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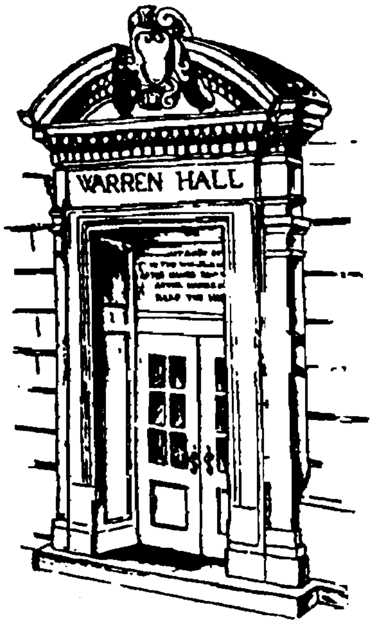

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An Exploration of the Differences in National Growth: Some Implications for Future Environmental Policy

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Abstract

This paper examines the role of energy in long-term growth. The authors estimate a translog production function in capital, labour, and energy, using data on 38 countries from 1965-1990. It is found that separating the countries into two groups, the high growth group and the rest of the world (ROW), yields slope coefficients that are statistically different. Furthermore, there are dramatic differences in the estimated production elasticities, returns to scale, and bias in technical change for the two country groups.

Based on the estimated coefficients, the authors approximate the contributions of the factors of production in explaining the observed growth in real GDP through a growth accounting exercise. Energy emerges as an important source of growth for both country groups, second only to increases in total factor productivity.

In light of the negotiations over a Protocol to the Climate Change Convention, the authors estimate the capital and labour requirements for national energy reductions.

Finally, the authors use the production function to provide analytical expressions for the elasticity of energy intensity with respect to other factor inputs, and also for autonomous energy efficiency improvements (AEEI). It is found that the deceleration of the AEEI in the ROW countries more than offsets the combined acceleration witnessed in Hong Kong, South Korea, and Thailand.

1. Introduction

This paper revisits an issue that was the subject of intensive research among economists in the three decades following the second World War. The central concern of this oeuvre was the quantification of the sources of economic growth using the concepts of a production function and growth accounting.[1] The most well known studies among these include Abramovitz (1956), Solow (1957), Kendrick (1961), Denison (1967), Griliches and Jorgenson (1966), Jorgenson and Griliches (1967), and Kuznets (1971).

Suppose that output, Y, in any time period is a function of two inputs, say capital, K, and labour, L, and time, t. That is

$$Y = A(t)f(K,L) \tag{1}$$

where $A(t)$ represents Hicks neutral technical change. The total differential of the above equation gives us the following identity, relating the growth of output to the growth in the factors of production, and total factor productivity or technical change:

$$\frac{dY}{Y} \equiv \frac{dA}{A} + \eta_K \frac{dK}{K} + \eta_L \frac{dL}{L} \tag{2}$$

where η_K and η_L are the production elasticities of K and L, respectively.

The common thread unifying this work involves the estimation of production elasticities for capital and labour inputs under the assumptions

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[1] See Jorgenson (1995, chapter 1) and Christensen *et al.* (1980) for an overview of the chronological development of the literature.

of constant returns to scale and perfectly competitive product and factor markets. Under this pair of assumptions, the production elasticities are numerically equal to the equilibrium value shares for the inputs, and sum to unity. In this way, price and quantity data were used in this literature to obtain estimates of these elasticities without necessitating the specification nor econometric estimation of the physical production function underlying the analysis. Furthermore, the production elasticities were typically assumed to be independent of the levels of factor use, and also constant over time.

The literature published in the last two decades has raised the analysis to a more sophisticated level. Included now are the impacts of factors such as the heterogeneity of capital and labour inputs, quality changes in inputs, and the impact of education on growth and productivity. Jorgenson (1995) provides a good overview.

In terms of methodology, a major shift in the literature came with the work of Christensen *et al.* (1980). While retaining the assumptions of perfect competition and linear homogeneity of the production function, they allowed the production elasticities to vary with the level of capital and labour use by employing a translog production function. In addition, they also relaxed the assumption of Hicks neutral technical change. The optimum value shares thus vary not only with the levels of factor inputs, but also with time. Their analysis was carried out for nine industrialized countries: Canada, France, Germany, Italy, Japan, Korea, Netherlands, UK, and USA. For eight of these countries, time series were developed from 1955-1973, while for Korea the first data point was 1960. An important result obtained from their analysis was that growth in factor inputs, i.e., capital and labour, was closely associated with growth in economic product. This was in contrast to the earlier literature, for example Kuznets (1971), which found that the growth in total factor productivity, *A(t)*, was the key factor in explaining the growth in total output.

Kim and Lau (1994) took the analysis a step further by relaxing two assumptions that have remained unquestioned in the literature: they did not assume a homogenous production function, nor did they assume perfect competition. Instead, they estimated a system of two equations consisting of a translog production function in capital and labour, and the labour share equation that would hold under perfectly competitive product and factor markets. Their sample comprised of data from at least 1966 to 1990 for nine countries: Hong Kong, Singapore, South Korea, and Taiwan (the Little Dragons of East Asia), and France, West Germany, Japan, and the United Kingdom (the Group-of-Five industrialized countries).

The Kim and Lau work reveals a clear dichotomy in the results for the four East Asian countries and the remaining countries included in their data set. The estimated production elasticities for capital are consistently higher for the Little Dragons as compared to the Group-of-Five countries; the estimated production elasticities for labour are consistently lower for the Little Dragons. Furthermore, they found that while capital accumulation was the chief source of economic growth for the Little Dragons, for the Group-of-Five countries technical progress accounted for the bulk of growth in national output.

This dichotomy in the results obtained by Kim and Lau lead us to explore the differences in the growth experience of the rapidly growing economies of East Asia as compared with that of the rest of the world. Table 1 below shows summary statistics on national level data from 1965-1990 for a sample of 38 countries.[2] The countries are organized into two groups: the first group comprises Hong Kong, South Korea, and Thailand, and the second group, the rest of the world (ROW). The statistics presented are the averages for each group.

Table 1

Average Annual Growth Rates, 1965-1990 (% per year)

	High Growth	Rest of the World
Real GDP per worker	5.62	1.98
Capital stock per worker	6.23	3.64
Energy per worker	6.67	2.54
Labour force	2.6	1.67

It is evident that the high growth countries of East Asia have witnessed significantly higher growth in output per worker than the ROW countries. Furthermore, this is supported by still higher growths in the capital and energy inputs on a per worker basis, even though, on average, these countries experienced a more rapid growth in their labour force than the remaining countries in the sample.

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[2] See appendix 1 for details on data and data sources, and definitions of the country groups.

These differences between the two country groups raise a set of related questions. First, is it correct to assume, as Kim and Lau do, that the high growth countries operate on the same production surface as the ROW countries? Second, is the high growth in output per worker the result of the growth in factor inputs alone, or is due in part to technological advances that raise the total factor productivity? Third, does technical change play a greater or smaller role in explaining the growth in output in the case of the ROW countries than in the case of the high growth countries? We attempt to answer these questions by estimating a translog production function with biased technical change in which the slope coefficients vary by country group. Instead of forcing the estimated slope coefficients to be identical for the two groups, *a priori*, we test whether the differences in the estimated coefficients are statistically significant. We will show that separating Hong Kong, South Korea, and Thailand from the rest of the countries in the sample leads to dramatically different results than those obtained by Kim and Lau, with obvious policy implications.

A conspicuous feature of the growth accounting literature is its focus on capital and labour as the only two significant inputs in the production process.[3] An additional purpose of the present paper is to

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[3] There is a substantial literature that compares the roles of capital, labour, and energy in the production process. However, the focus of this work is different from the current analysis. For instance, Berndt and Wood (1975) estimate the cost shares corresponding to a translog cost function in capital, labour, energy, and materials in order to analyze the degree of substitutability/complementarity between the factor inputs for the US manufacturing industry; Hudson and Jorgenson (1974) combine an econometric model of producer behavior with a growth model for the US economy to project energy utilization from 1975-2000; Berndt *et al.* (1993) focus on the role of embodied and disembodied technical change in explaining productivity growth in the manufacturing sectors of the US, Canada, and France.

extend the Kim and Lau type analysis to include energy as a third factor of production. Furthermore, in doing so we employ a much larger data set, including countries from Africa, South Asia, and Latin America.

The recent statements by several Heads of State detailing reductions in national carbon dioxide emissions (Cushman 1997) have squarely focussed attention on the role of energy in economic growth. Apart from estimating the historically observed contributions of the energy, capital, and labour inputs in explaining the growth in real GDP through a growth accounting exercise, we also estimate the capital and labour requirements for national energy reductions. Finally, we provide a theoretical underpinning for the observed decline in the energy to GDP ratio, and explore the impact of technological development on autonomous energy efficiency improvements.

2. The Model and Results

We use a translog production function in three inputs, capital, labour, and energy. Technical change is captured by the time trend. The production function is assumed to be non-homogenous and symmetric in factor use. Interactions between factor use and time are allowed, i.e., we do not assume Hicks neutral technical change.[4] The estimating equation,

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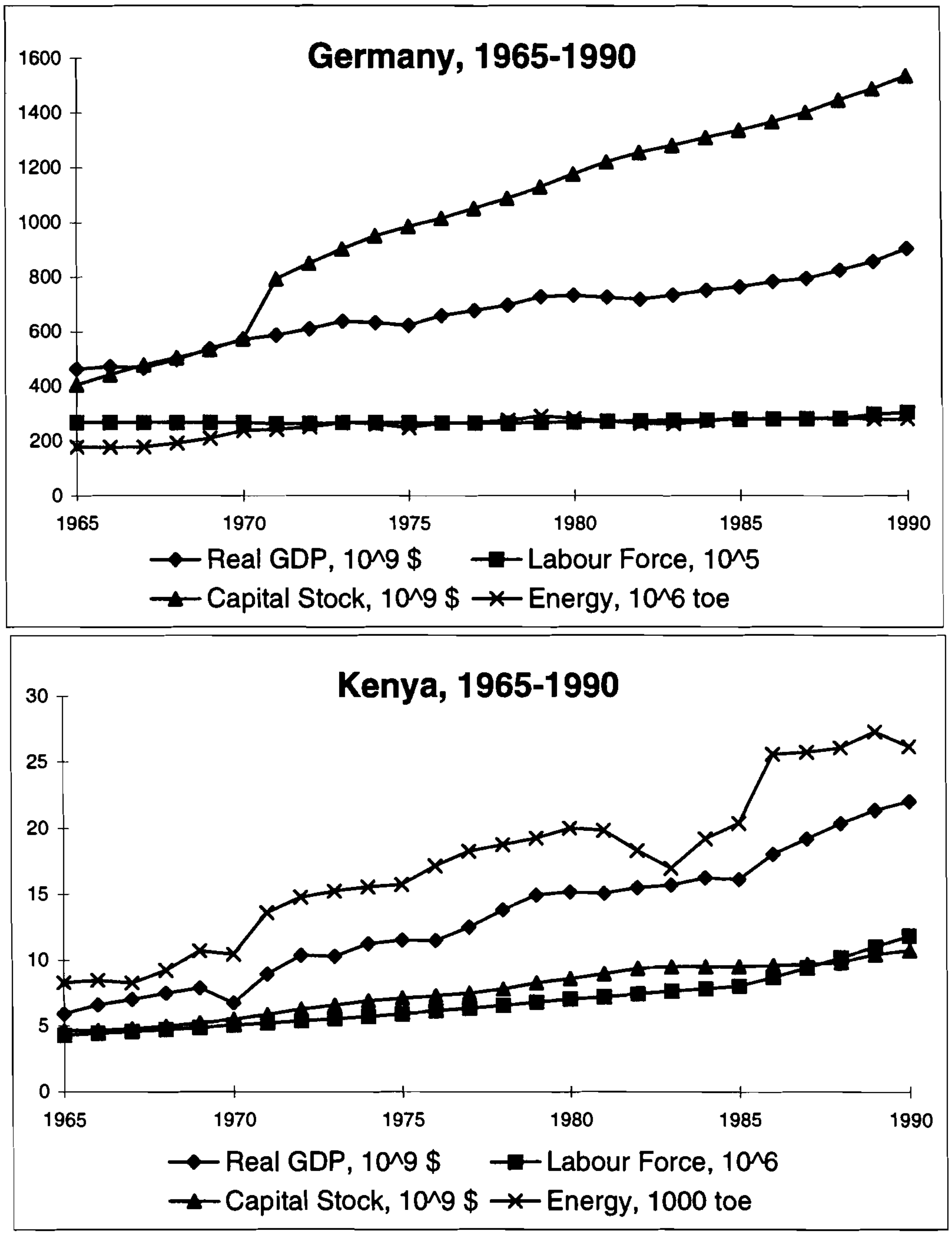
[4] Note that in case of a flexible functional form of the type specified above, the production elasticity for any factor input depends on the interaction term between that input and time. If the estimated coefficient is negative, it is possible that the production elasticity will become negative after a sufficiently long period of time. See figure 4.2. This is a theoretically unappealing consequence of modeling technical progress as a simple time trend. Yet, it is a commonly used method. See, for instance, Christensen *et al.* (1980), and Kim and Lau (1994). Appendix 3 presents an alternative way of modeling technical change that might be used in further research.

and analytical expressions for the production elasticities, elasticities of substitution, and bias in technical change are shown in appendix 2.

A few comments follow on the data. Figure 1 shows data on real GDP, capital stock, labour force and energy consumption for Germany and Kenya. It reveals some problems that arise in using national level time series data for econometric analyses. First, nations typically do not collect data on these variables annually. Often data are collected at 5 or 10 year intervals. For the interim years, the data are "generated" using some form of interpolation. This is particularly obvious in the case of the series on labour force. By definition, this method of data "collection" creates an autocorrelated series. Second, changes in the definitions used to determine highly aggregated variables, such as the national capital stock and GDP, are another possible source of error since they do not reflect any real change in the physical variable being measured. For instance, in the case of Germany, there is a sudden jump in capital stock between 1970 and 1971. If this is due to a change in the underlying definition of the national capital stock, or of some component that makes up the national aggregate, this should ideally not be reflected in the coefficients of the physical production function estimated using these data. However, in most cases, it is nearly impossible to "clean" the data set of such anomalies. Finally, there is the issue of multi-collinearity. Even a cursory look at figure 1 shows that the variables tend to track each other fairly well. In the presence of multi-collinearity, the statistical quality of the estimated coefficients is suspect. A small change in the data can cause a substantial change in the estimated values. We discuss our econometric results



Note: All monetary units are in 1985 international prices
For data sources, see appendix 1.

Figure 1

Data for Germany and Kenya

subject to these qualifications.

In the first instance, we re-estimated the Kim-Lau model using ordinary least squares for the pooled data from 1965-1990 for the 38 countries in our sample, and obtained very similar results. While the specific numerical values for the estimated coefficients are expectedly different, the estimated production elasticities are quite similar.[5] Not only do we get the same qualitative trends over time, the elasticities for the countries in the Kim-Lau data set are in the same range. The addition of energy as a third input did not effect these results.

Next, we allowed the estimated slope coefficients to vary with country group.[6] To begin with, we tested, separately, several hypotheses concerning the production function that have traditionally remained the maintained hypotheses in the growth accounting literature. The calculated F-statistics and the corresponding decision to reject or not reject the null are shown in table 2. The analytical restrictions imposed under hypothesis are shown in appendix 2.

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[5] There are some key differences between the Kim and Lau study and our attempts which account for the difference in the estimated coefficients. Not only do Kim and Lau have a much smaller data set from us, they also estimate a system of two equations using a number of instrumental variables. Both studies correct the errors for first degree autocorrelation.

[6] Throughout, the model was estimated using SAS (version 6.12) on a RS/6000 machine using the "autoreg" procedure.

Table 2
Hypotheses Tests

Null hypothesis	F-stat	Probability > F	Decision
Homogeneity	1.6156	0.1396	Do not reject
Cobb-Douglas production function	3.1187	0.0002	Reject
Neutral technical progress	6.8130	0.0001	Reject
Single production function	8.3487	0.0001	Reject

Since the only hypothesis that could not be rejected was that of a homogenous production function, the model was re-estimated subject to these restrictions. Once again, the errors were corrected for first degree autocorrelation. Note that even though we allow the slope coefficients to vary, we do not estimate the model as two separate regressions. Rather, we estimate a single equation, so that the error terms are common. Table A.1 in appendix 2 shows the estimated coefficients, standard errors, t-ratios, and other regression statistics for the homogenous translog model.

Based on the estimated equation we calculated the production elasticities, returns to scale, and the bias in technical progress for each country in the data set. For ease of analysis and presentation, we developed a representative data set for the high growth and ROW countries based on the summary statistics presented in table 1. Each variable, i.e., real GDP, capital stock, labour force, and energy consumption was assumed to start at the average 1965 value for each country group. Using the average annual growth rate for each country group, we extrapolated the values for 1966 through 1990. In this way, we generated a data set that was representative of the average nation in each country group.

Figure 2 shows the production elasticities for each factor input for the average high growth and average ROW country.[7] There are dramatic differences, not only in the numerical values, but more significantly in the sign of the slopes of the representative elasticities. For the average high growth country, η_K and η_L are falling over time, whereas η_E is rising. Exactly the opposite occurs for the average ROW country. This implies that at the competitive equilibrium, the value shares for capital and labour have, on average, been falling in the rapidly growing countries of East Asia, while for the ROW these have been rising in general.

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[7] Appendix 4 shows the 1965 and 1990 values for the production elasticities for each country in the data set.

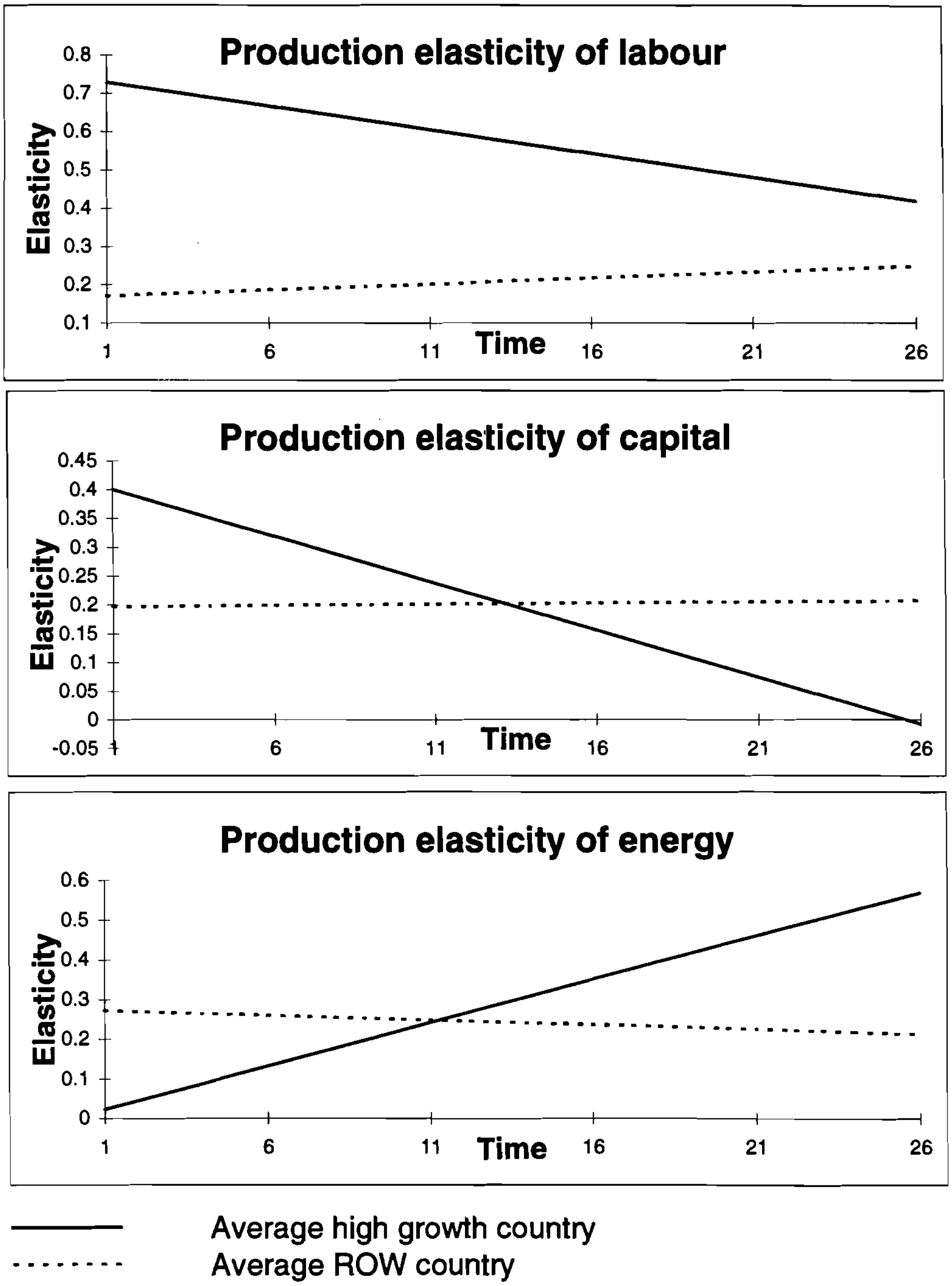
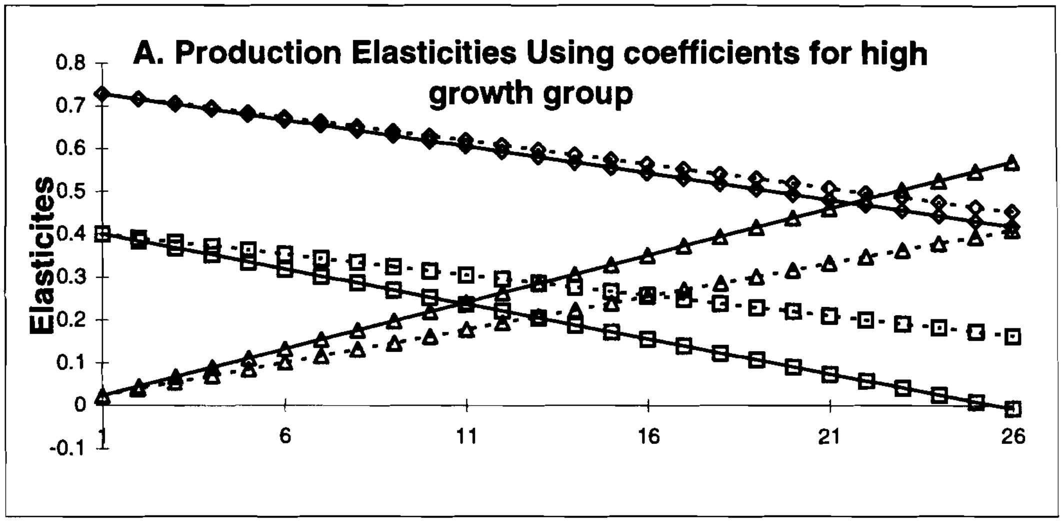


Figure 2

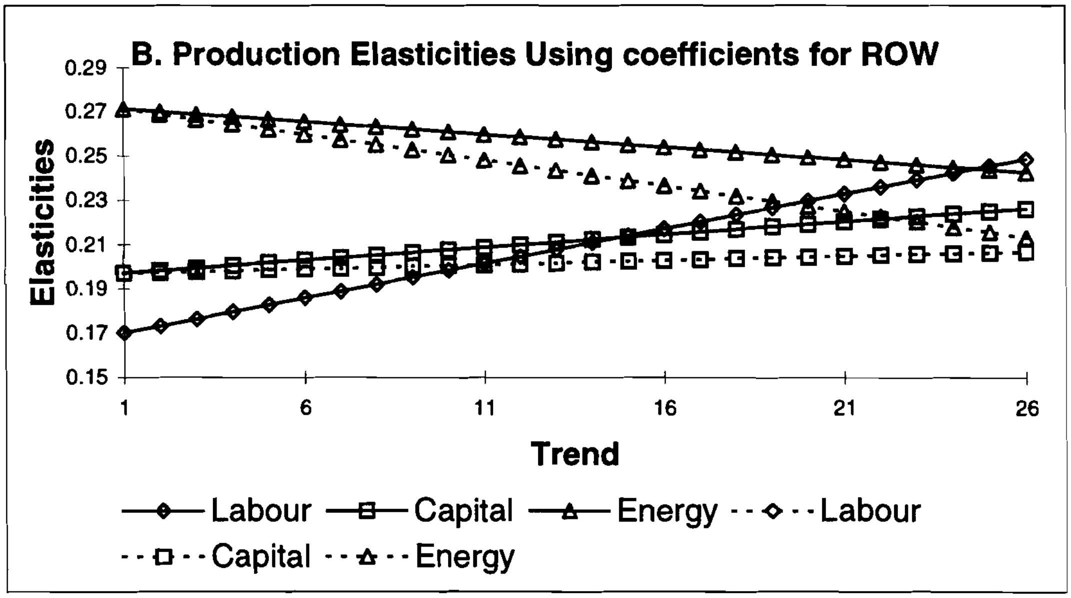
Production Elasticities

This is in sharp contrast to the results obtained by Kim and Lau (1994). According to their analysis, η_K is falling and η_L is rising *for all countries* in their data set. Furthermore, Kim and Lau find that η_K is higher for the Little Dragons while η_L is higher for the Group-of-Five countries. Once again, the opposite is true in our case: η_L is higher for the average rapidly growing economy and η_K is higher for the representative ROW economy for the first half of the time horizon of our analysis. For energy, the difference between the two country groups is equally dramatic. The difference in the estimated η_E for the two groups is intensified over time as η_E rises for the high growth group and falls for the ROW group.

Having a different model for the high growth and ROW countries begs the question of reversibility. What if a high growth country were to experience a slowdown in its growth rate? Would this mean that the country would now experience the same growth model as the ROW countries? In an attempt to answer this question, we re-estimated the production elasticities for K, L, and E for the high growth countries using the data set created for the representative ROW country and the estimated coefficients for the former group. Similarly, we also re-estimated the production elasticities for the low growth group using data for the average high growth country. The results are shown in panels A and B of figure 3. The elasticities depicted by the solid lines in these figures are identical to the production elasticities in figure 2, and are included for the sake of comparison. The dashed lines show the production elasticities recalculated under the changed growth rates.



<u>Note for Panel A:</u>
Elasticities depicted by solid lines are identical to those in fig. 2.
Elasticities depicted by dashed lines are calculated using growth rates for the average ROW country.



<u>Note for Panel B:</u>
Elasticities depicted by solid lines are identical to those in fig. 2.
Elasticities depicted by dashed lines are calculated using growth rates for average high growth country.
Solid line for labour elasticity coincides with dashed line.

Figure 3

Effect of Change in Growth Rates on Production Elasticities

It is clear from these figures that a change (acceleration or deceleration) in the growth rate of real GDP, capital stock, labour force, and energy consumption is by itself not enough to transfer a country from one model or production surface to the other. While there is the anticipated change in the numerical value of the elasticities, there is no change in the sign of the slope with time under the changed growth scenario for both groups of countries. This implies that it is some other aspect, such as a change in the shares of manufacturing imports and export in total GDP that has accompanied such growth in the past, is the crucial factor in determining the growth experience, and correspondingly, the production surface that a country operates on. The export-led growth of Honk Kong, South Korea, and Thailand is perhaps what sets them apart from the rest of the countries in the sample.[8]

Figure 4 shows the degree of homogeneity for both groups of countries. For the average high growth country, our results are very similar to those obtained by Kim and Lau. Both analyses find that the degree of homogeneity is numerically close to 1, and is falling over time. For the ROW countries, however, our results contradict those of Kim and Lau. Not only do we get a much lower numerical value, we also find that the scale elasticity is increasing rather than decreasing over time. The only similarity is that both studies find decreasing returns to scale in all time periods for this latter set of countries. It is not surprising that we

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[8] Of course, trade in energy intensive manufactured goods can have an important impact on domestic commercial energy consumption and on productivity. See Suri and Chapman (1996) and Chapman (1991) for an analyses on these issues.

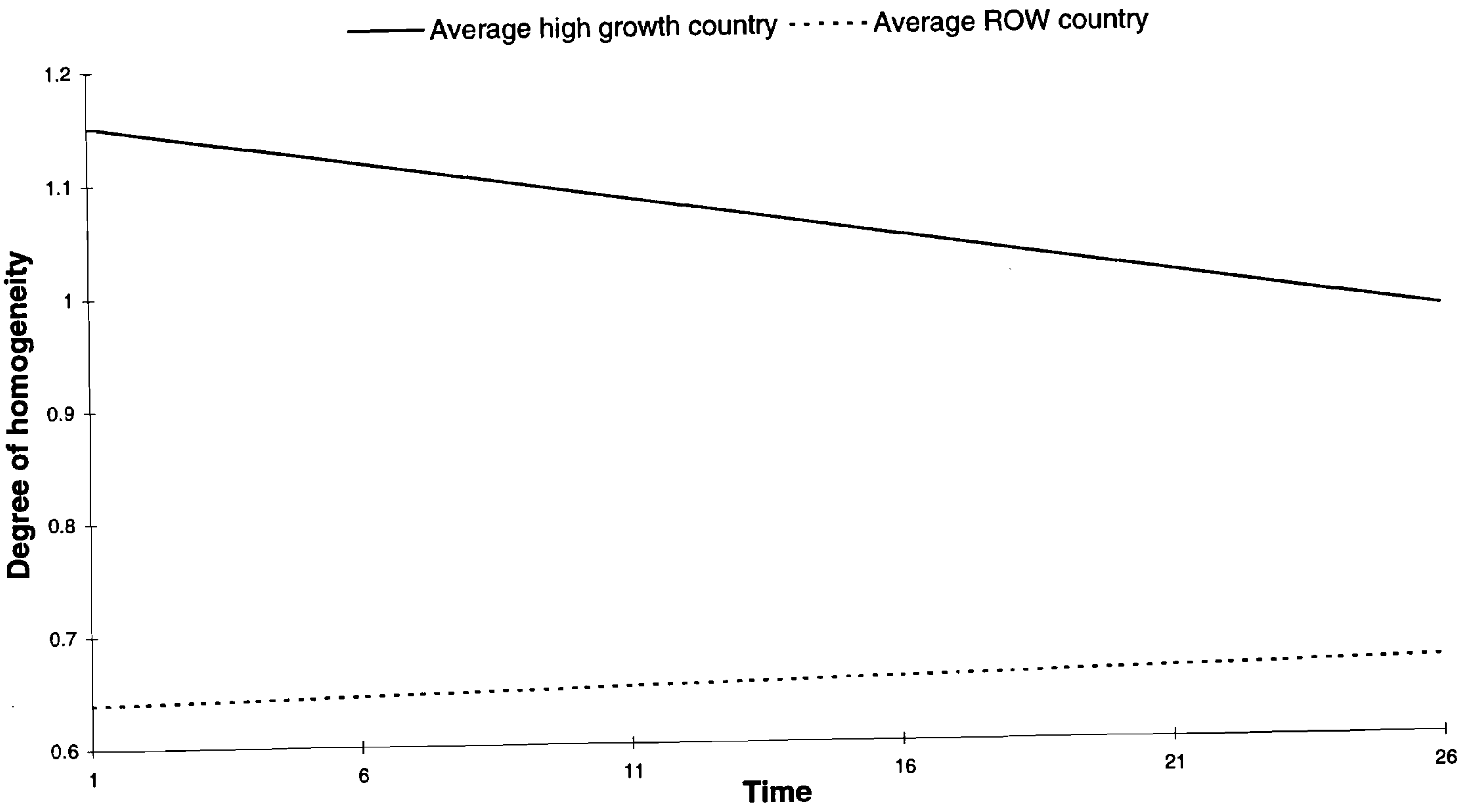
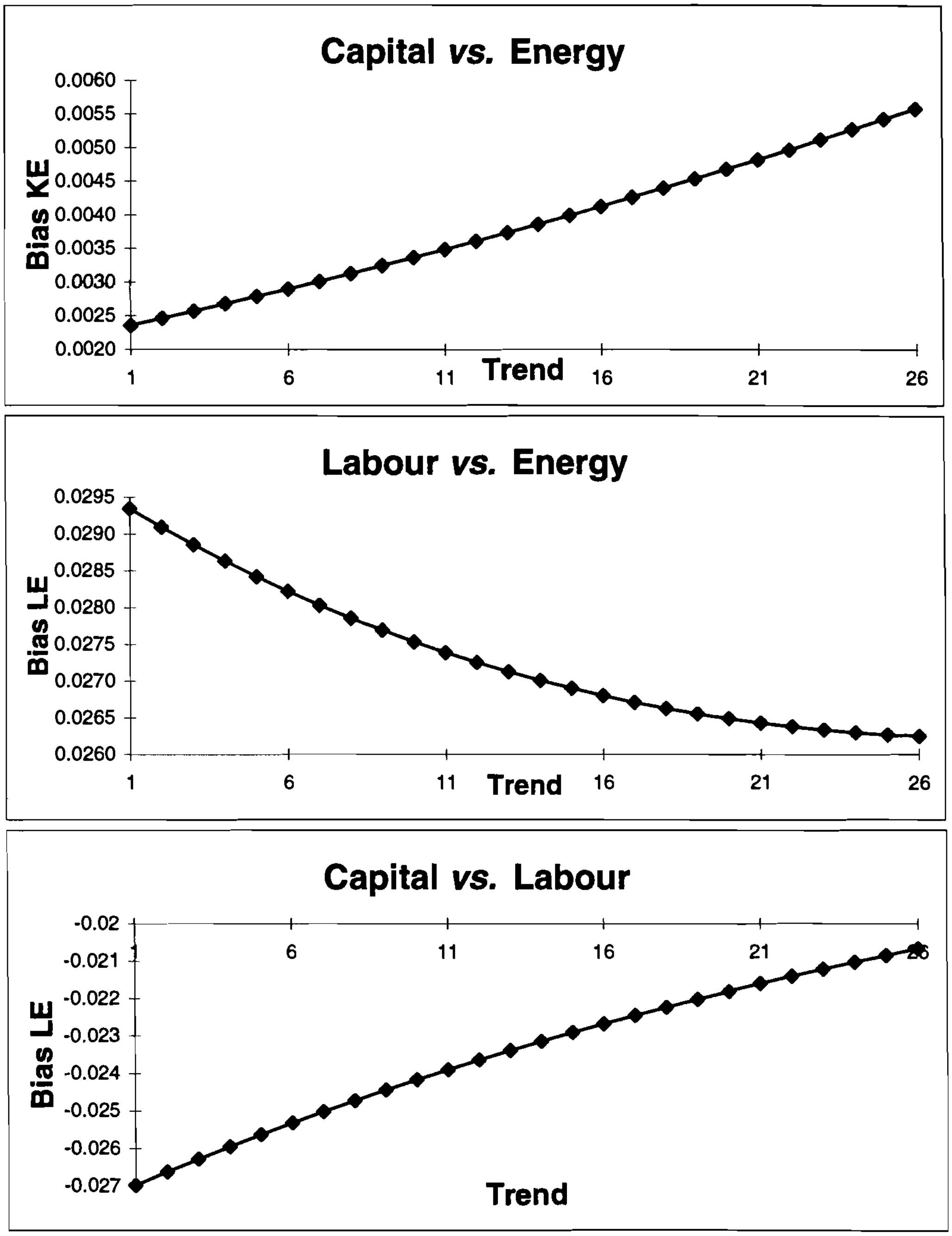


Figure 4
Returns to Scale

get very different scale elasticities as compared to the Kim-Lau study. The scale elasticity is defined as the sum of the production elasticities for all the factors of production. As noted before, our estimated production elasticities vary considerably from those obtained by Kim and Lau. On the contrary, it is somewhat surprising that the degree of homogeneity for the high growth countries is so similar in the two studies: the addition of energy as a factor input is offset by the change in the numerical values and trends in the production elasticities for capital and labour.

The bias in technical progress is another policy variable of interest. It compares the percentage change over time in the production elasticities for any pair of factor inputs. As shown in figure 2, the estimated production elasticity of capital for the average high growth country becomes negative in period 26. This not only creates sharp peaks and troughs in the calculated $Bias_{KL}$ and $Bias_{KE}$ for this group of countries, it is also inconsistent with economic theory. For this reason, we ignore the estimated bias for the high growth countries for the last period.

Figures 5 and 6 reveal another principal difference in the growth experience between the two country groups. For the high growth countries, $Bias_{KL} > 0$, $Bias_{LE} < 0$, and $Bias_{KE}$ starts out negative, but eventually becomes positive as η_K approaches 0. In other words, technical change has been either energy intensive or capital intensive, but not labour intensive. For the ROW countries we get the exact opposite results: $Bias_{KL} < 0$, $Bias_{LE} > 0$, and $Bias_{KE} > 0$. In the case of these countries, technical change is either labour or capital intensive, but not energy intensive.


Capital *vs.* Energy

Labour *vs.* Energy

Capital *vs.* Labour

Figure 5

Bias in Technical Progress: Average ROW Country

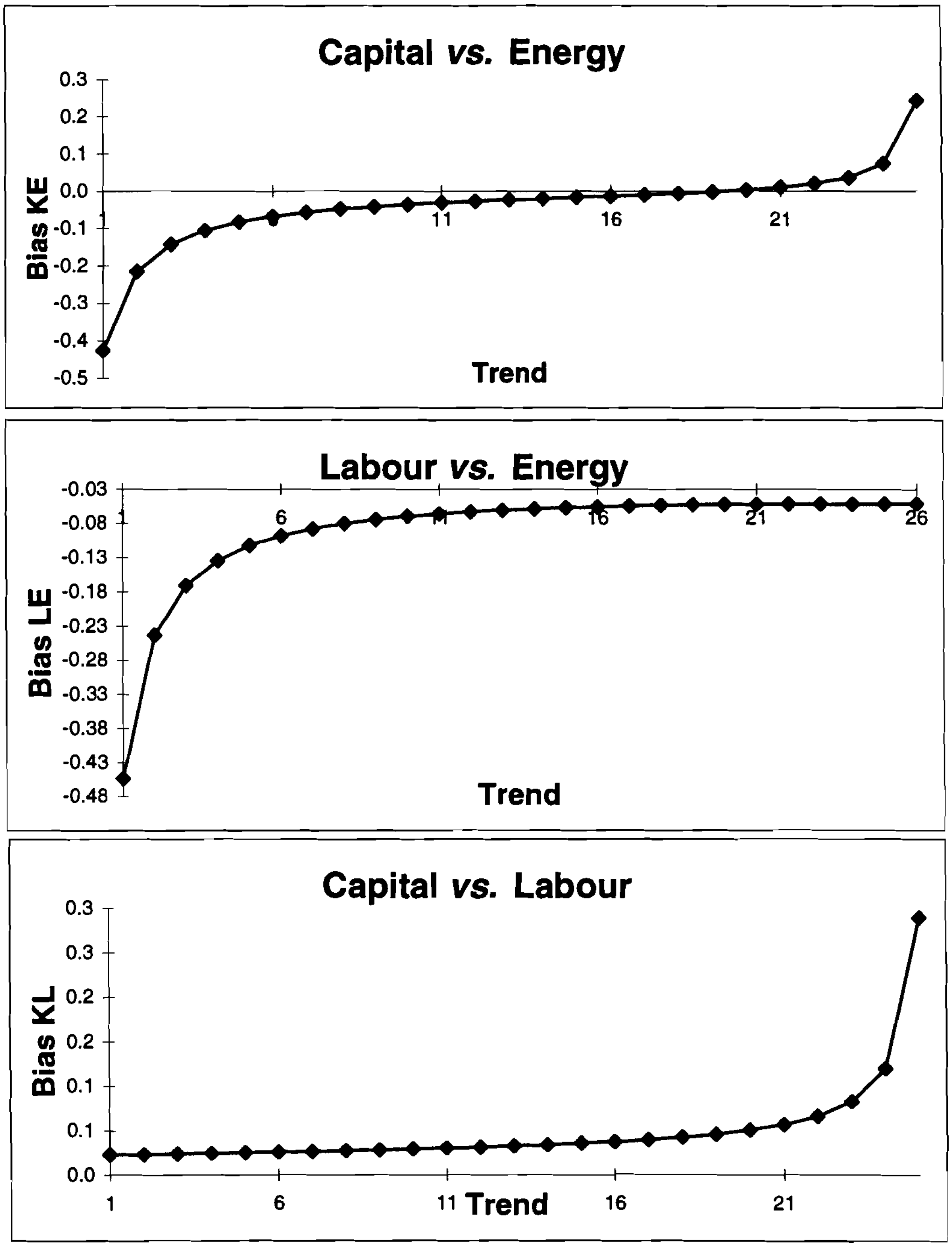
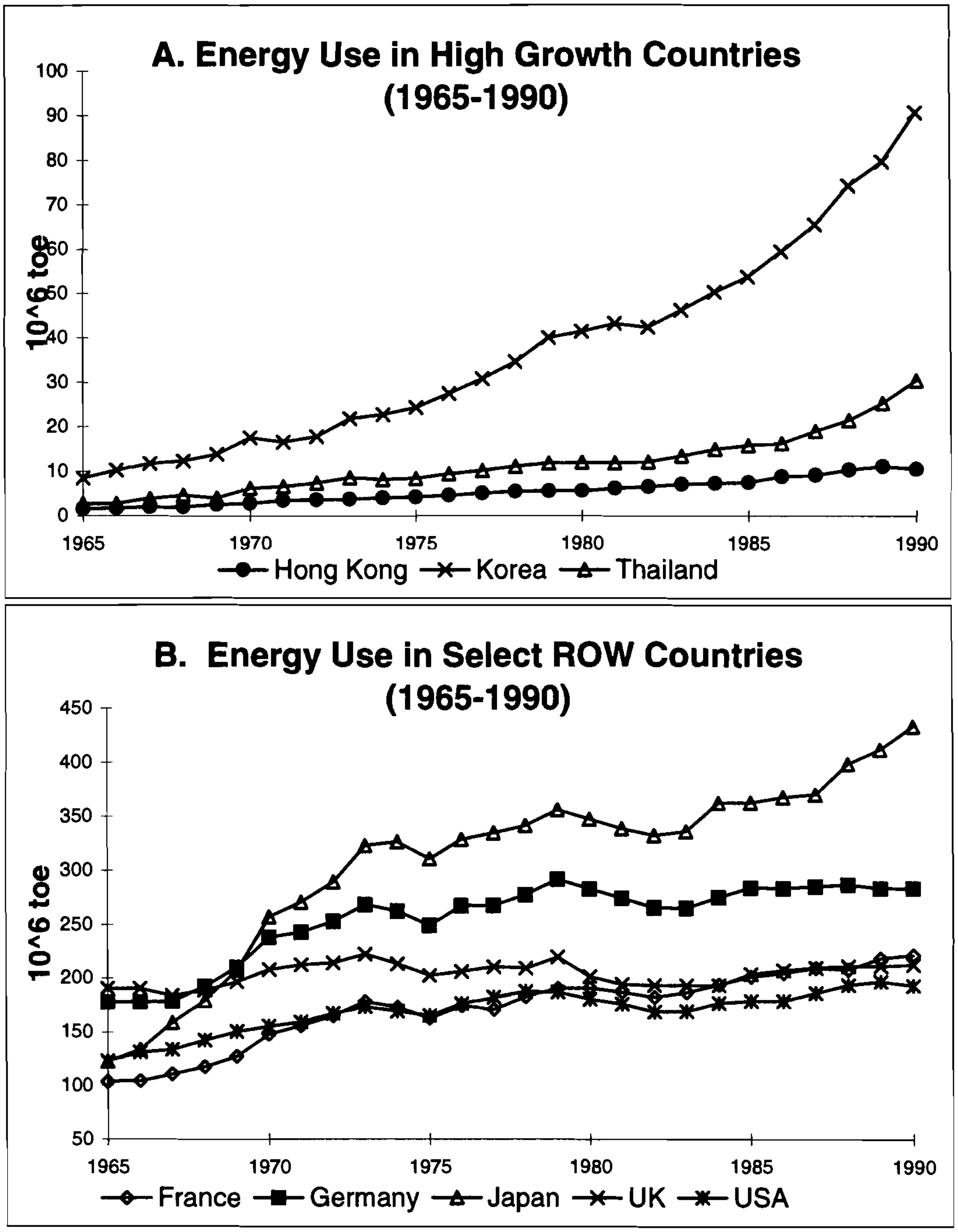


Figure 6

Bias in Technical Progress: Average High Growth Country

The divergence in results obtained for the high growth and ROW countries suggests some difference in economic structure, in addition to the obvious difference in the technology in place in the two sets of countries. Perhaps the hypothesis set out by Alexander Gerschenkron (1962, pp. 353-359) in the context of the historical development of Europe finds some support here. It is possible that the late developers (the high growth group of countries) had the advantage of a set of mature technologies available to them to import, rather than developing technologies indigenously. In addition, once we distinguish energy as significant factor of production, it seems that the late developers tend to adopt technologies that are relatively energy intensive. This, in turn, implies that these countries established the necessary institutional mechanisms to ensure a relatively secure energy supply during a period when the global economy was subject to two major oil shocks. Figure 4.7 shows energy use for the high growth countries a few ROW countries. Note that commercial energy consumption in Hong Kong, Korea and Thailand is relatively unaffected by the oil shocks of the 1970s and the 1980s.



Note: toe = tons of oil equivalent
Data for USA are in 10^7 toe

Figure 7

Energy Use in Selected Countries

What, if anything, does this mean for the relatively less developed countries in the ROW group, such as India? Very crudely, it suggests that, indeed, these countries have the opportunity for rapid growth, provided they are able to take advantage of the existing technologies, especially in the energy sector, and are able to complement this with an appropriate institutional structure. (With due respect for Gerschenkron's warnings against the use of terms such as preconditions for development, we do not imply that the shift to energy intensive technologies is a necessity for the development of the presently less developed countries. Instead, we are speculating a possible course that the development process in these countries might take.) At the same time, it is imperative to note that the neo-classical approach underlying this paper obscures the problem of unemployment which is a major economic issue for developing countries. If, as hypothesized above, these countries follow a relatively energy intensive growth path similar to that witnessed in the high growth countries, it is likely that the current unemployment problem of developing countries would get exacerbated in the future. Further research should examine the growth of the energy sector and its role in process of economic growth and development.

3. Implications for Environmental Policy

In this penultimate section, we examine some issues relating to global environmental policy. Each of these is discussed below.

3.1 *Growth Accounting*

First, we carry out a growth accounting exercise to determine the contributions of capital, labour, energy, and total factor productivity (TFP) to the growth in GDP, as set out in equation 2.[9] Table 3 shows the average results for the high growth and ROW countries over the period 1965-1990.

Table 3
Sources of Growth in GDP, 1965-1990 (% shares)

Group	**Labour**	**Capital**	**Energy**	**TFP**
High growth	21.98	19.00	26.69	29.32
ROW	8.82	24.91	27.00	39.27

Note: The table presents the average for all countries in each group. For this reason, the row sums do not necessarily add up to 100, but are close to that figure. For details on individual countries, see appendix 5.

It is apparent from the above table that energy has been a significant source of growth in real GDP in the high growth and the ROW countries. In both cases, it is second only to increases in TFP, accounting

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[9] The continuous growth rate for each variable is approximated as follows (Hulten 1992, p. 969, footnote 10):

$$\frac{\partial X}{X} \approx Ln\left(\frac{X_t}{X_{t-1}}\right)$$

The continuous production elasticity for any factor at period t, η^t, is approximated as (*ibid.*):

$$\eta^t \approx \frac{\eta^t + \eta^{t-1}}{2}$$

for almost a third of the total growth. Interestingly enough, labour has been much more important to the growth in real GDP in the high growth countries as compared to the ROW countries. This is because, on average, the former group of countries witnessed a much higher growth rate in labour force (see table 1), and also had a much higher production elasticity of labour between 1965 and 1990 (see figure 2). However, if the growth rate in labour force slows down in the future, and the declining trend in η_L is not reversed, it is likely that in future the contribution of labour might decrease significantly. Furthermore, if past trends in production elasticities and growth rates continue, energy is likely to become the most important source of growth among the factors of production being considered.

Note that our study aggregates over the differences in input quality. Christensen *et al.* (1980) have shown that analyses that do not account for the heterogeneity of capital and labour tend to assign a much higher share to the growth in TFP in explaining the growth in real GDP. It is likely that this conclusion would be corroborated if we were to take cognizance of the different forms of commercial energy input -- coal, oil, and natural gas, for instance. While these alternative energy forms are substitutable for one another to some degree, they are not perfect substitutes as our analysis implicitly assumes.

3.2 *Capital and Labour Requirements for Energy / Emissions Control*

With energy emerging as a major source of growth in real output, the recent meetings of the Conference of Parties to the United Nations

Climate Change Convention take on an added significance. These meetings have greatly emphasized the reduction of energy use, especially for large countries like USA. We examine the economic consequences of such a reduction through the following thought experiment. Suppose that each country in our sample reduces its energy consumption in 1990 by 10% in an attempt to reduce global carbon dioxide emissions. By how much would it have to increase the capital and labour inputs so as to maintain a constant real GDP? In other words, we estimate the movements along the 1990 production isoquant for capital and energy, and labour and energy, respectively. It was found that a 10% decline in energy use required a 5-15% increase in either the capital or the labour input on order to maintain the level of gross domestic product.

In addition, two intuitively appealing results emerge. First, at lower levels of GDP per capita, it is much easier to substitute labour than capital for energy. Second, as the level of GDP per capita rises, this dichotomy is eroded. These results are indicative of the change in the underlying structure of the economy that occurs with a growth in income, from a predominantly agricultural and informal sector economy to one that is dominated by the manufacturing and service sectors.

The implication for future energy/climate change policy is that countries at low levels of GDP per capita might be able to meet national emissions targets at relatively lower costs than high income countries.[10]

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[10] This conclusion is based on a partial equilibrium analysis. *Ex-post*, the economic impacts of energy/emissions control will be determined by the simultaneous change in the capital and labour inputs and productivities. The overall conclusion should, however, remain unaffected. The Intergovernmental Panel on Climate Change (1996, chapter 7)

Moreover, enhancing labour productivity through say, education, might be an effective means of arresting the escalation in abatement costs as these countries grow.

3.3 *Changes in Energy Intensity and Autonomous Energy Efficiency Improvements*

Energy intensity is a parameter that finds its way into most national or global level economic studies on climate change. It is defined as the ratio of energy use to total economic output. One of the most common ways of modeling changes in energy intensity is simply by estimating the ratio over time and extrapolating the observed trend into the future (see, for instance, Nordhaus 1994, p. 66-67). This is a purely empirical exercise with no obvious theoretical underpinnings. A production function enables us to associate a change in energy intensity with a change in factor inputs. The analytical expressions for the elasticity of energy intensity with respect to capital, labour, and energy, respectively, for the translog production are shown in equation (3) below:

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arrived at a similar conclusion: in general it is cheaper to reduce future carbon dioxide emissions in developing countries than in currently developed countries. Further research is necessary to confirm these conclusions (see Khanna and Chapman 1996, pp. 61-62).

$$
\begin{aligned}
\frac{\partial Ln(E/GDP)}{\partial Ln(K)} &= -(\alpha_K + \beta_{KL}Ln(L) + \beta_{KE}Ln(E) + 2*\beta_{KK}Ln(K) + \beta_{Kt}t) = -\eta_K \\
\frac{\partial Ln(E/GDP)}{\partial Ln(L)} &= -(\alpha_L + \beta_{KL}Ln(K) + \beta_{LE}Ln(E) + 2*\beta_{LL}Ln(L) + \beta_{Lt}t) = -\eta_L \qquad (3) \\
\frac{\partial Ln(E/GDP)}{\partial Ln(E)} &= -(\alpha_E + \beta_{KE}Ln(K) + \beta_{LE}Ln(L) + 2*\beta_{EE}Ln(E) + \beta_{Et}t) = (1-\eta_E)
\end{aligned}
$$

Note that the elasticity of energy intensity *w.r.t.* capital and labour is negative by definition. However, in the case of energy, the sign of the elasticity depends upon whether η_E is greater than or less than 1: if $\eta_E > 1$, then output increases more than proportionately with an increase in the energy input, and energy intensity declines as a consequence; otherwise the energy intensity increases.

The change in energy intensity in response to a change in factor input occurs due to substitution between the inputs as a result of a change in their relative price ratios. Another source of change in the energy to output ratio is technical progress. This is a change that occurs independent of input price changes, and is sometimes referred to as autonomous energy efficiency improvements (AEEI).[11] Using the translog production function, we can estimate AEEI as the percentage change in energy intensity over time, *ceteris paribus*, according to the following expression:

---

[11] Manne and Richels (1992) distinguish between price induced and non-price related changes in energy use. See chapter 2, pp. 32-34, and chapter 7, pp. 121-133.

$$\frac{\partial Ln(E/GDP)}{\partial t} = -(\alpha_t + 2*\alpha_{tt}t + \beta_{Kt}Ln(K) + \beta_{Lt}Ln(L) + \beta_{Et}Ln(E)) \qquad (4)$$

We estimated the AEEI for each country in our data set. The total for each country group and the sample total were estimated as a weighted average, where the weights are the country shares in sample real GDP. The results are shown in table 4. The table also shows an approximation of the rate of change in AEEI between 1987-1989 and 1988-1990. This is calculated as the weighted average of the change in national AEEIs between these years.[12]

Table 4
Autonomous Energy Efficiency Improvements

	AEEI: annual % change in energy intensity* (1988-90)	**Rate of change in AEEI* (1987-89 to 1988-90)**
High growth total	$-13.53*10^{-4}$	$4.5*10^{-5}$
ROW total	$-11.35*10^{-3}$	$-6.8*10^{-5}$
Sample total	$-12.70*10^{-3}$	$-2.3*10^{-5}$

Note: * see footnote 12 for details

---

[12] These calculations are based on the average AEEI and average GDP shares between 1988-90. For the rate of change in AEEI, we calculate the difference in the average AEEI between 1987-89 and 1988-90 for each country, and then weight it by the average GDP shares between 1988-90.

The magnitudes reported in the above table are not as important the signs of estimated changes. The table shows that while both high growth and ROW countries have been experiencing a decline in energy intensity with time, *ceteris paribus*, the rate of decline has been slowing down for the sample as a whole. The deceleration of the AEEI in the ROW countries more than offsets the combined acceleration witnessed in Hong Kong, Thailand, and Korea. Surprisingly, this empirical evidence is not reflected in many influential energy models. For instance, in their Global 2100 model, Manne and Richels assume a uniform AEEI of 0.5% per year throughout the world from the second half of the 21st century onwards (Manne and Richels 1992, p. 34).

Ex post, the decline in energy intensity is the result of the combined effect of the change in relative factor price ratios and technical progress. An extrapolation of the historically observed trend may yield inaccurate forecasts as it does not explicitly recognize the underlying interactions. Furthermore, future world energy intensity depends not only on the energy intensity of individual countries, but also on their shares in world GDP. If the countries with rapidly increasing energy to GDP ratios also witness a rapid increase in their share of world economic product, it is possible that the observed trend in global energy intensity might be reversed.

4. Conclusions

This paper extends the growth accounting literature to include energy as a third factor of production, in addition to capital and labour. A homogenous translog production function with biased technical change was estimated using pooled data for 38 countries from 1965-1990. Countries were classified as either high growth or ROW countries, and the estimated coefficients were allowed to vary by country group.

We found that the estimated coefficients are statistically different between the two groups indicating that countries do not operate on the same production model. In addition, other parameters of policy interest: production elasticities, returns to scale and the bias is technical progress also differ significantly: not only are the magnitudes very different, but more importantly, opposite trends over time are observed.

The paper also explores some policy issue relating to future energy/environmental policy. The estimated production elasticities were used in a growth accounting exercise. This revealed the growth in energy use to be a major source of the growth in real GDP, with the percentage share of energy in total GDP growth higher than that for capital in both country groups. Increases in total factor productivity had the highest percentage share in both high growth and ROW countries.

We also estimated the capital and labour requirements of potential environmental regulations by estimating movements along the 1990 production isoquants for capital and energy, and labour and energy. We found that the substitutability between the factors of production changes with the level of per capita GDP.

Changes in energy intensity were estimated for each country in the data set using a production function approach. The observed change in energy intensity was separated into two components: one part due to changes in relative factor prices, and a second part due to technical change. Forecasts of energy intensity need to take to take account of both components. It was found that while the global energy intensity has indeed been declining, the rate of decline has been slowing down. While this result is also obtained if the ratio of energy use to GDP is simply estimated over time, we are able to provide a theoretical grounding for the observed trend.

Appendix 1

Data and Data Sources

Our sample consists of data on real GDP, capital stock, labour force, and commercial energy consumption from 1965-1990 for 38 countries. Data on real GDP and capital stock were obtained from the Penn World Tables (version 5.6) which are available on-line at the National Bureau of Economic Research anonymous ftp server: ftp://nber.harvard.edu//pub/pwt56/. All monetary units are in 1985 international prices (see Summers and Heston 1991 for details). Labour force data were calculated by the authors using the series on real GDP per worker, real GDP per capita, and population from the same source. Commercial energy consumption data were obtained from World Bank (1995) for the years 1970/71 to 1990. For 1965 to 1970/71 these data were obtained from United Nations (1976). Note that the our energy consumption data excludes all forms of non-commercial energy, such as firewood collected by households.

The countries in our sample are divided into two groups. The high growth group comprises countries with an annual average growth rate o real GDP greater than 7% per year between 1965 and 1990. All other countries are in the rest of the world group. A complete list of countries included in the analysis is available in appendix 4.4.

Appendix 2

Model and Econometric Details

A. *Estimating Equation*

$$\begin{aligned} Ln(GDP) = {} & country\ dummies + \alpha_t^i t + \alpha_{tt}^i t^2 + \\ & \alpha_K^i Ln(K) + \alpha_L^i Ln(L) + \alpha_E^i Ln(E) + \\ & \beta_{KL}^i Ln(K) Ln(L) + \beta_{KE}^i Ln(K) Ln(E) + \beta_{LE}^i Ln(L) Ln(E) + \\ & \beta_{KK}^i (LnK)^2 + \beta_{LL}^i (LnL)^2 + \beta_{EE}^i (LnE)^2 + \\ & \beta_{Kt}^i Ln(K) t + \beta_{Lt}^i Ln(L) t + \beta_{Et}^i Ln(E) t \end{aligned} \tag{1}$$

where *i* refers to the country group; *GDP* refers to the gross domestic product; *K*, *L*, and *E* refer to capital, labour, and energy inputs, respectively, and *t* refers to the time trend.

B. *Production and Substitution Elasticities, and Returns to Scale*

$$\begin{gathered} \eta_K^i = \alpha_K^i + \beta_{KL}^i Ln(L) + \beta_{KE}^i Ln(E) + 2\beta_{KK}^i Ln(K) + \beta_{Kt}^i t > 0 \\ \sigma_{KE}^i = \frac{\eta_K^i + \eta_E^i}{\eta_K^i + \eta_E^i + 2\beta_{KE}^i - 2\beta_{KK}^i \frac{\eta_E^i}{\eta_K^i} - 2\beta_{EE}^i \frac{\eta_K^i}{\eta_E^i}} > 0 \\ RTS^i = \eta_K^i + \eta_L^i + \eta_E^i > 0 \end{gathered} \tag{2}$$

where η_K and η_E are the production elasticities for capital, labour, and energy, respectively; σ_{KL} is the elasticity of substitution between capital and energy; and *RTS* refers to the returns to scale or degree of homogeneity. Analogous expressions for η_L, η_E, σ_{KL} and σ_{LE} can be obtained easily. For a complete derivation, see Boisvert (1982). Note that since the production elasticities are a function of time, so is the degree of homogeneity (also called scale elasticity). Therefore, while the production function may be homogenous of degree r in a any given time period, the degree of homogeneity may change over time.

C. *Bias in Technical Change*

Following Hicks, the bias in technical change between two factors, say capital and energy, is defined as the proportional change in the marginal rate of technical substitution between these two factors over time, as shown in the equation below (Ferguson 1979, p. 225):

$$Bias_{KE}^{i} = \frac{\frac{\partial}{\partial t}\left(\frac{F_K^i}{F_E^i}\right)}{\frac{F_K^i}{F_E^i}} \begin{matrix} > \\ = \\ < \end{matrix} 0 \tag{3}$$

where F_K and F_E are the marginal productivities of capital and energy, respectively,

$$\begin{aligned} F_K &= \eta_K\left(\frac{GDP}{K}\right) \\ F_L &= \eta_L\left(\frac{GDP}{L}\right) \end{aligned} \tag{4}$$

Then, the marginal rate of technical substitution (MRTS) is:

$$\frac{F_K}{F_L} = \frac{L}{K}\left(\frac{\beta_K + \beta_{KL}Ln(L) + \beta_{KE}Ln(E) + 2\beta_{KK}Ln(K) + \beta_{Kt}t}{\beta_L + \beta_{KL}Ln(K) + \beta_{LE}Ln(E) + 2\beta_{LL}Ln(L) + \beta_{Lt}t}\right) \tag{5}$$

The change in MRTS with time is defined by the derivative *w.r.t.* t:

$$\begin{aligned}\frac{\partial}{\partial t}\left(\frac{F_K}{F_L}\right) = {} & \frac{L}{K}[\beta_{Kt}(\beta_L + \beta_{KL}Ln(L) + \beta_{LE}Ln(E) + 2\beta_{LL}Ln(L) + \beta_{Lt}t)^{-1}] - \\ & \frac{L}{K}[\beta_{Lt}(\beta_K + \beta_{KL}Ln(L) + \beta_{KE}Ln(E) + 2\beta_{KK}Ln(K) + \beta_{Kt}t) * \\ & (\beta_L + \beta_{KL}Ln(K) + \beta_{LE}Ln(E) + 2\beta_{LL}Ln(L) + \beta_{Lt}t)^{-2}]\end{aligned} \tag{6}$$

Dividing equation (5) by equation (6), and after a few algebraic manipulations, $Bias_{KE}$ works out to the following expression:

$$\begin{aligned}& Bias^i_{KE} = \frac{\beta^i_{Kt}}{\eta^i_K} - \frac{\beta^i_{Et}}{\eta^i_E} \\ & where \quad \beta^i_{Kt} = \frac{\partial\eta^i_K}{\partial t} \quad ; \quad \beta^i_{Et} = \frac{\partial\eta^i_E}{\partial t}\end{aligned} \tag{7}$$

Thus, the direction of the bias in technical progress between capital and energy is determined by the relative magnitudes, and signs of the proportional change in the production elasticities of these two factors over time. Analogous expressions for $Bias_{KL}$ and $Bias_{LE}$ can be obtained.

D. *Hypotheses Tests*

D.1 Homogenous Production Function

Under the null hypothesis of a homogenous production function, the rows and columns of the matrix of the second order derivatives of equation (1) must sum to zero (Boisvert 1982, p. 11). Given the assumed symmetry of the production function, the following set of restrictions must hold simultaneously for each region, *i*:

$$\begin{aligned} \beta^i_{KK} + \beta^i_{KL} + \beta^i_{KE} &= 0 \\ \beta^i_{KL} + \beta^i_{LL} + \beta^i_{LE} &= 0 \\ \beta^i_{KE} + \beta^i_{LE} + \beta^i_{EE} &= 0 \end{aligned} \qquad \textbf{(8)}$$

D.2 Cobb-Douglas Production Function

In the case of a homogenous translog production function the individual production elasticities vary with the level of factor use, but their sum remains constant. The Cobb-Douglas production function is a special case of a homogenous translog function where the individual production elasticities are independent of input levels. The translog function collapses to the Cobb-Douglas form if, in addition to the restrictions shown in the equation above, the estimated coefficients on all the cross-product terms are simultaneously zero. That is, in addition to the restrictions under the homogeneity hypothesis, the following must hold:

$$\beta^i_{KL} = \beta^i_{KE} = \beta^i_{LE} = 0 \qquad \textbf{(9)}$$

D.3 Hicks Neutral Technical Change

For each region, *i*:

$$\beta^i_{Kt} = \beta^i_{Lt} = \beta^i_{Et} = 0 \qquad \textbf{(10)}$$

D.4 Single Production Function

Under this null hypothesis, all the estimated coefficients are statistically identical across all regions in the model.

Table A.1
Estimated Parameters for the Homogenous Translog Production Function

Variable	Country group	Estimated coefficient	Std. error	t-ratio
Trend	High growth	0.021	0.061	0.341
	ROW	0.027	0.005	5.396
Trend^2	High growth	-0.0001	0.0001	-0.086
	ROW	-0.0001	0.0009	-0.874
Ln(K)	High growth	0.918	0.868	1.059
	ROW	0.034	0.053	0.637
Ln(L)	High growth	0.617	0.465	1.326
	ROW	0.166	0.068	2.457
Ln(E)	High growth	-0.055	0.099	-0.548
	ROW	0.208	0.029	7.199
Ln(K)Ln(L)	High growth	0.109	0.159	0.682
	ROW	-0.006	0.012	-0.540
Ln(K)Ln(E)	High growth	0.038	0.110	0.343
	ROW	-0.023	0.016	-1.427
Ln(L)Ln(E)	High growth	-0.102	0.088	-1.156
	ROW	0.003	0.013	0.238
(LnK)^2	High growth	-0.146	0.191	-0.767
	ROW	0.029	0.011	2.792
(LnL)^2	High growth	-0.007	0.173	-0.041
	ROW	0.003	0.022	0.139
(LnE)^2	High growth	0.064	0.063	1.007
	ROW	0.020	0.007	2.976
t Ln(K)	High growth	0.002	0.022	0.105
	ROW	-0.002	0.002	-1.056
t Ln(L)	High growth	-0.012	0.007	-1.850
	ROW	0.003	0.001	4.810
t Ln(E)	High growth	0.010	0.010	1.010
	ROW	-0.003	0.001	-2.559

Sum of squares of errors = 1.197; $R^2 = 0.99$; DW statistic = 1.86

Appendix 3

Non-linear Technical Change

Modeling technical progress as a time trend can produce empirical results that are inconsistent with economic theory. In this appendix we explore another possible way modeling technical change that might avoid some of these problems. Let technical progress in each country group be a logistic function of time, $A^i(t)$:

$$A^i(t) = \frac{e^{\gamma^i + \delta^i t}}{1 + e^{\gamma^i + \delta^i t}} \tag{1}$$

where δ^i determines the curvature of the logistic function, and γ^i determines which part of the curve the country group is operating on.

By construction, the logistic curve lies in the (0, +1) range. We can estimate a coefficient, μ^i, a scale parameter that expands or shrinks the curve beyond the (0, +1) range. So long as the estimated μ^i is positive, $A^i(t)$ will *always* be asymptotic to the x-axis at the lower end, and μ^i at the upper end, regardless of how far into time we extrapolate the estimated curve. If the estimated μ^i is negative, then the entire curve will lie below the x-axis. Negative values for μ^i can be rejected, *a priori,* since they imply that technical change has a negative impact on output in all cases.

We tried to estimate the parameters in equation (1) and also μ^i for both country groups, in the context of a translog production function. Despite several attempts using various starting values, convergence criteria, and search methods, however, we were unable to obtain convergence.

Appendix 4
Estimated Production Elasticities, 1965 and 1990

	Labour		**Capital**		**Energy**	
	1965	**1990**	**1965**	**1990**	**1965**	**1990**
High Growth						
Hongkong	0.825	0.461	0.261	0.082	0.046	0.516
Korea	0.684	0.428	0.365	-0.227	0.110	0.704
Thailand	0.756	0.447	0.464	0.017	-0.088	0.483
Rest of the World						
Argentina	0.168	0.246	0.176	0.176	0.245	0.178
Australia	0.162	0.241	0.207	0.211	0.248	0.188
Austria	0.165	0.238	0.157	0.193	0.236	0.156
Belgium	0.163	0.240	0.182	0.189	0.250	0.178
Canada	0.166	0.243	0.204	0.225	0.279	0.208
Colombia	0.163	0.243	0.192	0.195	0.201	0.149
Denmark	0.161	0.237	0.170	0.186	0.232	0.148
DR	0.164	0.242	0.085	0.119	0.157	0.112
Ecuador	0.158	0.238	0.170	0.175	0.142	0.118
Finland	0.159	0.237	0.188	0.188	0.210	0.161
France	0.168	0.244	0.231	0.248	0.272	0.202
Germany	0.169	0.243	0.244	0.271	0.284	0.201
Greece	0.163	0.240	0.171	0.177	0.198	0.157
Honduras	0.159	0.241	0.105	0.098	0.133	0.095
India	0.183	0.262	0.203	0.215	0.266	0.211
Ireland	0.162	0.238	0.117	0.134	0.218	0.152
Italy	0.167	0.244	0.242	0.243	0.252	0.193
Japan	0.174	0.246	0.234	0.292	0.277	0.207
Kenya	0.168	0.253	0.118	0.094	0.166	0.125
Malawi	0.176	0.252	-0.014	0.036	0.152	0.082
Mexico	0.168	0.249	0.201	0.207	0.237	0.198
Netherlands	0.163	0.241	0.191	0.195	0.247	0.185
New Zealand	0.156	0.236	0.169	0.158	0.197	0.150
Norway	0.154	0.235	0.215	0.189	0.201	0.152
Panama	0.156	0.234	0.113	0.139	0.151	0.082
Philippines	0.168	0.251	0.182	0.165	0.196	0.158
Portugal	0.166	0.243	0.143	0.151	0.199	0.159
Spain	0.168	0.243	0.194	0.222	0.239	0.183
Sri Lanka	0.160	0.238	0.190	0.206	0.140	0.066
Sweden	0.162	0.239	0.186	0.197	0.244	0.174
Switzerland	0.156	0.233	0.231	0.234	0.201	0.138
Turkey	0.170	0.250	0.179	0.187	0.211	0.182
UK	0.172	0.248	0.207	0.223	0.301	0.211
USA	0.174	0.251	0.266	0.278	0.336	0.259
Zimbabwe	0.161	0.246	0.153	0.118	0.176	0.132

Appendix 5
Contribution to Growth: Country Averages (1965-1990)

		Labour	Capital	Energy	TFP
Rest of the World	Argentina	6.67	25.27	21.23	46.83
	Australia	13.73	30.27	23.54	32.46
	Austria	5.78	30.45	25.03	38.74
	Belgium	4.38	25.45	29.75	40.42
	Canada	13.08	34.13	27.39	25.39
	Colombia	12.55	24.30	21.77	41.39
	Denmark	6.10	22.75	28.23	42.91
	DR	13.00	26.01	36.96	24.03
	Ecuador	11.77	12.40	26.88	48.96
	Finland	4.53	24.22	35.59	35.65
	France	5.81	34.49	29.63	30.07
	Germany	4.96	39.67	25.29	30.08
	Greece	3.96	21.62	32.92	41.51
	Honduras	14.27	13.59	19.07	53.07
	India	9.33	24.59	24.60	41.48
	Ireland	5.55	21.91	24.86	47.68
	Italy	3.95	31.12	30.00	34.93
	Japan	4.33	46.96	26.27	22.43
	Kenya	18.64	7.27	19.56	54.53
	Malawi	11.10	5.88	17.05	65.97
	Mexico	13.30	25.18	34.36	27.16
	Netherlands	8.79	25.19	33.94	32.09
	New Zealand	10.22	20.19	28.10	41.49
	Norway	11.35	20.17	25.84	42.64
	Panama	11.09	22.29	22.69	43.92
	Philippines	10.74	17.52	28.07	43.66
	Portugal	7.69	20.87	24.67	46.78
	Spain	4.48	34.88	27.45	33.20
	Sri Lanka	8.24	23.15	18.01	50.60
	Sweden	5.08	23.22	37.09	34.61
	Switzerland	5.70	30.96	26.85	36.49
	Turkey	9.20	24.44	30.32	36.04
	UK	4.16	33.62	23.70	38.53
	USA	11.38	39.00	30.57	19.04
	Zimbabwe	13.89	8.72	27.54	49.85
High Growth	Hongkong	23.15	11.92	25.68	39.25
	S. Korea	18.03	23.09	31.08	27.79
	Thailand	24.76	22.00	32.31	20.93

Note: The average for each country was calculated using only those years for which the growth rates and estimated production elasticities were positive. Also, for most countries, the oil shock years witnessed a decline in energy use. These were excluded since this yields a negative contribution to growth in GDP.

References

Abramovitz M. 1956. Resource and Output Trends in the United States Since 1870. *American Economic Review.* 46(2): 5-23. May.

Berndt E.R. and D.O. Wood. 1975. Technology, Prices, and the Derived Demand for Energy. *Review of Economics and Statistics.* 57(3): 259-268. August.

Berndt E.R., Kolstad C., and J.K. Lee. 1993. Measuring the Energy Efficiency and Productivity Impacts of Embodied Technical Change. *Energy Journal.* 14(1): 33-55. David Wood Memorial Issue.

Boisvert R.N. 1982. The Translog Production Function: Its Properties, Its Several Interpretations And Estimation Problems. A.E.Res 82-28. Dept. of Agricultural Economics, Cornell University, Ithaca, NY. September.

Chapman D. 1991. Environmental Standards an International Trade in Automobiles and Copper: The Case for a Social Tariff. *Natural Resources Journal.* 31: 449-461. Winter.

Christensen L.R., Cummings D., and D.W. Jorgenson. 1980. Economic Growth, 1947-1973: An International Comparison. In Kendrick J.W. and B. Vaccara (eds.), *New Developments in Productivity Measurement and Analysis*. Studies in Income and Wealth, Vol. 41. Chicago University Press, Chicago: 595-698

Cushman J.H., Jr. 1997. President Plans Energy Savings In a Moderate Step on Warming. *New York Times.* October 23.

Denison E.F. 1967. *Why Growth Rates Differ.* The Brookings Institution. Washington DC.

Ferguson C.E. 1979. *The Neoclassical Theory of Production and Distribution.* Cambridge University Press, London, England.

Gerschenkron A. 1962. *Economic Backwardness in Historical Perspective.* Harvard University Press, Cambridge, MA. As reprinted in Meier (ed.). 1984. Leading Issues in Economic Development. Oxford University Press, New York and Oxford. 4th edition, pp. 101-104.

Griliches Z. and D.W. Jorgenson. 1966. Sources of Measured Productivity Change: Capital Input. *American Economic Review.* 56(2): 50-61. May.

Hudson E.A. and D.W. Jorgenson. 1974. US Economic Policy and Economic Growth, 1975-2000. *Bell Journal of Economics and Management.* 5(2): 461-514. Autumn.

Hulten C.R. 1992. Growth Accounting When Technical Change Is Embodied in Capital. *American Economic Review.* 82(4):964-980. September.

Intergovernmental Panel on Climate Change. 1996. *Climate Change 1995: Economic and Social Dimensions of Climate Change.* Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jorgenson D.W. 1995. *Productivity.* Volumes 1 and 2. The M.I.T. Press, Cambridge, MA, and London, England.

_____, and Z. Griliches. 1967. The Explanation of Productivity Change. *Review of Economic Studies.* 34: 349-83. July.

Kendrick J.W. 1961. *Productivity Trends in the United States.* Princeton University Press, Princeton.

Khanna N. and D. Chapman. 1996. Time Preference, Abatement Costs, and International Climate Policy: An Appraisal of IPCC 1995. *Contemporary Economic Policy.* 14: 56-66. April.

Kim J.-I. and L.J. Lau. 1994. The Sources of Economic Growth of the East Asian Newly Industrialized Countries. *Journal of the Japanese and International Economies.* 8: 235-271.

Kuznets S. 1971. *Economic Growth of Nations: Total Output and Production Structure.* The Belknap Press of Harvard University Press, Cambridge, MA.

Manne A.S. and R.G. Richels. 1992. *Buying Greenhouse Insurance: The Economic Costs of* CO_2 *Emission Limits.* M.I.T. Press, Cambridge, MA, and London, England.

Nordhaus W.D. 1994. *Managing the Global Commons: The Economics of Climate Change.* M.I.T. Press, Cambridge, MA and London, England.

Solow R.M. 1957. Technical Change and the Aggregate Production Function. *Review of Economics and Statistics.* 39(3): 312-320. August.

Summers R. and A. Heston. 1991. The Penn World Tables (Mark 5): An Expanded Set of International Comparisons, 1950-1988. *Quarterly Journal of Economics.* 327-368. May.

Suri V. and D. Chapman. 1996. Economic Growth, Trade and the Environment: An Econometric Evaluation of the Environmental Kuznets Curve. Working Paper WP 96-05. Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, NY. April.

United Nations. 1976. *World Energy Supplies, 1950-1974.* Statistical Papers, series J, number 19. Department of Economic and Social Affairs, Statistical Office. New York.

World Bank. 1995. *World*Data 1995: Socio-economic Time-series Access and Retrieval System (STARS), version 3.0.*

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