

Measurement of Energy Price Induced Technological Change: A Directional Distance Function Approach



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Motivation

- **Kyoto Protocol Vs Asia Pacific Partnership on Clean Development and Climate**
- **Short-term Vs Long-term and/or Direct Vs Indirect impacts of Energy Prices**
- **Theoretical: Distinguishing between factor substitution and shift of production technology frontiers.**



Outlines

- **Objectives**
- **Analytical tool**
- **Luenberger Productivity Indicator**
- **Decomposition of Technological change**
- **Estimation and Results**
- **Summary and Conclusions**



Objectives

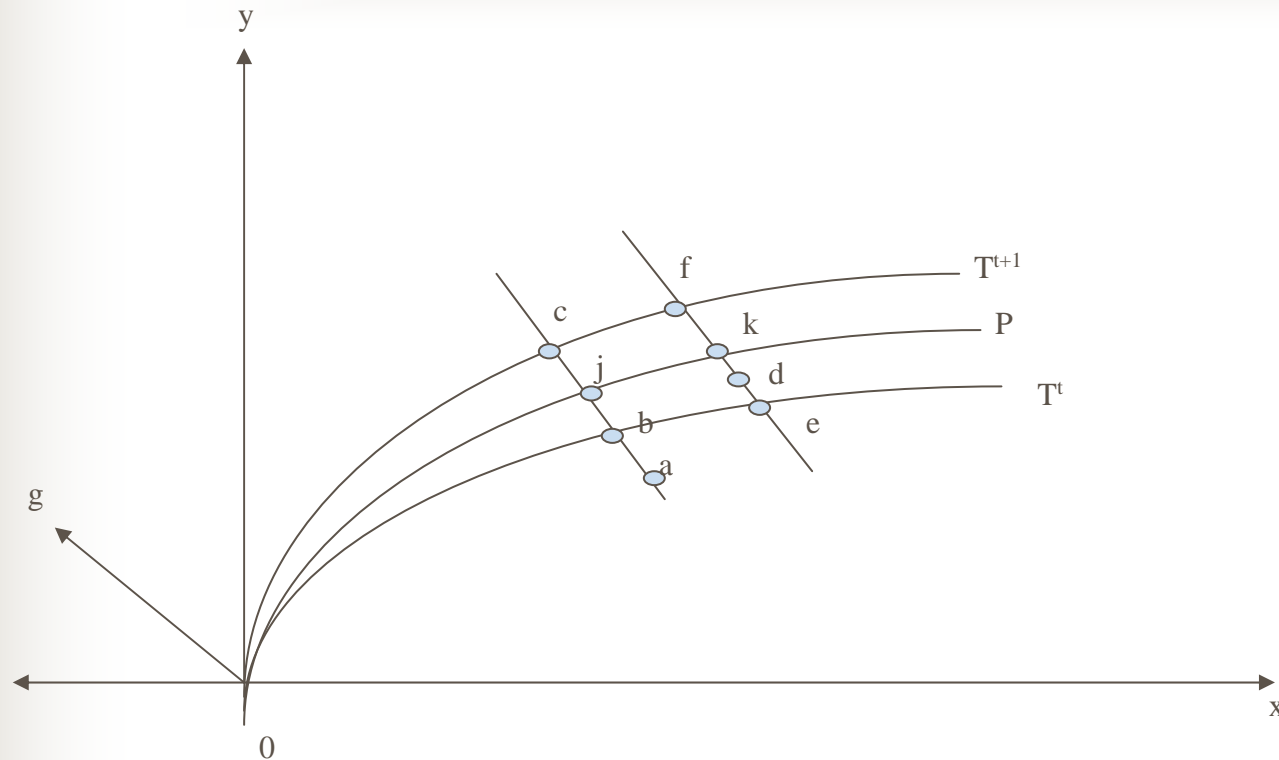
- **Identification and Measurement of Exogenous and Energy Price Induced:**
 - **Extent and Pace of technological progress**
 - **Direction of technological progress**
 - **Changes in input substitutability**



Analytical Tool: 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**
- **The directional distance function satisfies the translation property**

Luenberger Productivity Indicators



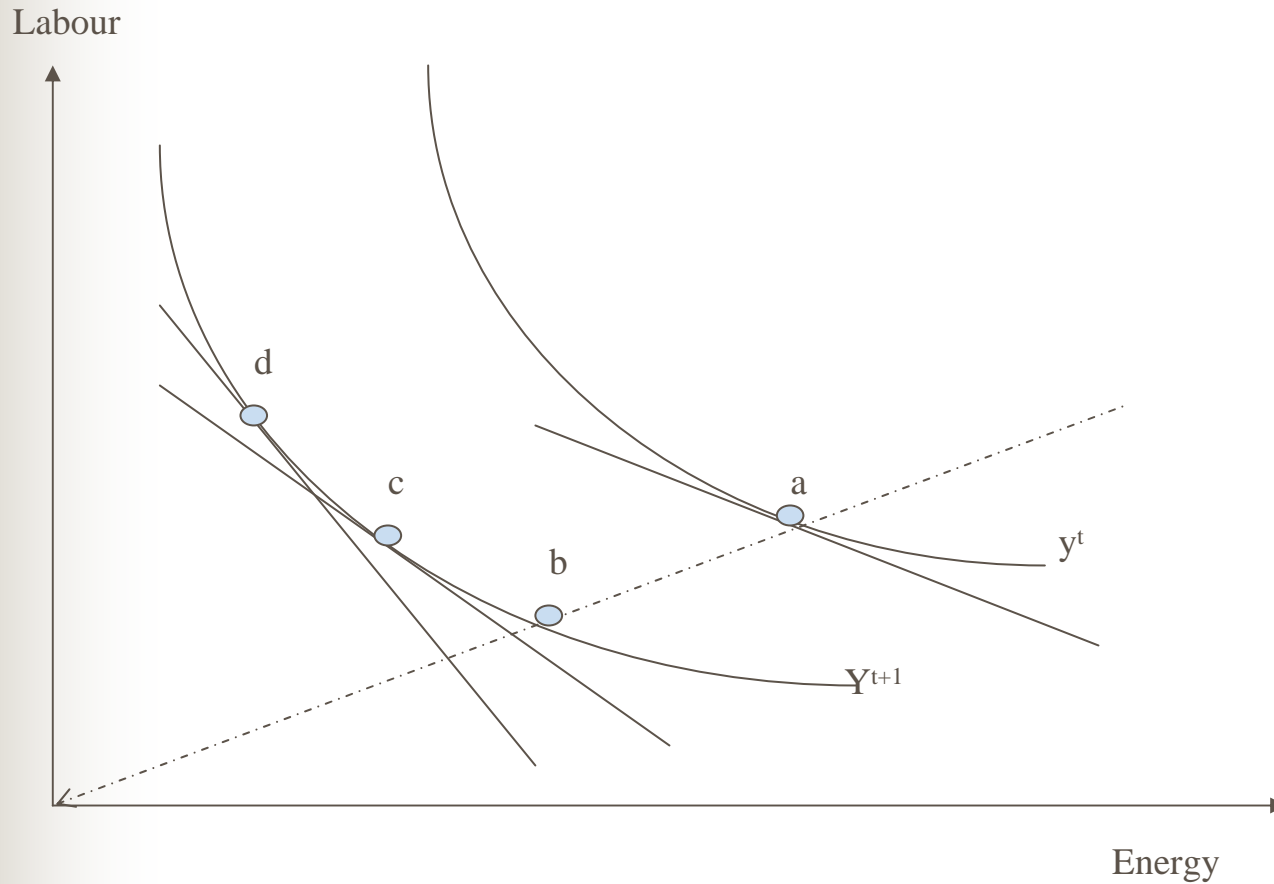
$$EC = (b - a) - (f - d)$$

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

or

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

Decomposition of Price Induced Innovation





Data

- **Conventional Output and Inputs: GDP, Labour, Capital and Energy Consumption**
- **Energy Price: Country specific crude oil price**
- **Long term Energy Price: 3-year moving average of past energy prices**
- **Study Period: 1974-2000**

Countries

- **Low income countries (19): CAMEROON, COTE d'IVOIRE, EGYPT, EL SALVADOR, ETHIOPIA, GHANA, GUATEMALA, HONDURAS, INDIA, KENYA, NIGERIA, PAKISTAN, PARAGUAY, PHILIPPINES, SENEGAL, SRI LANKA, SYRIA, TANZANIA, TOGO,**
- **Low middle income countries (14): COLOMBIA, COSTA RICA, DOMINICAN REP., ECUADOR, GABON, INDONESIA, JAMAICA, JORDAN, MOROCCO, PERU, SOUTH AFRICA, TRINIDAD & TOBAGO, URUGUAY, VENEZUELA**
- **High middle income countries (7): ARGENTINA, CHILE, IRAN, MALAYSIA, MEXICO, THAILAND, TURKEY**
- **High income countries (15): AUSTRALIA, BOLIVIA, CANADA, DENMARK, GREECE, ICELAND, ISRAEL, JAPAN, KOREA REP. OF, NEW ZELAND, NORWAY, SWEDEN, SWITZERLAND, UNITED KINGDOM, USA**

Estimation and Results

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

Tests of Hypotheses for Functional Form of Directional Distance Function

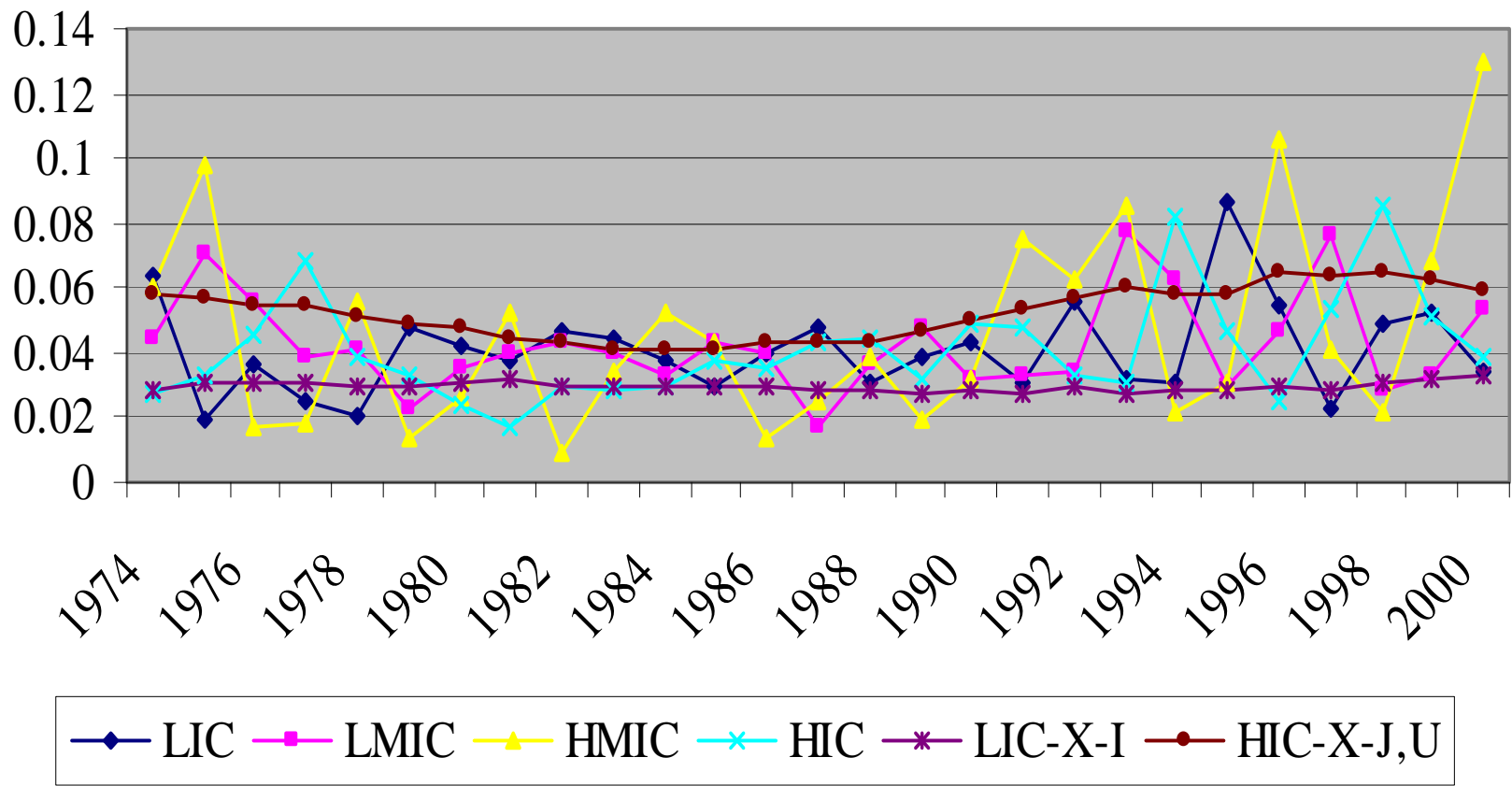
Null Hypothesis	Log Likelihood Ratio Test Statistics (λ)	Critical χ^2	Decision
$H_0:$ $\gamma_1 = \gamma_{11} = \eta_{11} = \eta_{21} = \eta_{31} = \mu_1 = 0$	21.198	12.592	Reject H_0
$H_0:$ $\gamma_2 = \gamma_{22} = \eta_{12} = \eta_{22} = \eta_{32} = \mu_2 = \phi = 0$	125.302	14.067	Reject H_0
$H_0: \psi_1 = \psi_2 = \psi_3 = 0$	205.300	7.815	Reject H_0

$$\lambda = -2\{\text{Log(Likelihood } (H_0)) - \text{Log(Likelihood } (H_1))\}$$

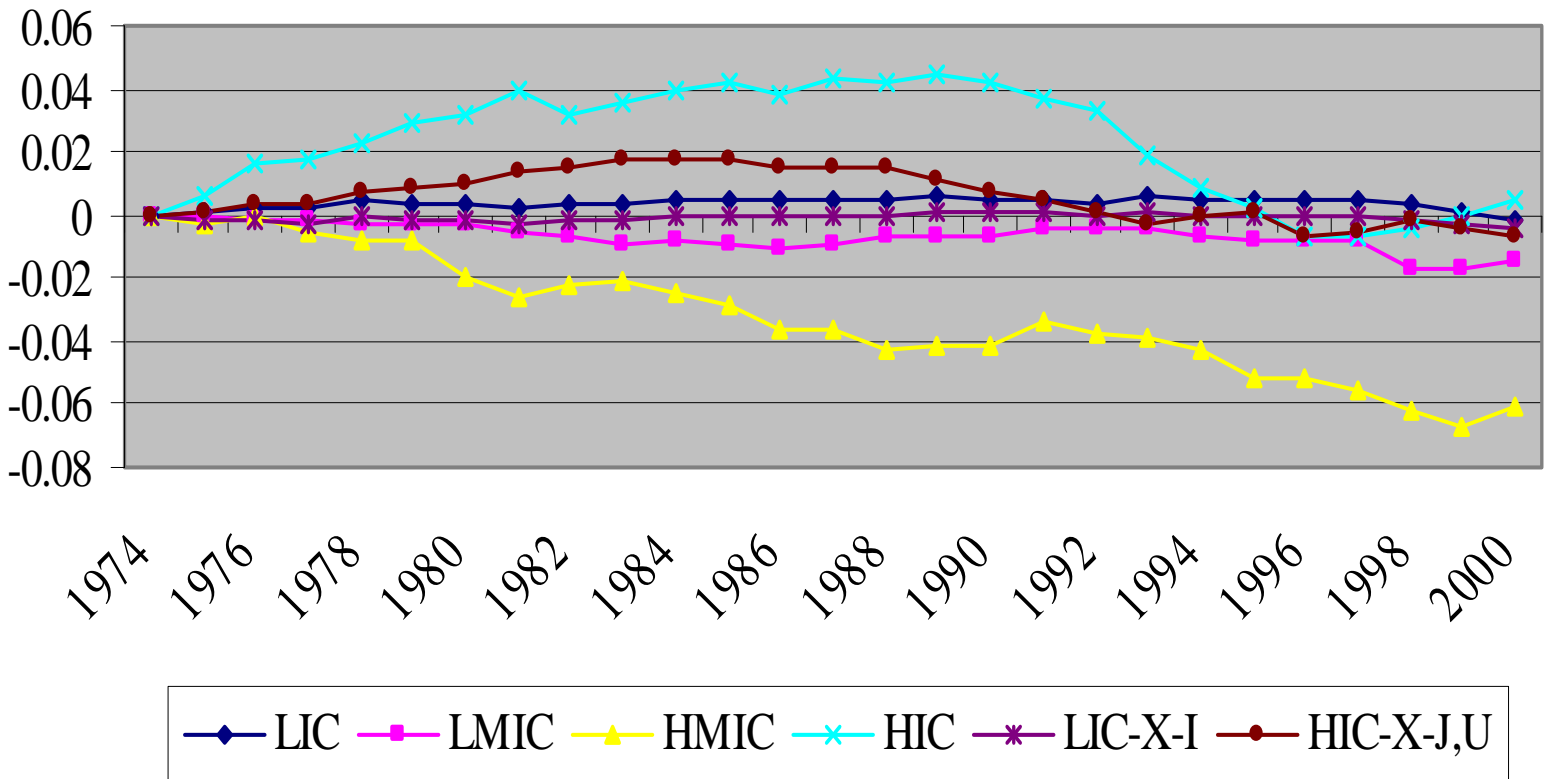
Parameter Estimates of Mean Normalized Directional Distance Function

Name of Variable	Coefficient	t-Statistics	Name of Variable	Coefficient	t-Statistics	Name of Variable	Coefficient	t-Statistics
intercept(α_0)	-0.0244	-4.035	$0.5^2(\gamma_{22})$	-0.0014	-1.436	$X_{2,t}(\eta_{31})$	0.001	
$Y(\beta_1)$	-0.452	-203.257	$Y.X_1(\delta_{11})$	0.0097	14.384	$X_{2,\bar{r}}(\eta_{12})$	-0.0055	
$X_1(\alpha_1)$	0.0843	17.629	$Y.X_2(\delta_{21})$	-0.0051		$X_{3,t}(\eta_{22})$	0.0001	0.237
$X_2(\alpha_2)$	0.2984		$Y.X_3(\delta_{31})$	0.0028	2.815	$X_{3,\bar{r}}(\eta_{23})$	0.0032	1.635
$X_3(\alpha_3)$	0.1653	16.396	$Y.t(\mu_1)$	-0.0001	-0.552	$t_{\bar{r}}(\phi)$	-0.0003	-1.023
$t(\gamma_1)$	-0.0009	-1.386	$Y.\bar{r}(\mu_2)$	-0.0048	-4.618	$G1(\psi_1)$	0.0312	8.107
$\bar{r}(\gamma_2)$	0.0116	2.596	$0.5X_1.X_2(\alpha_{12})$	0.0077		$G2(\psi_2)$	0.0358	10.641
$0.5Y^2(\beta_2)$	0.0074	12.295	$0.5X_1.X_3(\alpha_{13})$	0.0199	3.783	$G3(\psi_3)$	0.0574	16.76
$0.5X_1^2(\alpha_{11})$	-0.0179	-19.068	$0.5X_2.X_3(\alpha_{23})$	0.0084		q	11.7082	15.541
$0.5X_2^2(\alpha_{22})$	-0.0213		$X_{1,t}(\eta_{11})$	-0.0011	-6.266	P	0.4902	11.031
$0.5X_3^2(\alpha_{33})$	-0.0255	-12.408	$X_{1,\bar{r}}(\eta_{21})$	-0.0025	-0.94	s_v	0.0194	23.881
$0.5t^2(\gamma_{11})$	0.0001	2.478						

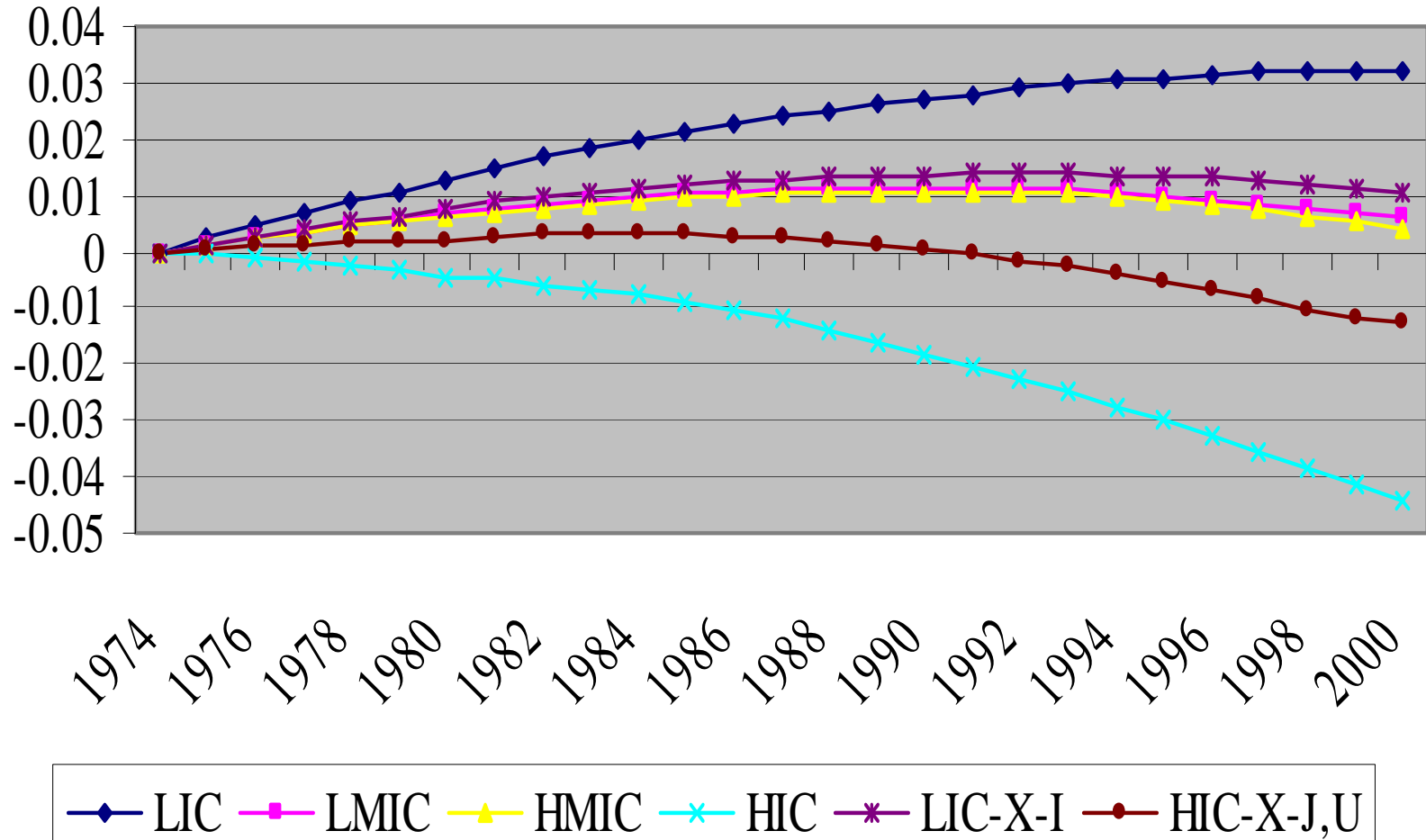
Average Levels of Inefficiency



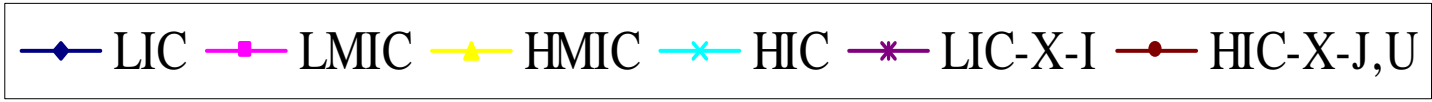
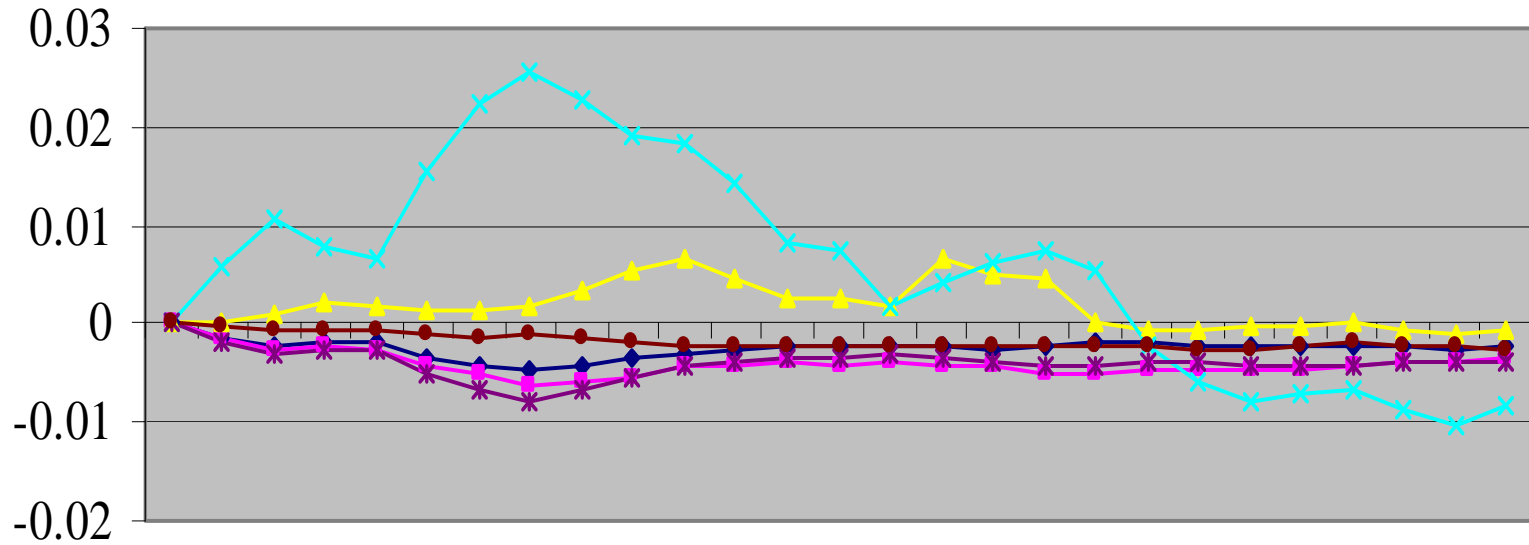
Cumulative Efficiency Changes



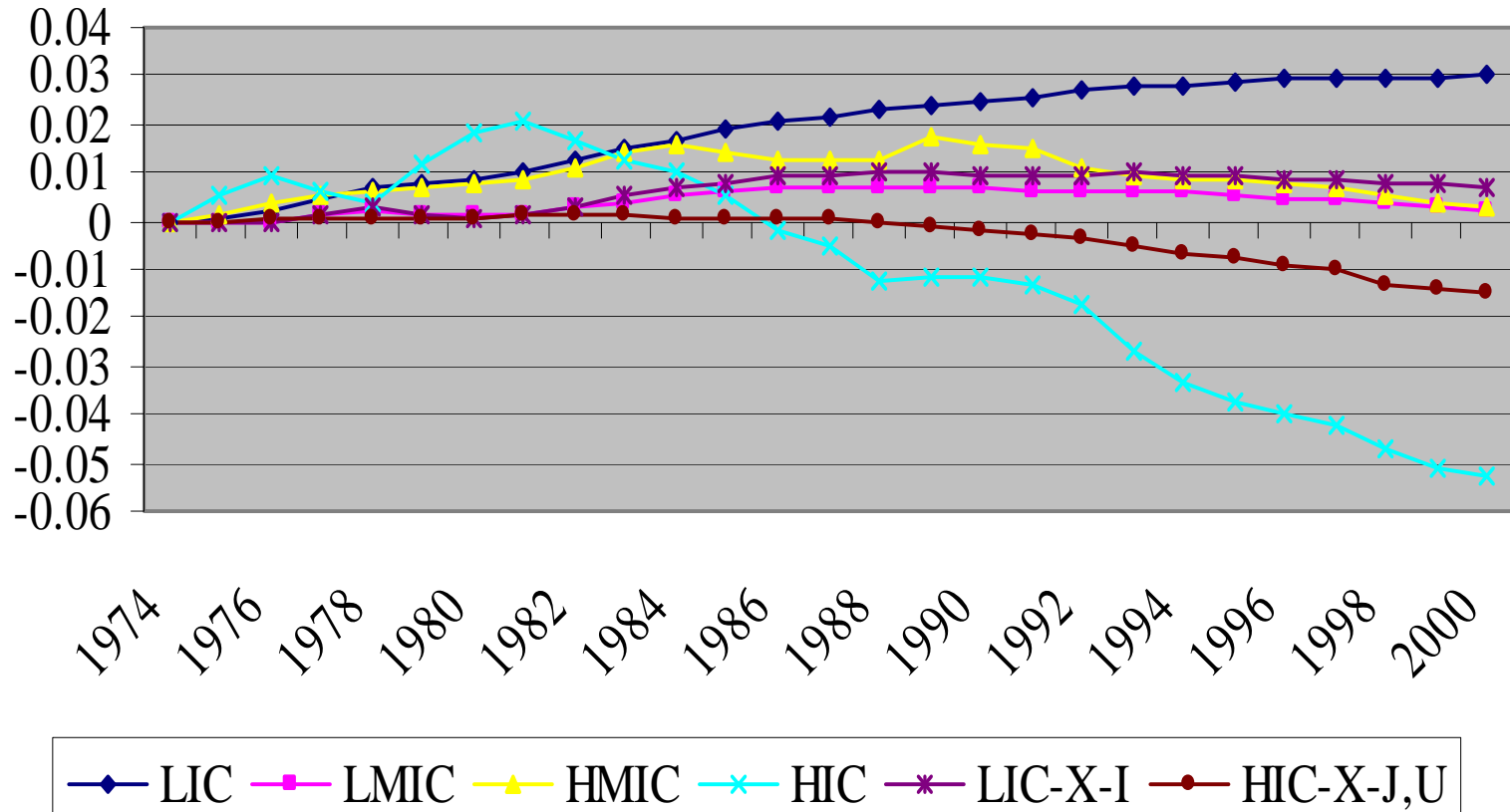
Cumulative Exogenous Technological Change



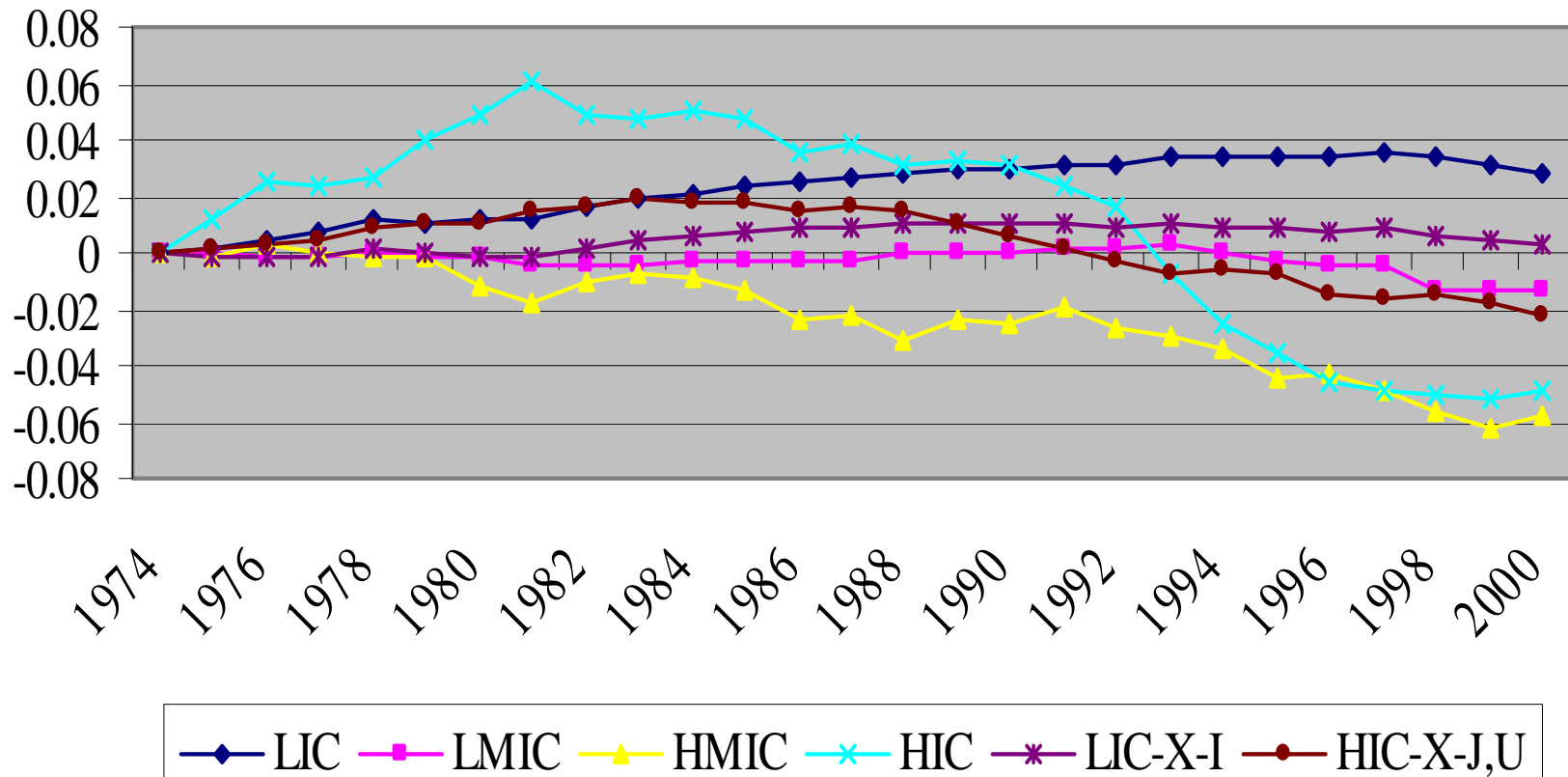
Cumulative Induced Technological Change



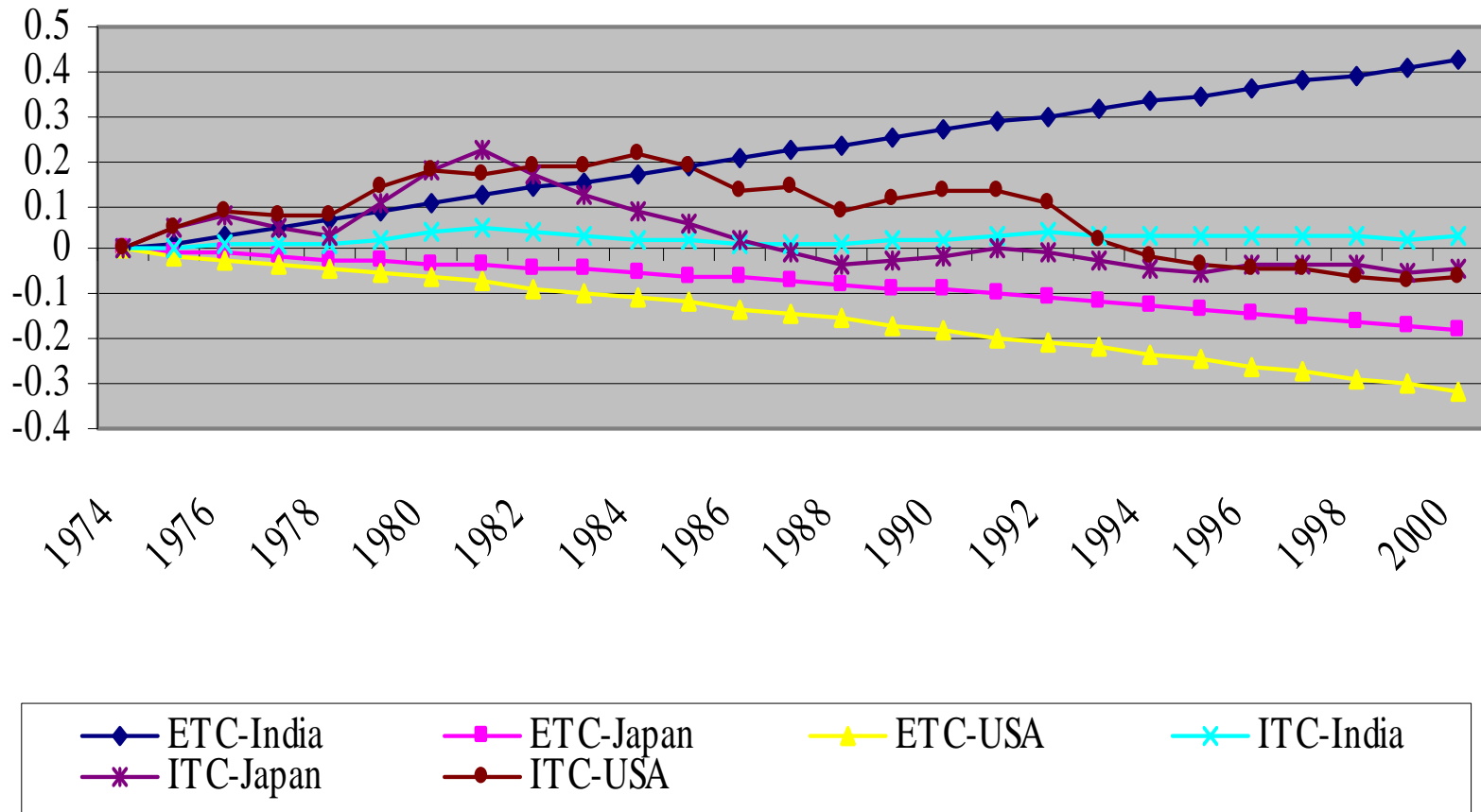
Cumulative Technological Change (ETC+ITC)



Cumulative Productivity Change



Cumulative ETC and ITC in Some Major Countries



Average of Input Biases of Exogenous and Induced Technical Progress for Different Groups of Countries

Year	Exogenous Input Bias			Induced Input Bias		
	Labour	Capital	Energy	Labour	Capital	Energy
Low income countries (Per Capital Income: < \$825)						
1974-198	-0.0149	0.0061	0.0087	-0.0356	0.0071	0.0285
1981-198	-0.0076	0.0035	0.0041	-0.0172	0.0009	0.0163
1986-199	-0.0063	0.003	0.0033	-0.0143	0.0002	0.0141
1991-199	-0.006	0.0027	0.0033	-0.0138	-0.0001	0.0139
1996-200	-0.0059	0.0026	0.0033	-0.0139	-0.0002	0.0141
Low middle income countries (Per Capita Income \$826-3256)						
1974-198	-0.0027	0.0022	0.0005	-0.0046	-0.0036	0.0082
1981-198	-0.0027	0.0022	0.0005	-0.0046	-0.0038	0.0084
1986-199	-0.0028	0.0023	0.0006	-0.0051	-0.0035	0.0086
1991-199	-0.003	0.0023	0.0007	-0.0058	-0.0032	0.009
1996-200	-0.0031	0.0023	0.0008	-0.0062	-0.0031	0.0093
High middle income countries (Per Capita Income \$3256-10065)						
1974-198	-0.0026	0.0023	0.0003	-0.0037	-0.0034	0.0072
1981-198	-0.0025	0.0022	0.0003	-0.004	-0.0038	0.0078
1986-199	-0.0025	0.0021	0.0004	-0.0042	-0.004	0.0081
1991-199	-0.0022	0.002	0.0003	-0.0038	-0.0044	0.0082
1996-200	-0.0021	0.0018	0.0002	-0.0036	-0.0046	0.0082
High-income countries (Per Capita Income: > \$10066)						
1974-198	-0.0025	0.0015	0.001	0.001	-0.0085	0.0075
1981-198	-0.0017	0.0016	0.0001	-0.0001	-0.0082	0.0083
1986-199	-0.0016	0.0016	0.0001	0	-0.0084	0.0084
1991-199	-0.0014	0.0015	-0.0001	-0.0004	-0.0082	0.0086
1996-200	-0.0013	0.0014	-0.0001	-0.0006	-0.008	0.0086

Low income countries (Per Capital Income: < \$825) (Excluding India)

1974-198	-0.0039	0.0023	0.0016	-0.008	-0.0011	0.0091
1981-198	-0.0041	0.0024	0.0017	-0.0087	-0.0012	0.0099
1986-199	-0.0044	0.0024	0.002	-0.0096	-0.0009	0.0105
1991-199	-0.0048	0.0023	0.0025	-0.011	-0.0007	0.0117
1996-200	-0.0053	0.0023	0.0029	-0.0123	-0.0005	0.0128

High-income countries (Per Capita Income: > \$10066) (Excluding Ja)

1974-198	-0.0011	0.0013	-0.0002	-0.0013	-0.0058	0.0071
1981-198	-0.0011	0.0013	-0.0002	-0.0015	-0.0061	0.0076
1986-199	-0.001	0.0012	-0.0002	-0.0015	-0.0063	0.0078
1991-199	-0.001	0.0012	-0.0002	-0.0015	-0.0064	0.0079
1996-200	-0.001	0.0012	-0.0002	-0.0016	-0.0064	0.008

Averages of Morishima Elasticity of Substitutions between Inputs for Different Groups of Countries

Year	σ_{12}	σ_{13}	σ_{21}	σ_{23}	σ_{31}	σ_{32}
Low income countries (Per Capital Income: < \$825)						
1974-198	0.0078	0.0699	0.0124	0.0164	0.0332	0.0357
1981-198	0.0121	0.0765	0.0146	0.0177	0.0421	0.0427
1986-199	0.0348	0.1029	0.0137	0.0175	0.049	0.0453
1991-199	0.0682	0.1388	0.012	0.017	0.0579	0.0476
1996-200	0.0873	0.1599	0.0105	0.0178	0.0642	0.0501
Low middle income countries (Per Capita Income (\$826-3256)						
1974-198	0.1565	0.189	0.0365	0.025	0.0876	0.0346
1981-198	0.1637	0.1971	0.0426	0.0265	0.1117	0.0433
1986-199	0.1717	0.2059	0.0428	0.0244	0.1194	0.044
1991-199	0.1718	0.2079	0.0428	0.0232	0.1281	0.0454
1996-200	0.1878	0.2251	0.0463	0.0232	0.1405	0.0465
High middle income countries (Per Capita Income (\$3256-10065)						
1974-198	0.2057	0.2726	0.1253	0.094	0.1692	0.0794
1981-198	0.2295	0.2992	0.1359	0.0978	0.2185	0.0993
1986-199	0.2427	0.3153	0.1302	0.0888	0.2456	0.1051
1991-199	0.2432	0.3172	0.1399	0.0931	0.2838	0.1189
1996-200	0.2521	0.3271	0.1536	0.0986	0.3186	0.1286
High-income countries (Per Capita Income: > \$10066)						
1974-198	0.1721	0.1064	0.6893	0.6115	0.0634	0.1353
1981-198	0.2021	0.0787	0.9358	0.8185	-0.0361	0.1315
1986-199	0.2166	0.0615	1.1702	1.0328	-0.0847	0.1855
1991-199	0.1788	0.0393	0.9063	0.7486	-0.1451	-0.0259
1996-200	0.1808	0.0099	0.9513	0.7488	-0.2578	-0.1214

Low income countries (Per Capital Income: < \$825) (Excluding India)						
1974-1980	0.1441	0.1856	0.0149	0.0096	0.0587	0.0227
1981-1985	0.1604	0.2026	0.018	0.0109	0.0749	0.0272
1986-1990	0.1947	0.24	0.0178	0.0101	0.0872	0.0284
1991-1995	0.2419	0.2896	0.017	0.0088	0.1029	0.0292
1996-2000	0.2816	0.3315	0.0173	0.0082	0.1179	0.0307
High-income countries (Per Capita Income: > \$10066) (Excluding Japan)						
1974-1980	0.0762	0.1134	0.1486	0.1324	0.2418	0.1467
1981-1985	0.0787	0.1144	0.1361	0.1144	0.2508	0.1418
1986-1990	0.0749	0.1097	0.1339	0.1121	0.2591	0.1434
1991-1995	0.0734	0.1067	0.1359	0.1113	0.2658	0.1416
1996-2000	0.073	0.1049	0.1363	0.1089	0.2745	0.1412



Summary and Conclusions

1. **A distinguishing feature of this framework is that it provides several pieces of information simultaneously:**
 - a) **it describes the structure of production technology;**
 - b) **it provides the direction and pace of price induced as well exogenous technological change; and**
 - c) **it provides the measure of substitutability between different inputs without explicitly considering current price of inputs**



Summary and Conclusions

- 2. The average value of directional distance function for the world comes out to be 0.04.**
- 3. In developed countries we observe larger ITC effects in comparison to developing countries in the periods after first (1974), and second (1980) world oil crisis that caused substantial energy price increases.**
- 4. The parameter estimates of directional distance function reveal the absence of neutral ETC but presence of neutral ITC. The embodied TC is observed with respect to both ITC and ETC effects.**



Summary and Conclusions

- 5. The magnitude of factor bias arising from energy price induced forces is typically greater than the factor bias arising from exogenous forces.**
- 6. We observe lower values for MES between capital and energy than MES between energy and capital implying that increase in energy prices that stimulate investment in energy-efficient machinery may be more effective.**



Thank you !