Energy Price-Induced and Exogenous Technological Change

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Motivation

- **Technological advancements play a crucial ameliorating role in managing the long-standing problems of climate change, energy security, and local environment**
- **A change in relative factor prices stimulates inventions directed at saving the factors (that have become relatively expensive) (Hayami and Ruttan, 1971, and Jaffe et al., 2003).**
- **Energy tax spur Technological Change (TC)**

Objectives

- **Identification of Exogenous and Energy Price Induced TC**

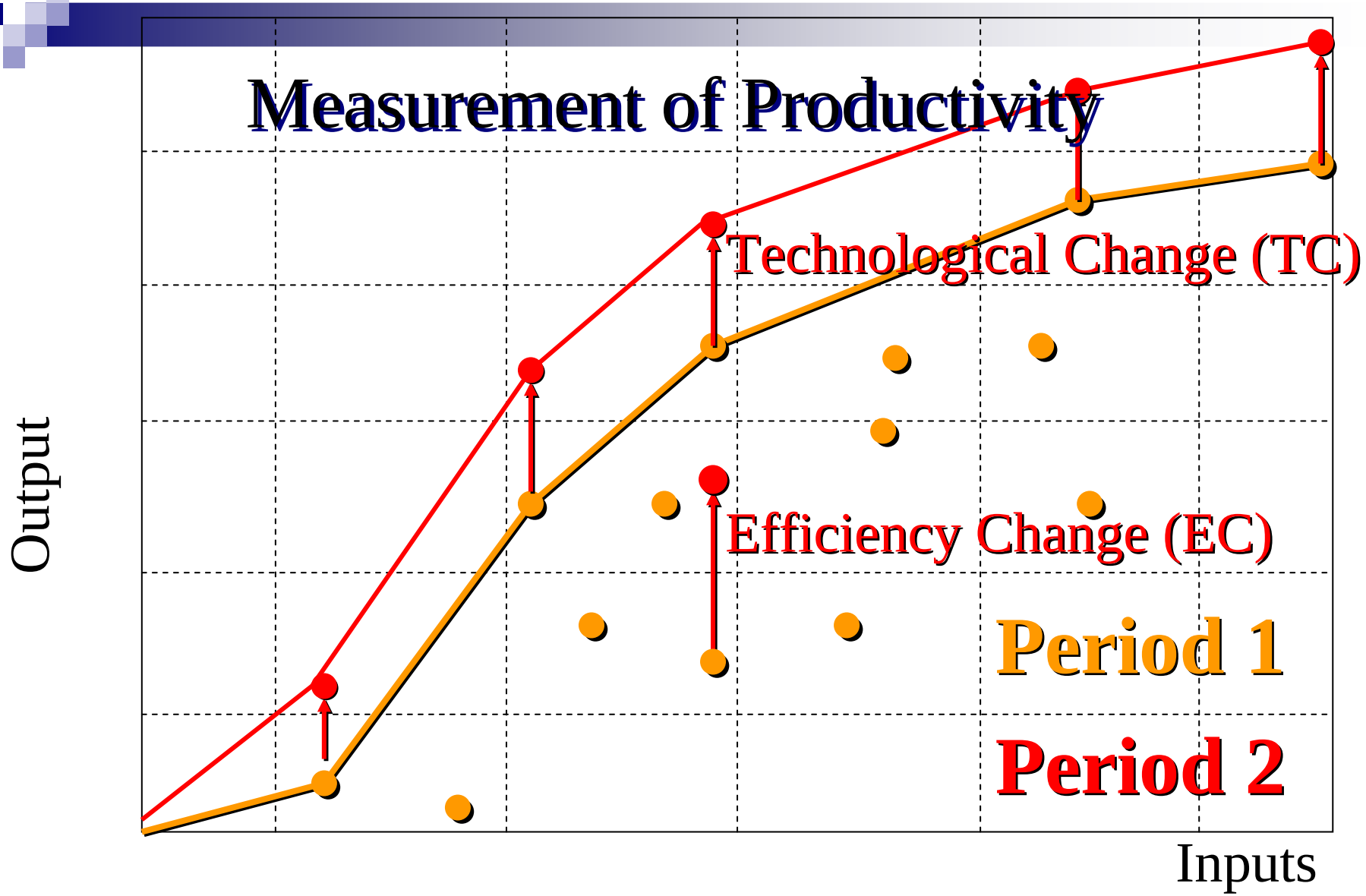
- **Find how the changes in energy prices are related to induced innovations that are not only energy saving, but also emission reducing.**

Background

- **Popp (2002, AER) finds the effect of energy prices on US patent over 1970 to 1994.**
- **Newell et al. (1999, QJE) find energy prices are positively associated with the energy efficiency of electrical appliances in US using a product-characteristics framework.**

Our Model:
Directional Distance Function

- **The directional function is a particular representation of a multi-output, multi-input production technology and it simultaneously seeks to expand output and contract inputs.**
- **The directional distance function and profit function are dual to each other**



TFP Change =
Efficiency Chg * Technological Chg

Estimation

$$D(x, y, b; g) = \max_{\beta} \{\beta : (y + \beta \cdot g_y, b - \beta \cdot g_b) \in P(x)\}.$$

$$\begin{aligned} D^{kt}(x^{kt}, y^{kt}; g, t, \bar{r}) = {} & \alpha_0 + \sum_{n=1}^{3} \alpha_n x_n^{kt} + \beta_1 y^{kt} + \gamma_1 t + \gamma_2 \bar{r}^{kt} \\ & + \frac{1}{2} \sum_{n=1}^{3} \sum_{n'=1}^{3} \alpha_{nn'} x_n^{kt} x_{n'}^{kt} + \sum_{n=1}^{3} \delta_{n1} x_n^{kt} y^{kt} + \sum_{n=1}^{3} \eta_{n1} x_n^{kt} t + \sum_{n=1}^{3} \eta_{n2} x_n^{kt} \bar{r}^{kt} \\ & + \frac{1}{2} \beta_2 y^{kt} y^{kt} + \mu_1 y^{kt} t + \mu_2 y^{kt} \bar{r}^{kt} + \frac{1}{2} \gamma_{11} t t + \phi_{12} t \bar{r}^{kt} + \frac{1}{2} \gamma_{22} \bar{r}^{kt} \bar{r}^{kt} \\ & + \sum_{j=1}^{3} \varphi_j G_j \end{aligned}$$

Data

- **Conventional Output and Inputs: GDP, Labor, Capital and Energy Consumption**
- **Environmental Bads: CO2 and SO2**
- **Long term Energy Price: 3-year moving average of past energy prices**
- **1971-2000, 80 countries**
- **Data Source: SO2 from Stern (2005)**

CO2 from World Development Indicators

GDP per capita (measured in real PPP-adjusted dollars) is from the Penn World Table 6.1. Others are from Extended Penn World Table

Main Results

- **Developed countries experienced higher exogenous TC in comparison with developing countries and the gap between the two groups has increased.**
- **On average, an absence of energy price-induced TC.**
- **Both groups of countries observed substantial energy price-induced TC when long-term oil prices were rising.**
- **The growth rate is more volatile in developed countries than in developing countries.**

Main Results

- **The direction of TC was GDP-increasing and emissions-reducing in the 1970s in the developed countries when oil prices were rising.**
- **However, the direction was both GDP- and emissions-increasing during the 1980s and the 1990s.**

Estimation Result

- **Inefficiency; 0.08**
- **The potentials are 11.5% (developed countries) & 5.5% (developing countries).**
- **Total factor productivity has increased by about 0.26% per year**

Output Biases Technological Change

- **Exogenous: GDP saving and emission-increasing technological progress**

- **Induced: In favor of emissions but against GDP.**

Output Biases Technological Change

- **Developed countries: GDP and emissions-increasing**

  - But, in the 1970s: GDP increasing and emissions-saving

  - USA, Japan: emissions-saving

  (high induced effect)

- **Developing countries: GDP-saving and emission-increasing**

  - India: emissions-saving when oil price rises

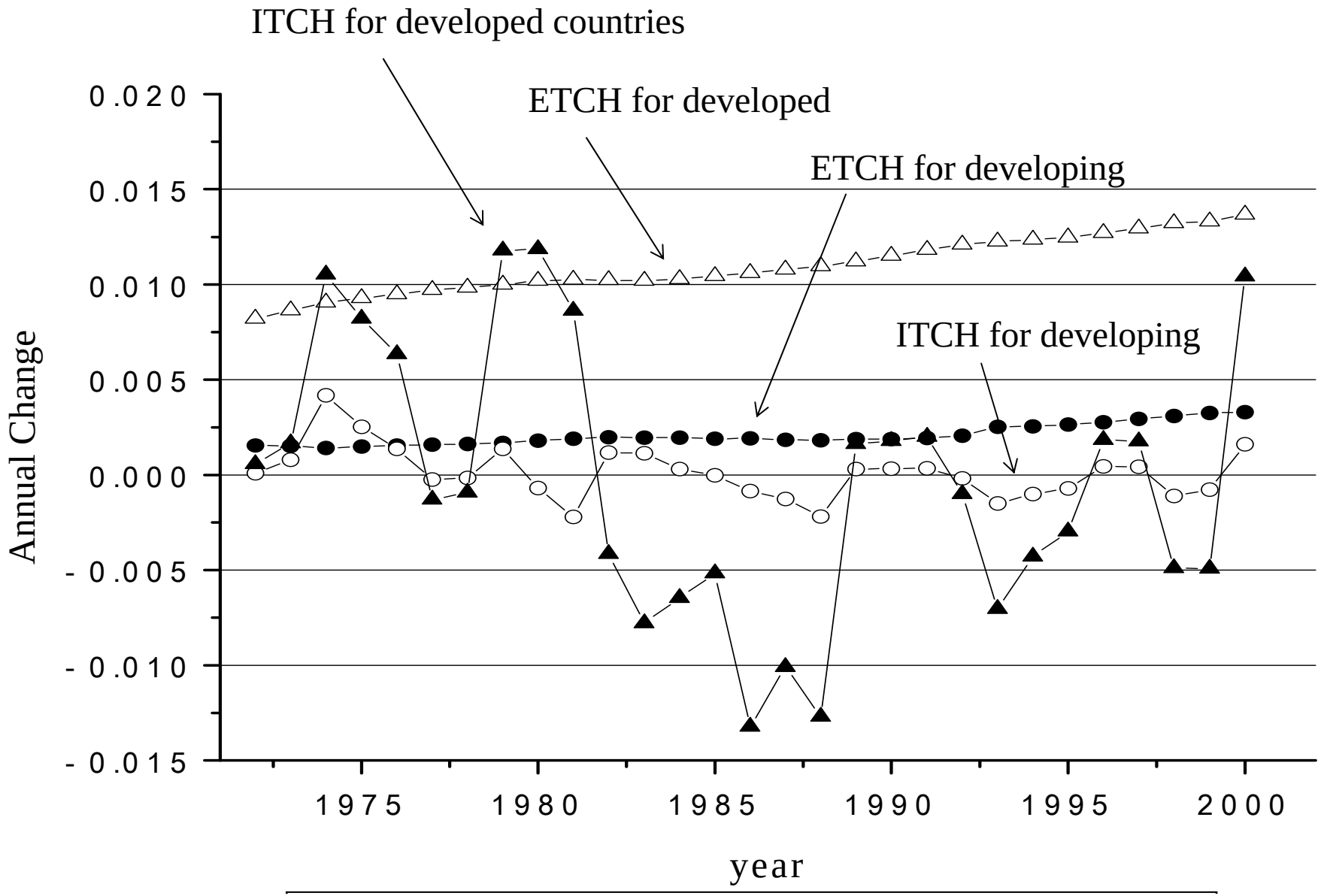
Input Biases Technological Change

- **The world observed input-increasing TC**
- **USA: in favor of labor and capital and against energy consumption. The magnitude of ITC bias against energy consumption was higher than ETC bias.**
- **Japan:**
  - **ITC was energy saving, but ETC was energy increasing**
  - **The direction of ITC was labor and capital using, but the direction of ETC was labor and capital saving from 1982 to 1999.**

Input Biases Technological Change

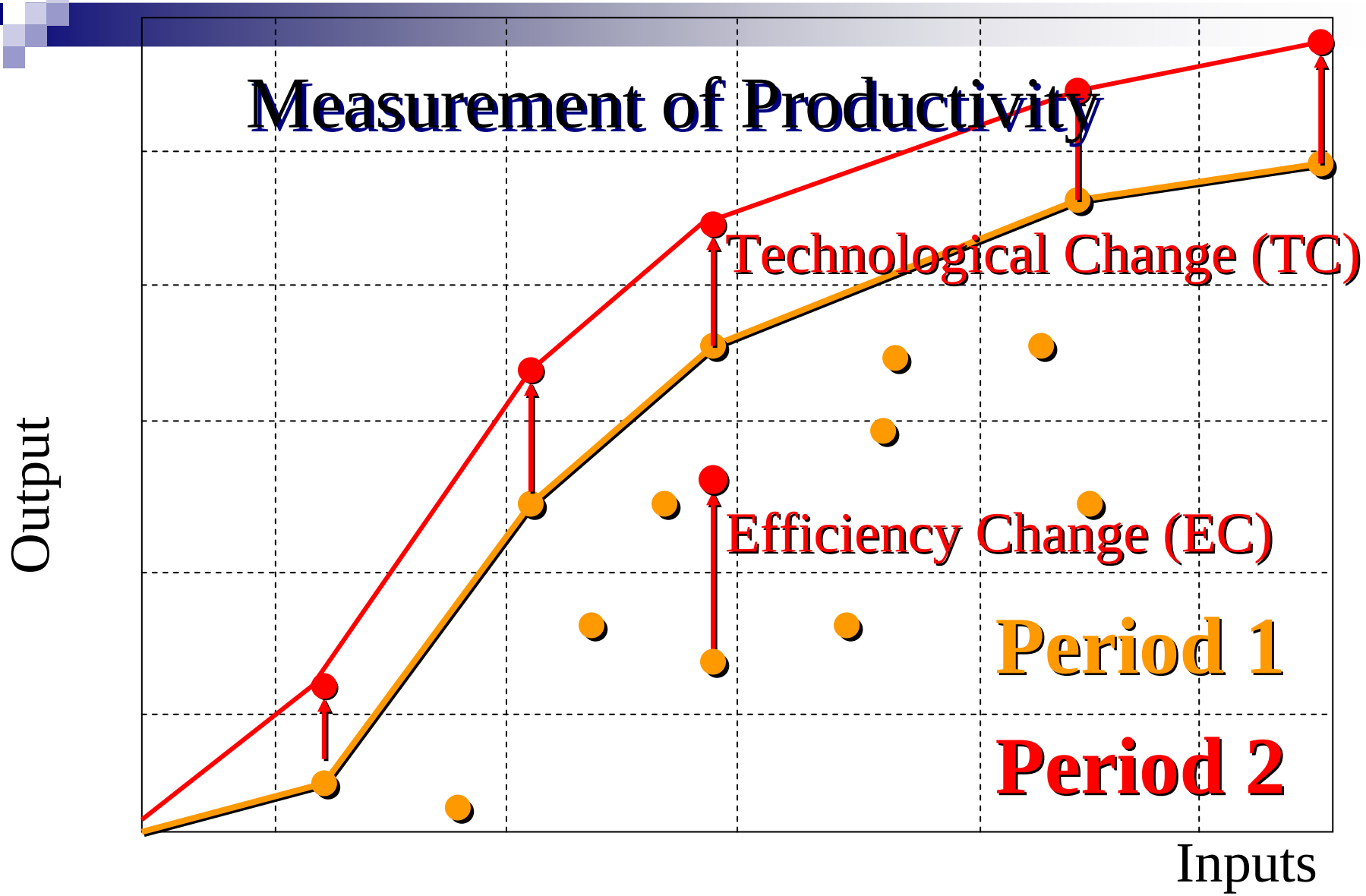
- **India:**
  - **ITC: labor and capital saving and energy using.**
  - **ETC: labor and capital saving and energy using during 1971 to 1988,**
  - **but it was all inputs (capital, labor and energy) saving from 1989 to 1999.**

Exogenous and Induced Technological Change



Conclusions

- **This study finds how the changes in energy prices are related to induced innovations that are not only energy saving but also measure the impact on emissions.**
- **We find substantial energy price-induced technological progress when long-term oil prices were rising.**



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Conclusions

The implications of the output bias for carbon taxation debate

- **Energy prices induce TC that internalizes the externalities. The output bias leads to TC biased in favor of emissions and against GDP.**
- **TC is GDP-saving and emission-augmenting in developing countries.**
- **These results imply that developing countries are insensitive to increasing energy prices.**

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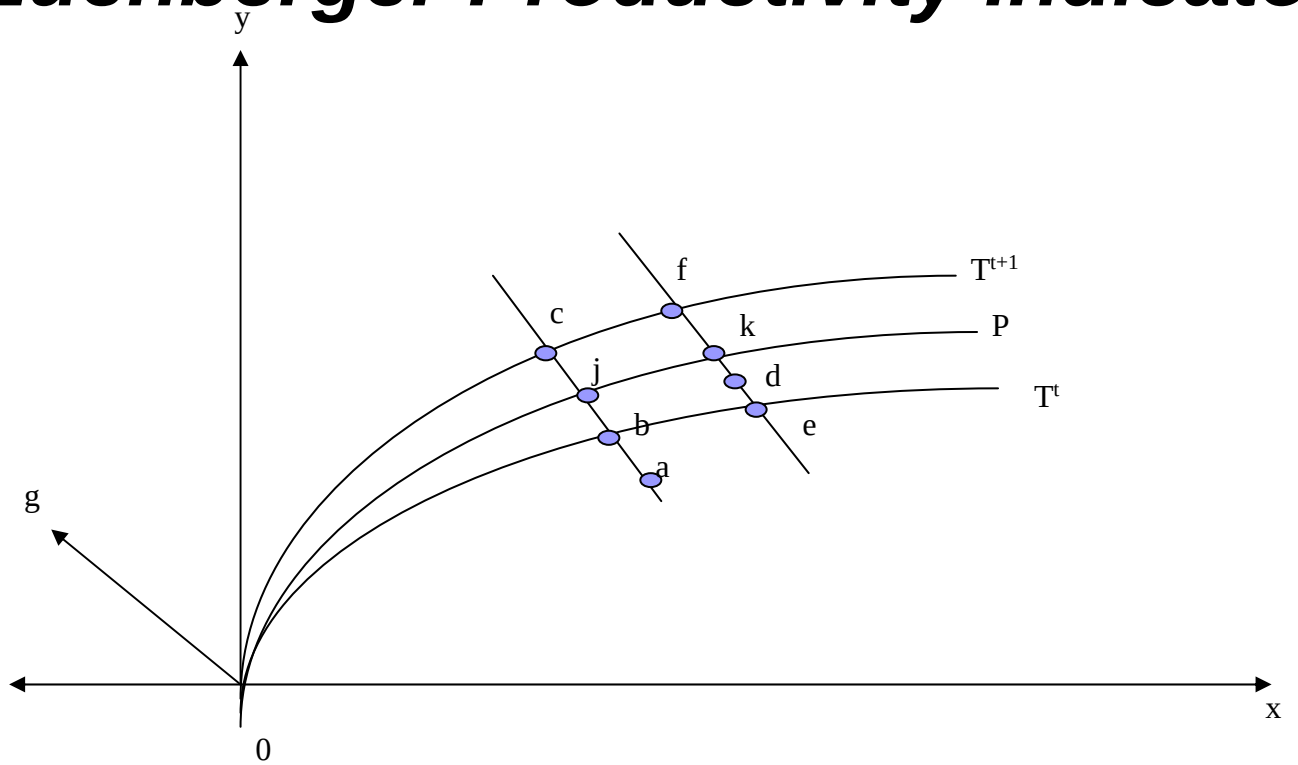
Luenberger Productivity Indicators



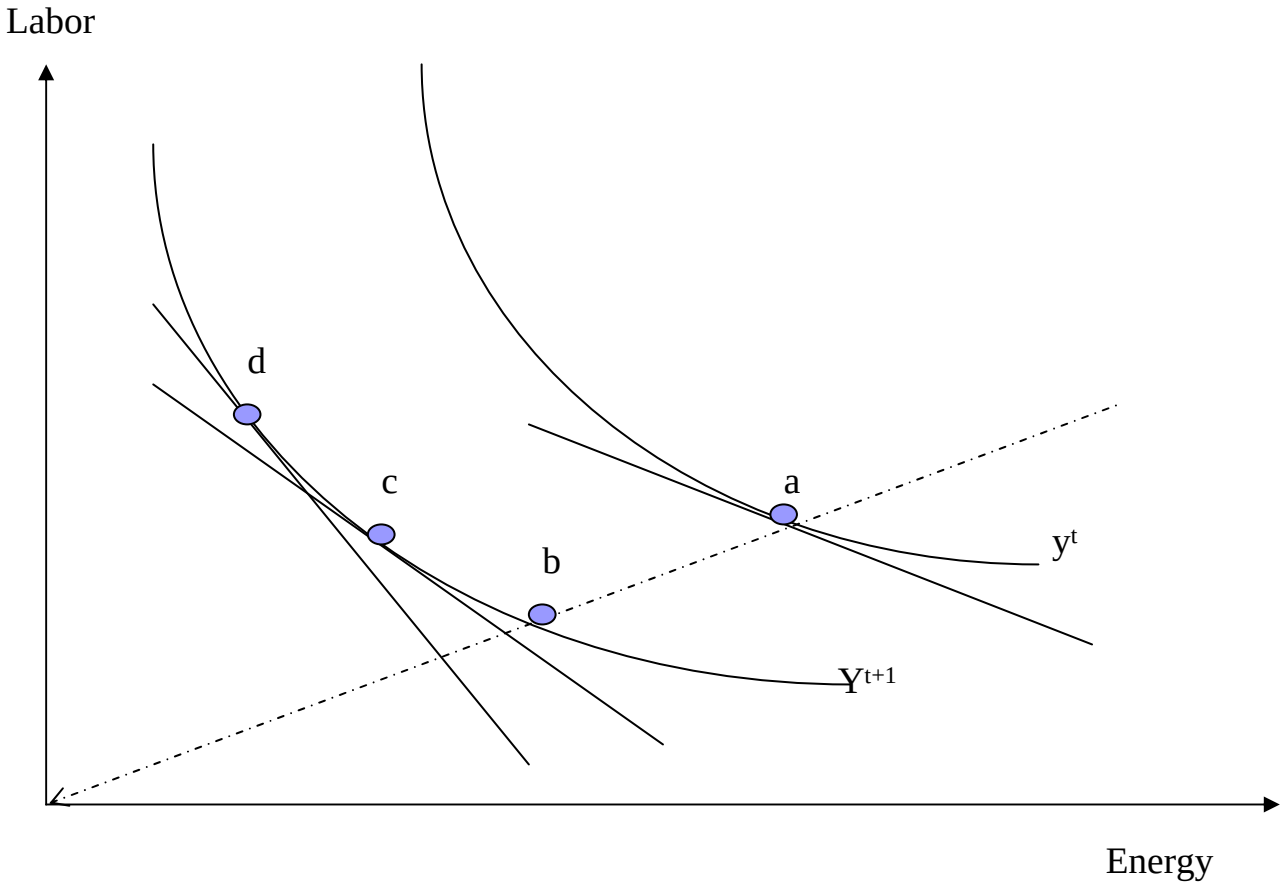
$$EC = (b-a)-(f-d)$$

$$TC = 0.5((f-e)+(c-b)) = 0.5(((f-k)+(k-e))+((c-j)+(j-b)))$$

or

$$TC = 0.5((f-k)+(c-j))+0.5((k-e)+(j-b)) = ETC + ITC$$

Decomposition of Price Induced Innovation



Estimation

$$PCH = \underbrace{(D^{t+1} - D^{t})}_{EFFCH} - \underbrace{0.5\left[\frac{\partial D^{t+1}}{\partial t} + \frac{\partial D^{t}}{\partial t}\right]}_{ETCH} - \underbrace{0.5\left[\frac{\partial D^{t+1}}{\partial q} + \frac{\partial D^{t}}{\partial q}\right].(q^{t+1} - q^{t})}_{ITCH}.$$

$$\text{i}^{\text{th}}\ \text{output} \begin{Bmatrix} Saving \\ Neutral \\ Augmenting \end{Bmatrix} \text{ when } B_{it} \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0$$

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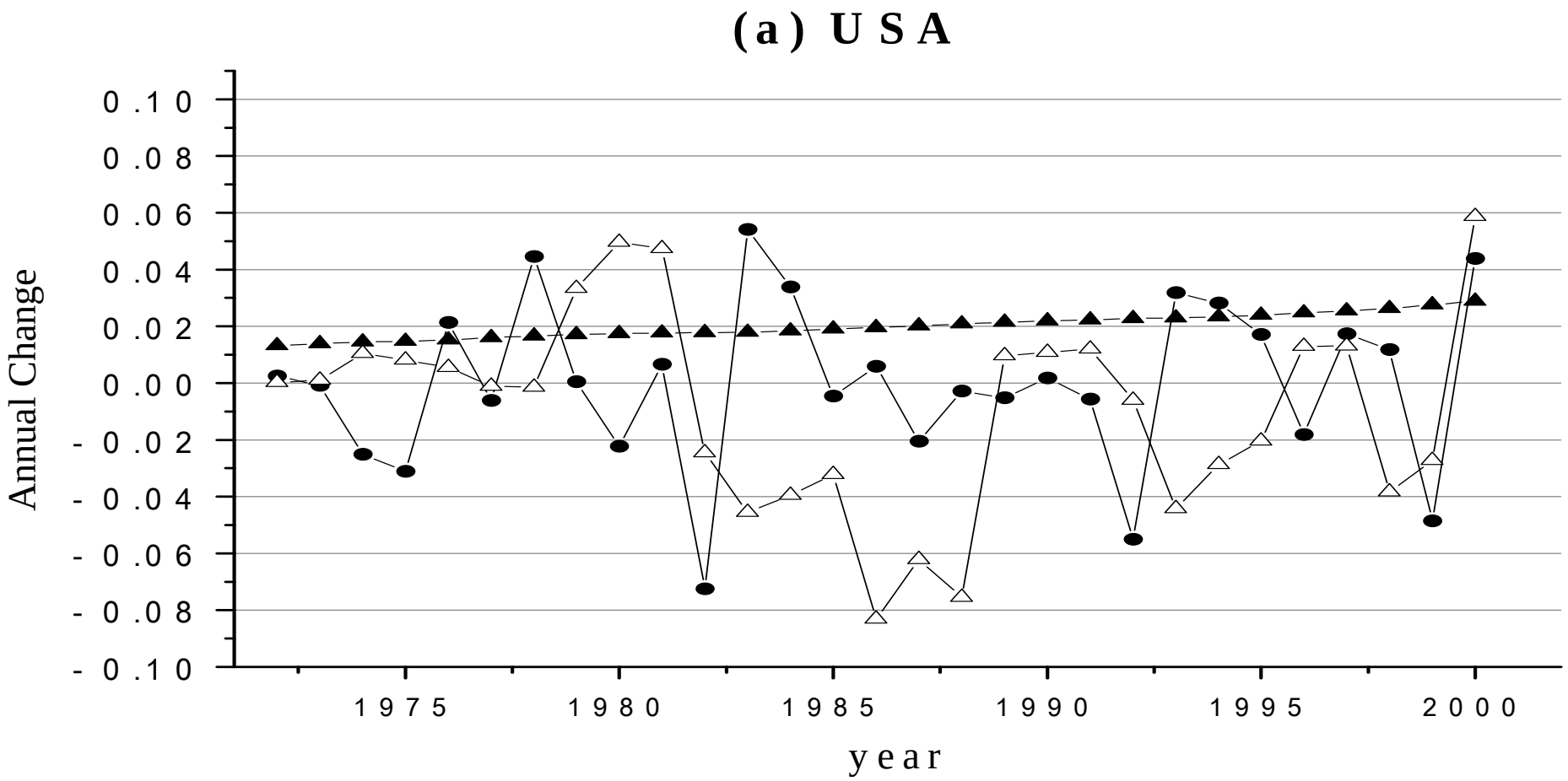
Technological Changes



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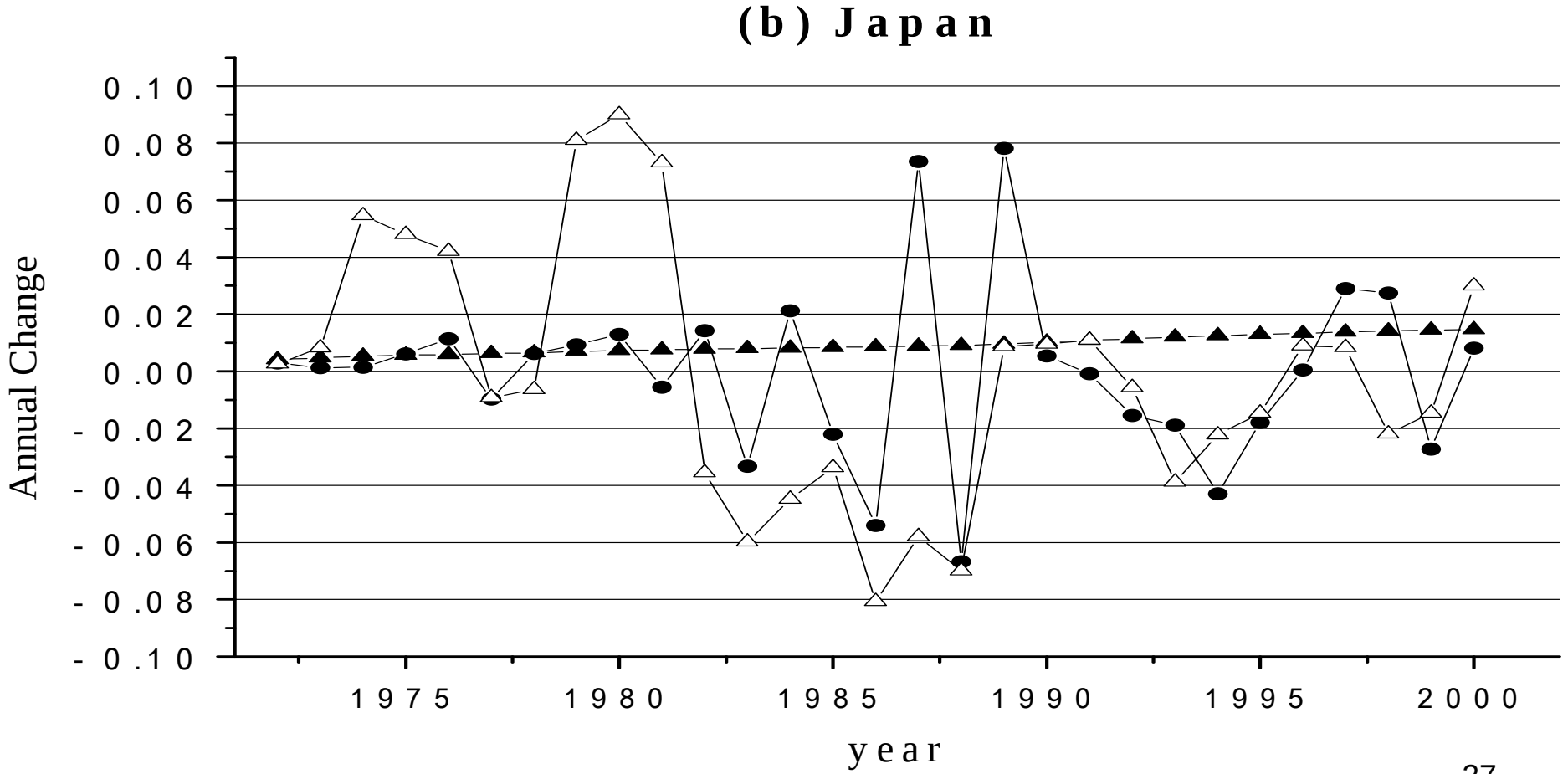
Technological Changes



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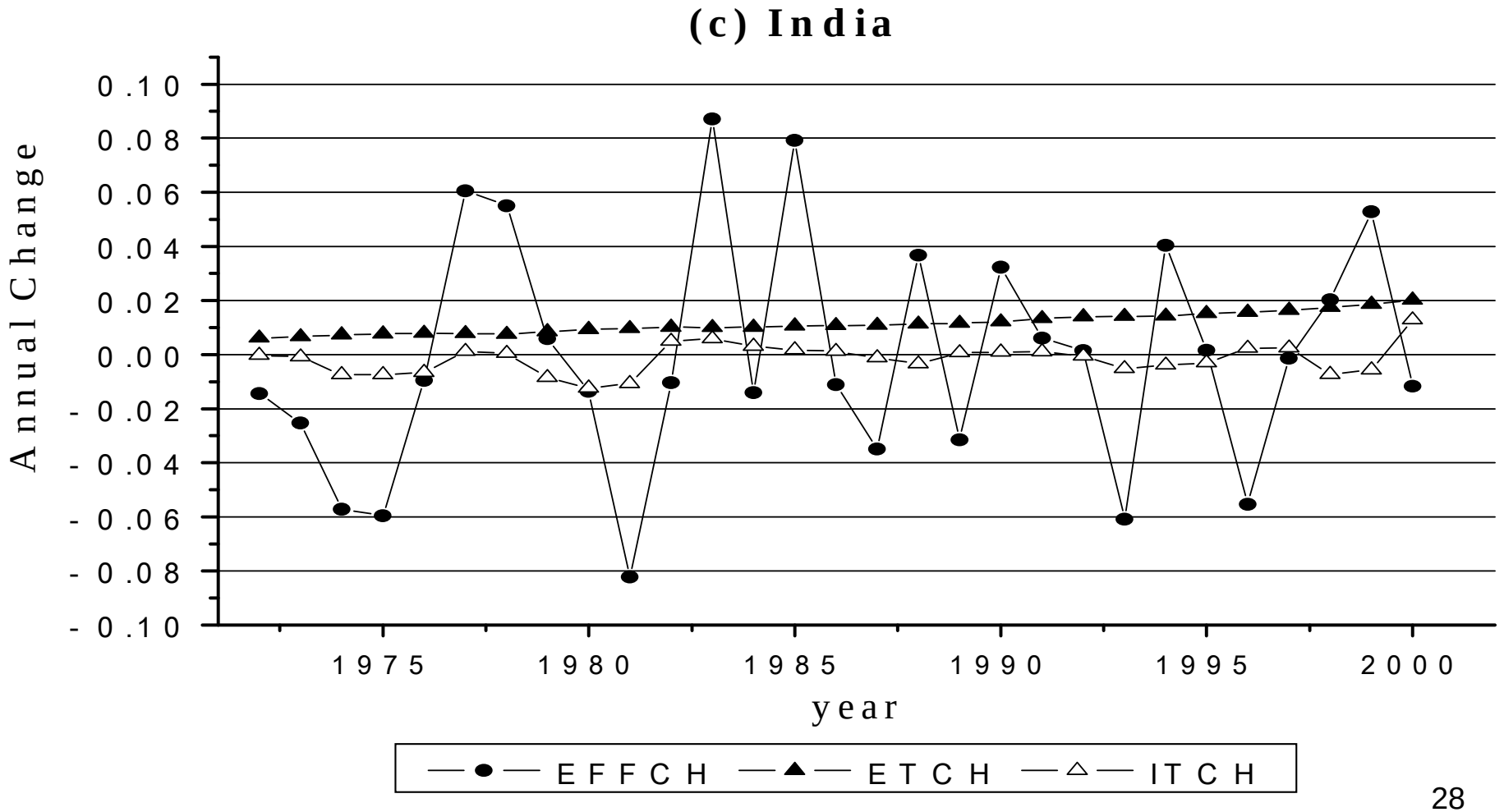
Technological Changes



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