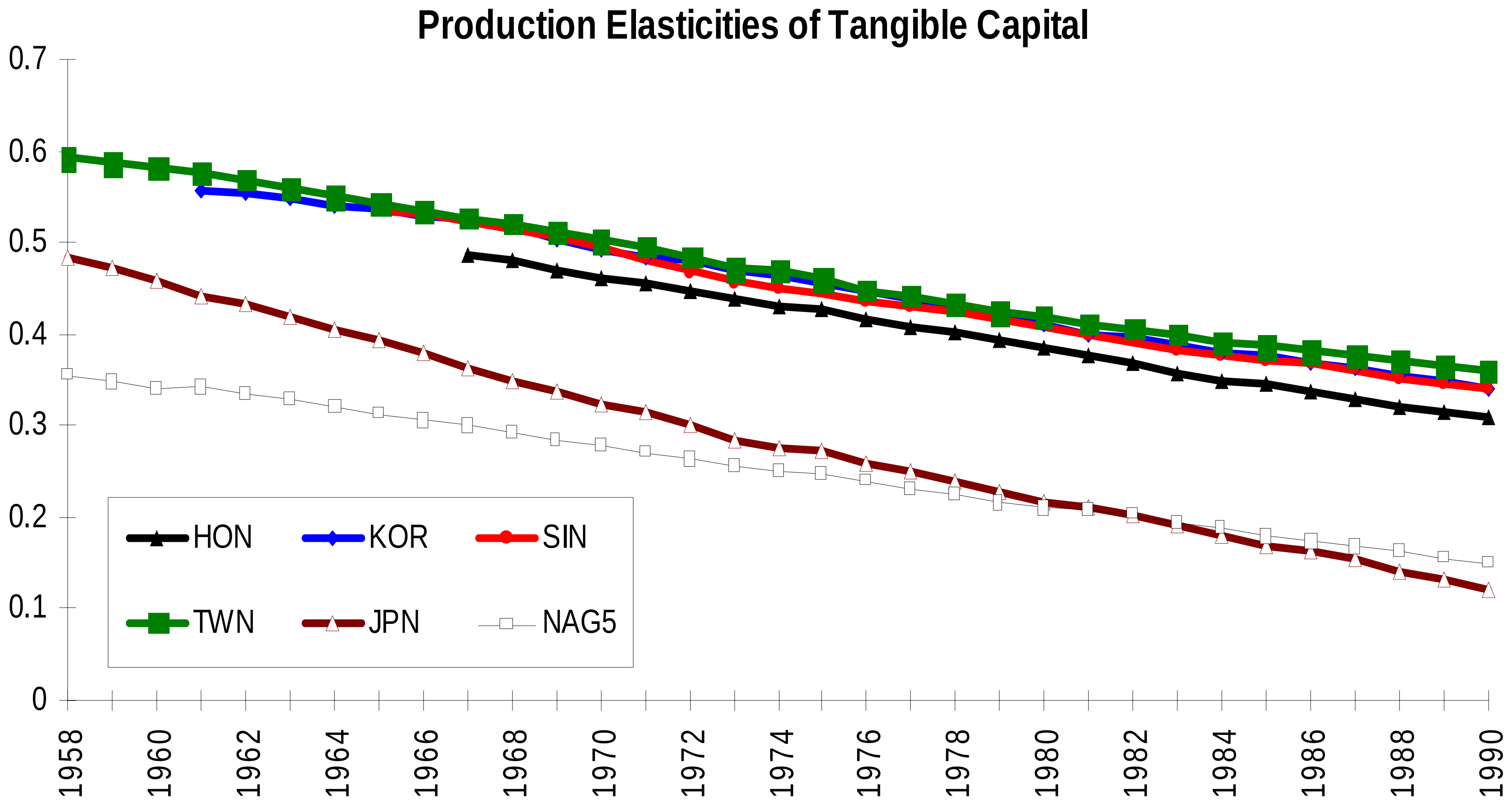
Implications of Rejection of the Hypothesis of Purely Labor-Augmenting Technical Progress

- Technical progress is not simply equivalent to more labor (One thousand janitors are not equivalent to a Kenneth Arrow)
- The existence of a steady state growth can no longer be assured
- Capital-augmenting technical progress implies the complementarity between tangible capital and technical progress (intangible capital)

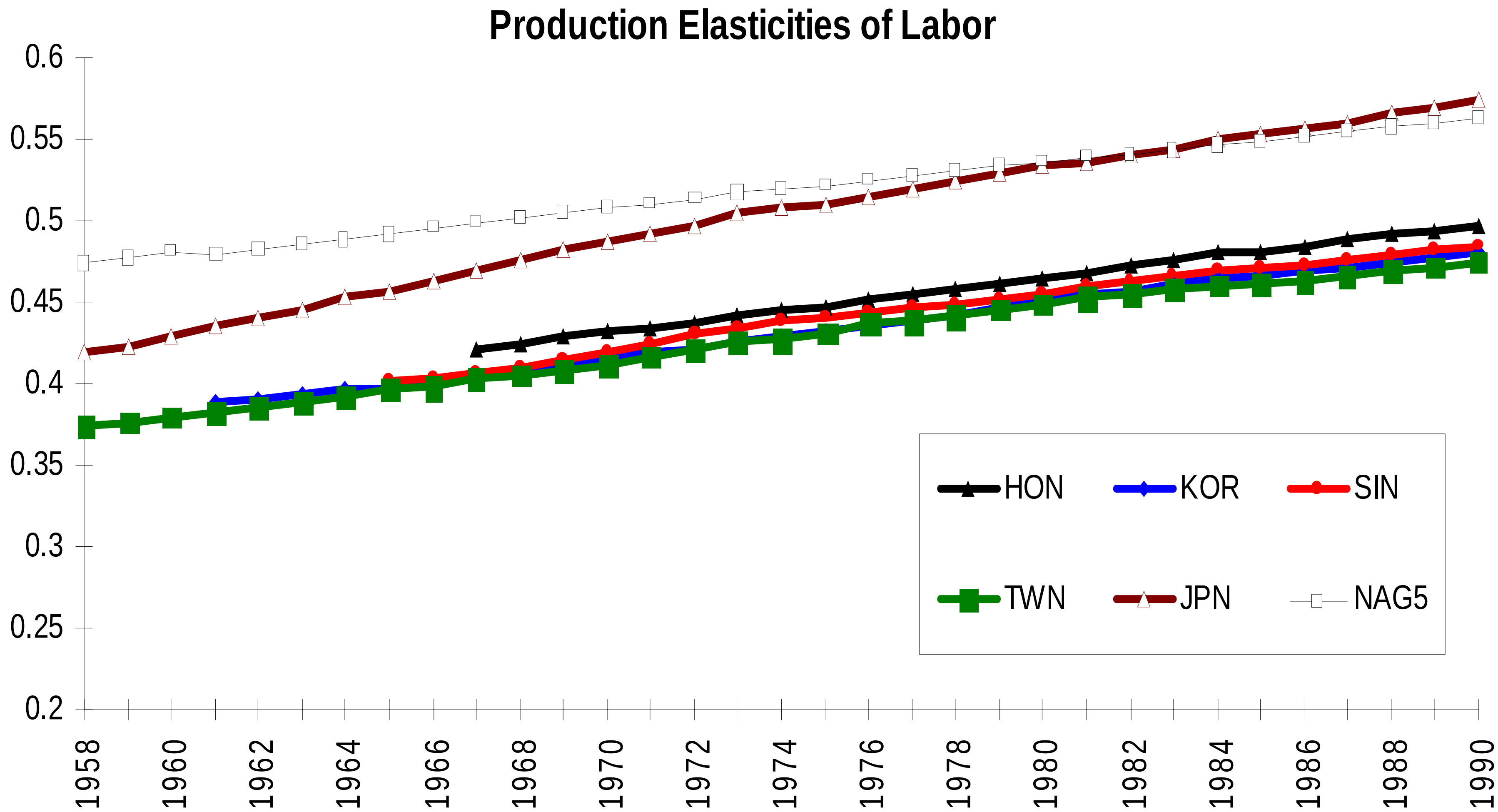
Accounts of Growth: Kim & Lau (1992, 1994a, 1994b)

Table 2.2: Relative Contributions of the Sources of Economic Growth (percent)				
Economy	Tangible Capital	Labor	Technical Progress	
Hong Kong	74	26	0	
Singapore	68	32	0	
S. Korea	80	20	0	
Taiwan	85	15	0	
Japan	56	5	39	
Non-Asian G-5	36	6	59	

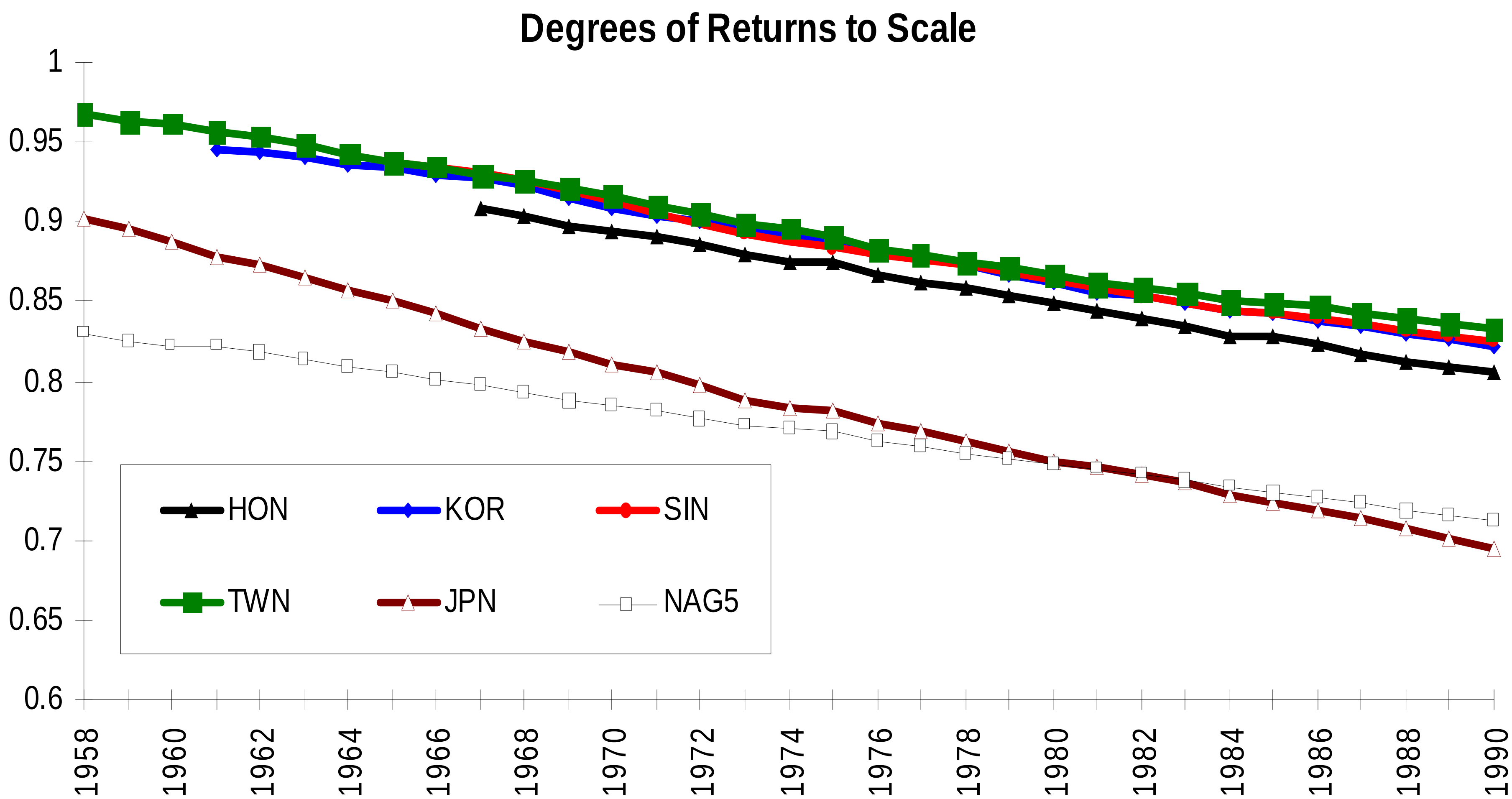
Production Elasticities of Capital



Production Elasticities of Labor



Degrees of Returns to Scale

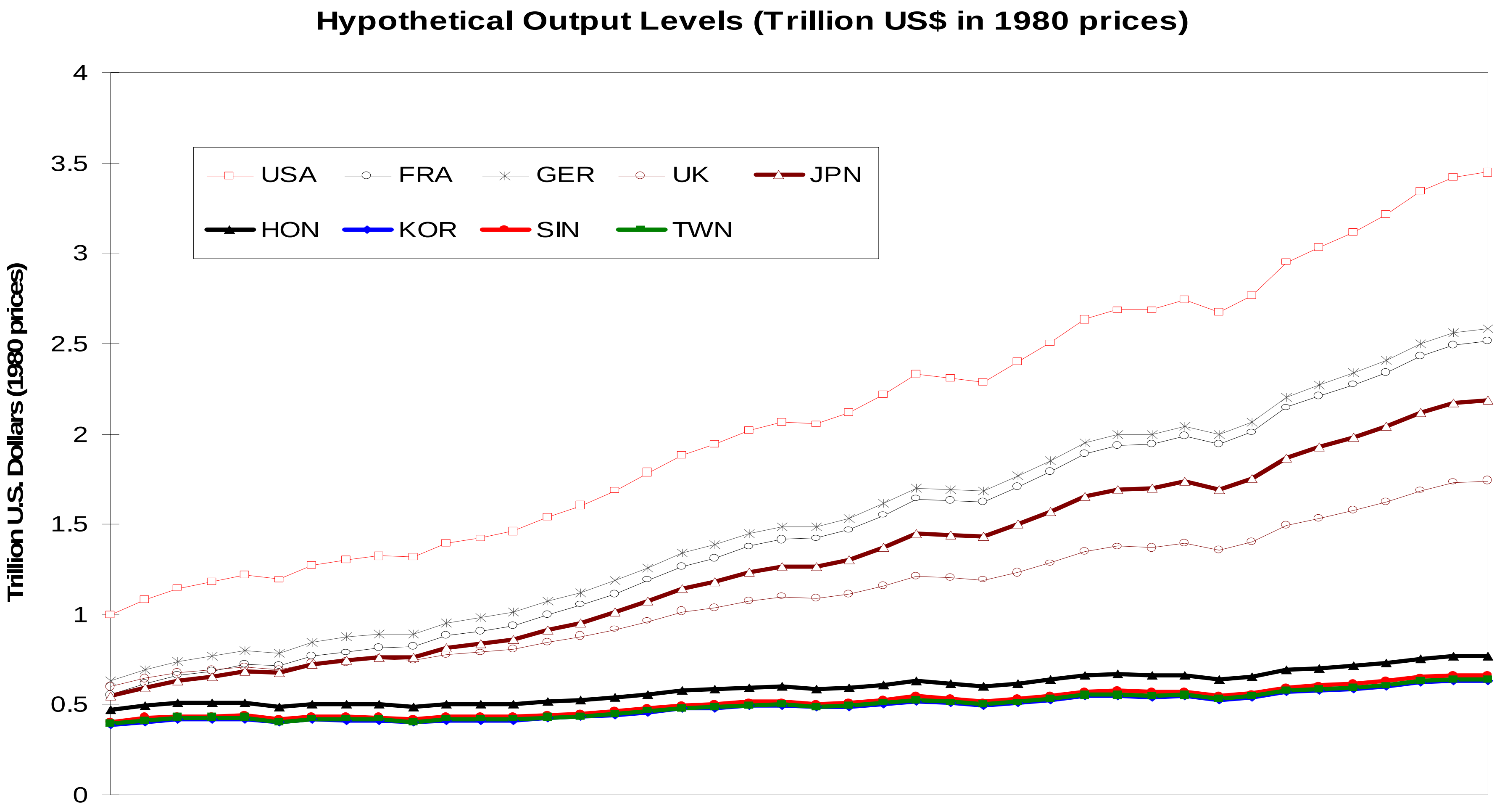


International and Intertemporal Comparison of Productive Efficiency: A Thought Experiment

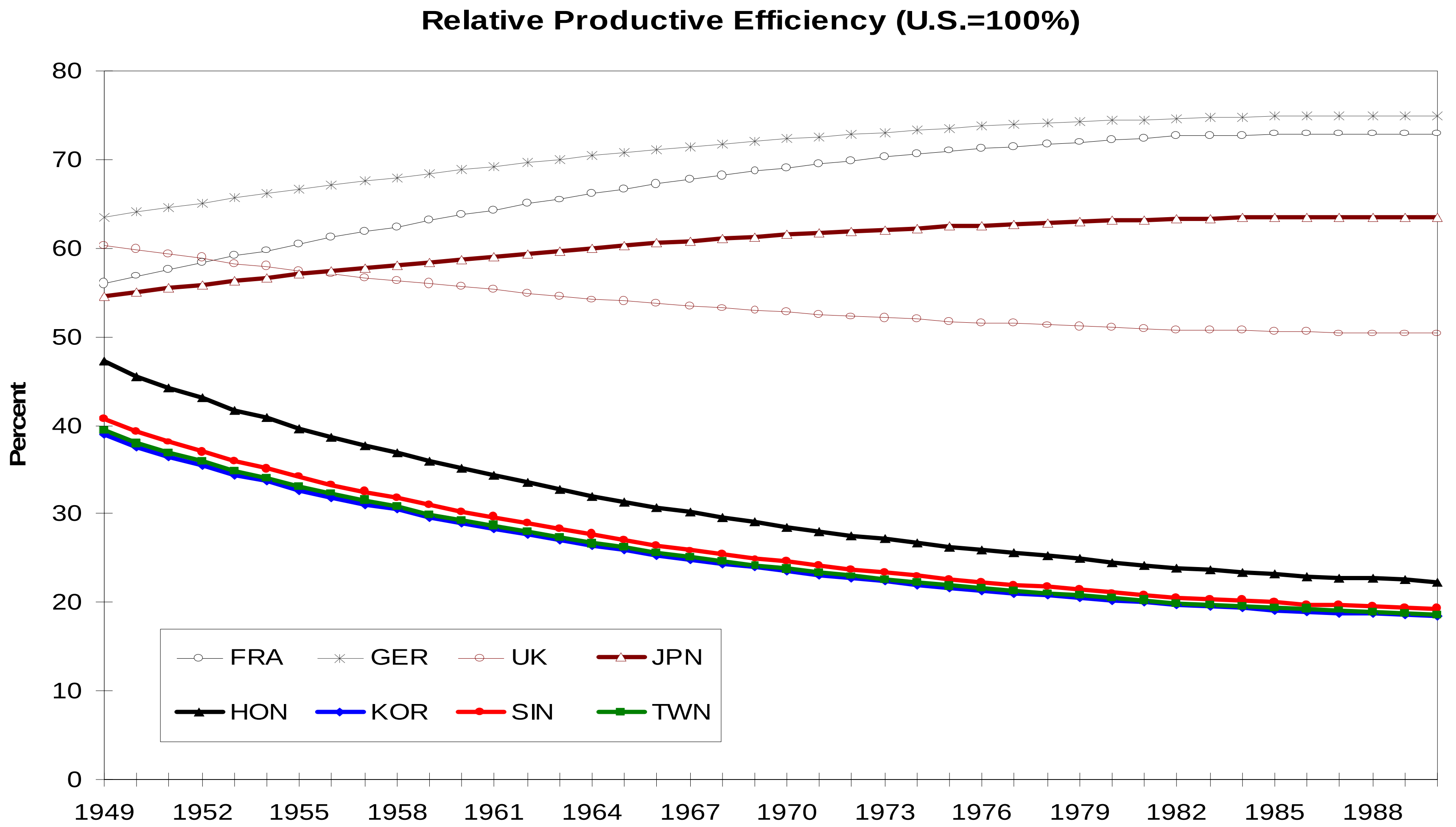
- Suppose all countries have the same quantities of **measured inputs** of capital and labor as the United States
- What would have been the quantities of their real outputs? and
- How would they evolve over time?

WE COMPARE THEIR OUTPUTS
HOLDING MEASURED INPUTS CONSTANT!

Hypothetical Output Levels



Relative Productive Efficiency (U.S.=100%)



The Advantages of the Meta-Production Function Approach

- Theoretical:
  - All producer units have potential access to the same technology but each may operate on a different part of it depending on specific circumstances
- Empirical:
  - Identification of the rate of technical progress, the degree of economies of scale, as well as their biases
  - Identification of the relative efficiencies of the outputs and inputs and the technological levels
  - Econometric identification through pooling
  - Enlarged domain of applicability
  - Statistical verifiability of the maintained hypotheses

Applications of the Meta-Production Function Approach

- Lau & Yotopoulos (1989)
- Lau, Lieberman & Williams (1990)
- Boskin & Lau (1990)
- Kim & Lau (1992, 1994a, 1994b)
- Kim & Lau (1995)
- Kim & Lau (1996)
- Boskin & Lau (2000)
- Lau & Park (2003)