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TECHNOLOGICAL CHANGE AND CONTRIBUTION TO GROWTH AND CONVERGENCE

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This paper incorporates data on efficiency and output per worker for 1965 and 1990 for 57 countries divided into four groups to seek an understanding of similarities and differences among them. Tools employed were testing for equality of means and testing for convergence. The findings indicate that the gaps between the groups were widened during the period studied for both efficiency and output per worker. While divergence was observed when all countries were grouped in one set, there were indications of convergence when the groups were treated separately.

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1. INTRODUCTION

According to Petrakos and Saratsis (2000), the problem of unequal spatial distribution of income, technology, economic growth, economic opportunities and the like are important theoretical and practical issues. Many articles have been and continue to be written regarding the inequalities. On a parallel level, many articles deal with the question of convergence or divergence between and within countries. According to Rupasingha, Goetz and Freshwater (2002), the convergence concept relates to the decline in cross-sectional dispersion. Poorer co countries, according to the neoclassical growth model, tend to grow faster than do richer countries, ultimately catching up. They point out that some researchers have begun to focus on a concept of convergence known as conditional convergence, which is dependent on factors such as property rights, trade barriers, transaction costs, ineffective government policies, income inequality and cultural differences.

Mbaku and Kimenyi (1997) and Graff (1999) go further by examining democracy

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and political freedom as engines for growth and convergence. Staab (2003) goes even deeper by constructing a business-friendly index that measured the degree of government openness and helpfulness toward the private sector. Demographic influences on economic growth and convergence receive attention from Barlow (1998), who investigated the effect of population on the growth of output, with the finding that higher fertility in some 85 countries studied tended to lower output in the short term, but tended to raise it in the long run. Yet another example of convergence studies is provided by Liu and Yoon (2000), who dealt with the question of productivity differentials in China, especially between the coastal East and the interior West. By examining patterns of changes in total factor productivity differentials for the period 1986-1991 across regions of China, Liu and Yoon came to the conclusion of regional convergence. This study by Liu and Yoon is of importance because it provides an assessment of the decentralization of governmental policies pursued as part of the reform of the Chinese economy. The decentralization of economic control policies pursued in China, can, perhaps, serve as a model for other countries.

Ferguson, Jr. and Wascher (2004), dealing with productivity in the United States, claim that the annual productivity rate over the period 1995-2003 was about 3 percent, which is much higher than the rate of 1.5 percent between 1973 and 1995. At the 3 percent level, the standard of living in the United States would roughly double every 24 years, a feat that would take 47 years at 1.5 percent. Ferguson and Wascher credit productivity booms to technological innovations, ability of owners and corporate managers to re-engineer the organization of their firms, innovations by the financial sector and a skilled and flexible workforce.

Keller (2004) tackles the question of international technology diffusion, considered an important factor for economic growth. It is especially so for small and relatively poor nations because of the relatively small size of their domestic R&D investments. For such countries, Keller prescribes learning-by-importing and learning-by-exporting, though Keller doubts that diffusion of technology is of great importance. Keller also credits foreign direct investment (FDI) as a means of diffusion. He admits the possibility of spillover, though he does not believe it occurs everywhere to the same degree. Globalization is a third plausible engine for the transfer of technology. Again, Keller questions this effect by stating that technology is not global. Diffusion of technology, at best, follows a geographic pattern. Changes in the pattern of such diffusion may be the mechanisms of growth, especially in analyses that include rich and poor countries.

Other kinds of spillovers are envisioned by Lee (2005), who investigated the extent an individual country - through R&D - can influence the productivity of other countries. The increase in productivity is considered by Lee an important determinant in the processes of per capita convergence and globalization. Lee analyzed direct spillover effects on R&D through channels such as physical communication networks, knowledge and information as well as the indirect spillover effects through trade. The results for direct effect appeared to be significant when comparing the G7 countries with non-G7 countries, while the indirect effects were not. Lee, therefore, recommends consideration of direct spillover

effects in studies of growth and convergence across countries. Das (2002), however, finds some basis, through simulation, for indirect spillover effects through trade between the United States and other countries, especially the European Union countries.

Narayan and Smyth (2004), in their study of temporal causality between human capital and real income in China, find, in the long run, a unidirectional causality running from human capital to income. In the short run, however, the direction is reversed - causality runs from real income to human capital. In other words, conceptually, causality could run in either direction. Education increases human capital, which contributes to growth. Also, economic growth spawns resources needed for investment in human capital.

Kumar and Russell (2002), recognizing the potential welfare gains from fast economic growth, point out that the recent empirical literature is flavored with international perspective. The question is whether there is a tendency for growth rates or growth paths of the world's economies to converge culminating in the narrowing of gaps between the rich and the poor. Kumar and Russell outline the controversy generated in understanding these issues. For this, they trace the development of theories starting with Solow (1956). Solow's theory emphasizing technological progress was followed by the endogenous growth theory advocated by Romer (1986) and Lucas, Jr. (1988). Their theories include physical and human capital as important elements of growth leading to convergence. Then there is the exogenous growth theory, which emphasizes the accumulation of capital as the source of conditional convergence. Bernard and Jones (1996) come on board on the side of technology as the source of convergence.

Quah (1996) asks the question whether labor productivities and per capita income of poorer countries are catching up with richer countries or whether countries converge within clubs with the conclusion of a little cross-country convergence. The features, instead, are persistence, immobility, and polarization exemplified by convergence clubs dynamics. Quah (1997) amplified his discussion regarding convergence clubs, emphasizing that the index set of economies constituting the clubs must be taken as fixed throughout the discussion and that the economies included in a club comprise a single coalition.

Moreno and Trehan (1997) spell out three ways to combine countries into clubs. The first is by geographic location in that a country's long-term growth is tied to countries that are close by. Fast growing countries and slow growing countries cluster together as, for instance, East Asia on one end and Sub-Saharan Africa on the other end. The second way to combine countries is by income levels, since countries with similar income tend to cluster together. Here, for instance, countries with the highest income are all in Western Europe and those with the lowest incomes are in Africa. The third way suggested to combine countries is by the size of nearby markets. Moreno and Trehan show that being close to large markets makes a difference for growth. Examples are Canada, a neighbor of the United States, and Hong Kong, a neighbor of China.

The interest in dividing the countries according to income has support from Arifovic, Bullard and Duffy (1997). They state that in recent years there are persistent and large differences in per capita income across economies, although the poor and the rich grew at about the same rates and thus the disparity remained constant between 1965 and 1985.

One reasoning is the existence of multiple steady states in output per worker.

For this reason, according to Arifovic, Bullard and Duffy, models for multiple steady states of growth rate of output per capita were built. Low-growth steady states, described as poverty traps, characterize pre-industrial or developing countries, which co-exist with high-growth steady states, which characterize industrialized or highly developed countries. Such models, however, cannot explain how to emerge out of the poverty trap where examples of successes to avoid the trap are plenteous. On this line of thought, Cozzi (1997) provides alternative growth trajectories whereby the introduction of new product varieties follow various trajectories based on rational profit maximization to yield the highest return.

Barro (2000), in his study of inequality and growth for a large number of countries, also bases the analysis on levels of income, concluding that inequality retards growth in poor countries while it encourages it in rich countries. On a similar note, Azariadis (1996) also bases his countries' study on levels of income in the sense that the levels accrue according to identical earning potential.

Kumar and Russell, using data on 57 countries at various levels of economic development for 1965 and 1990, calculated for each period an efficiency index and output per worker. They explain that through a mathematical programming technique, the resulting index, which measures technical catch-up, is interpreted as the ratio of actual to potential output. It is the distance of the actual output from the best practice production frontier. Three macroeconomic variables are imbedded; one is aggregate output and the other two are aggregate inputs - labor and capital. Kumar and Russell then carried out calculations for labor productivity to find the improvements in productivity over the period 1965-1990.

The purpose of this paper is to look deeper into the results provided by Kumar and Russell by disaggregating their data for the 57 countries on the efficiency index and labor productivity into four segments. Each of these is concerned with a particular set of countries (club) categorized as low income, low-middle income, high-middle income and high income, identified by coding the economies in the tables by respective numbers 1, 2, 3 and 4. The dividing line for partitioning the economies into the suggested four groups was made by consulting World Bank (2002) and Human Development Report (UNDP 2002). The motivation for segmentation by income levels is spelled out earlier in this introductory section. The analysis pursued takes on two aspects. The first is testing for equality of means and the second is to propose a measure of convergence for the four groups of countries as well as all the countries. The next section provides the statistical methodology, followed by an empirical results section. The final section is conclusions.

2. STATISTICAL METHODOLOGY

The methodology followed in this research is based on a random effects model analysis of variance to test equality of income and contribution to dispersion between

and within the groups of countries, and regression methodology to test for convergence between 1965 and 1990. One-way analysis of variance is a tool to test equality of means of the four groups. A useful characteristic of analysis of variance, according to Rohatgi (1984), is the partitioning of total sum of squared deviations into a portion due to between groups and a portion due to within groups given by the identity

$$SST = SSB + SSW, \tag{1}$$

where SST is total variation, SSB is variation between the groups and SSW is the variation within the groups. Such a partitioning indicates the relative importance of variation across groups of countries as compared with variation within the various groups. This approach will be utilized for the efficiency index as well as for output per worker for the two periods 1965 and 1990.

To deal with the question of convergence, the scheme adopted is regressing each country's data for the efficiency index and output per worker supplied by Kumar and Russell for 1990 on 1965. The resulting equation is

$$Y' = \overline{Y} + b(X - \overline{X}), \tag{2}$$

where Y' is the expected or predicted value obtained from the regression line for a country's efficiency index or output per worker, $\overline{Y}$ is the mean of 1990, X is the observed value in 1965 and $\overline{X}$ is the mean for 1965. When $b > 1.00$, divergence takes place because countries with index values or output per worker above or below the mean in 1965 diverge further from the mean in 1990 when multiplied by a number greater than 1.00.

Note that in Equation (2) Y' is an estimation of a conditional mean

$$\mu(Y|X) = \mu_Y + \beta(X - \mu_X), \tag{3}$$

where

$$\beta = \rho(\sigma_Y / \sigma_X), \tag{4}$$

and where ρ, σ_Y, and σ_X are the correlation coefficient between Y and X, and the standard deviations of Y and X, respectively. β and μ_X in Equation (3) are estimated by b and $\overline{X}$, respectively, in Equation (2).

The conditional variance according to Larson (1982) is

$$\sigma^2(Y|X) = \sigma_Y^2(1 - \rho^2), \tag{5}$$

estimated according to Kleinbaum *et al*. (1988) by

$$S^2(Y|X) = S_Y^2(1-r^2), \tag{6}$$

where r^2 is the sample estimator of the squared correlation coefficient ρ^2 in Equation (5).

A further use of this model is to observe the difference between 1990 designated by Y and 1965 designated by X by adding and subtracting Y' as follows

$$\begin{aligned} Y - X &= Y - X + Y' - Y' \\ &= (Y' - X) + (Y - Y'), \end{aligned} \tag{7}$$

where the first term of Equation (7) depicts the temporal difference in a country's score because of worldwide influences as observed from the sample of 57 countries. The second part of Equation (7) is the residual between an actual observation in 1990 and the prediction from the regression, which is interpreted in this model as a country's differential effect. Differential effects from a statistical standpoint might be considered outliers, but in the current application, according to Quah (1997), they denote extraordinary better or extraordinary worse relative to others in the sample. When a differential effect is positive, the indication is that a country's score improved relative to its previous score. The opposite is true when negative. Statistical significance is obtained, according to Congdon and Shepherd (1988), through a test

$$t = \frac{Y - Y'}{S_Y(1-r^2)^{1/2}}, \tag{8}$$

where $S_Y(1-r^2)^{1/2}$ is the sample estimator of the standard error of Equation (6). The regression scheme described above was applied in a variety of studies such as Creedy (1985), Kwoka (1982), Stonebraker (1979) and, in particular, Congdon and Shepherd (1988) who provided the theoretical basis for use in convergence analysis. Larson (1982) has indicated that the scheme followed here is best used when regressing matched data in a later period on a former period.

3. RESULTS

Table 1, reproduced from Kumar and Russell, constitutes the data on which this research is based. The first column, denoted "code," is identification of a country in the four levels of income: (1) low income, (2) lower-middle income, (3) upper-middle income, and (4) high income. The second two columns display the efficiency index for 1965 and 1990. A peculiar observation is the score of 1.00 in 1965 for the efficiency index for

Argentina, Paraguay and Sierra Leone, which are included with the United States.

Table 1. Efficiency Index and Output per Worker

		Efficiency Index		Output per Worker			Contribution to Change		
Country	Code	1965	1990	1965	1990	% Change	Efficiency	Technology	Deepening
Argentina	3	1.00	0.65	12818	13406	4.60	-35.48	1.79	59.26
Australia	4	0.76	0.82	21246	30312	42.70	8.20	13.87	15.80
Austria	4	0.85	0.73	13682	26700	95.10	-14.60	15.42	97.98
Belgium	4	0.70	0.86	17790	31730	78.40	22.41	12.68	29.31
Bolivia	1	0.50	0.41	4005	5315	32.70	-18.70	5.15	55.24
Canada	4	0.79	0.93	22245	34380	54.60	16.67	11.72	18.58
Chile	3	0.85	0.65	10169	11854	16.60	-23.87	1.92	50.24
Colombia	2	0.41	0.45	5989	10108	68.80	7.59	2.41	53.17
Denmark	4	0.76	0.70	17955	24971	39.10	-7.69	12.84	33.52
Dom. Rep.	2	0.72	0.51	4544	6898	51.80	-29.23	8.64	97.44
Ecuador	3	0.38	0.36	4993	9032	80.90	-3.62	-2.11	91.73
Finland	4	0.51	0.73	13938	27350	96.20	43.07	11.65	22.85
France	4	0.79	0.83	17027	30357	78.30	4.13	16.33	47.18
Germany, West	4	0.69	0.78	17282	29509	70.70	13.28	14.38	31.78
Greece	4	0.55	0.60	7721	17717	129.50	9.58	3.08	103.14
Guatemala	2	0.81	0.73	5784	7435	28.50	-10.22	9.42	30.85
Honduras	1	0.45	0.41	3633	4464	22.90	-8.64	6.88	25.84
Hong Kong	4	0.45	1.00	6502	22827	251.10	120.00	2.39	55.85
Iceland	4	0.96	0.87	15010	24978	66.40	-9.57	2.08	80.26
India	1	0.37	0.41	1792	3235	80.50	12.40	15.65	38.88
Ireland	4	0.71	0.85	10322	24058	133.10	19.49	1.20	92.75
Israel	4	0.60	0.84	12776	23780	86.10	39.50	2.34	30.38
Italy	4	0.67	0.88	14163	30797	117.40	31.86	13.32	45.52
Ivory Coast	1	0.66	0.47	2674	3075	15.00	-29.11	-7.03	74.49
Jamaica	2	0.56	0.52	5336	5146	-3.60	-8.29	6.22	-1.00
Japan	4	0.60	0.61	7333	22624	208.50	3.07	15.19	159.87
Kenya	1	0.26	0.29	1377	1863	35.30	14.37	24.16	-4.72
Korea, South	3	0.43	0.61	3055	16022	424.50	41.72	2.87	259.73
Luxembourg	4	0.76	1.00	21238	37903	78.50	32.00	24.40	8.68

Madagascar	1	0.37	0.21	2220	1561	-29.70	-44.19	17.86	6.90
Malawi	1	0.28	0.33	846	1217	43.90	17.33	-42.66	113.80
Mauritius	2	0.94	0.97	6496	10198	57.00	2.91	9.88	38.83
Mexico	3	0.85	0.74	11536	17012	47.50	-13.33	2.07	66.71
Morocco	2	0.74	0.86	4428	6770	52.90	17.24	16.57	11.87
Netherlands	4	0.84	0.88	20628	31242	51.50	5.31	11.16	29.38
New Zealand	4	0.84	0.71	23658	25413	7.40	-15.60	9.27	16.48
Nigeria	1	0.37	0.40	1481	2082	40.60	8.00	-13.85	51.10
Norway	4	0.61	0.78	17233	29248	69.70	26.36	33.04	0.96
Panama	2	0.44	0.33	6020	7999	32.90	-24.83	-0.86	78.32
Paraguay	2	1.00	1.00	3910	6383	63.20	0.00	-14.57	91.08
Peru	2	0.58	0.40	8162	6847	-16.10	-32.02	1.41	21.68
Philippines	2	0.42	0.47	3326	4784	43.80	10.28	7.88	20.90
Portugal	4	0.67	0.78	6189	16637	168.80	15.50	4.80	122.06
Sierra Leone	1	1.00	1.00	2640	2487	-5.80	0.00	-57.74	122.92
Spain	4	0.93	0.82	12451	26364	111.70	-12.30	7.08	125.47
Sri Lanka	2	0.32	0.33	3337	5742	72.10	3.28	2.98	61.78
Sweden	4	0.81	0.76	20870	28389	36.00	-5.34	12.63	27.59
Switzerland	4	0.84	0.86	23660	32812	38.70	259.00	28.44	5.25
Syria	2	0.42	0.65	7634	15871	107.90	54.90	0.19	33.96
Taiwan	3	0.52	0.59	4394	18409	319.00	14.79	9.60	233.01
Thailand	2	0.44	0.56	2292	6754	194.70	28.25	12.61	104.05
Turkey	3	0.50	0.55	3765	8632	129.30	9.94	6.61	95.60
UK	4	0.99	0.95	16645	26755	60.70	-3.81	1.37	64.85
USA	4	1.00	1.00	28051	36771	31.10	0.00	9.89	19.29
Yugoslavia	2	0.69	0.59	5320	10007	88.10	-15.29	6.60	108.32
Zambia	1	0.42	0.29	3116	2061	-33.90	-29.50	16.13	-19.21
Zimbabwe	1	0.17	0.23	2188	2437	11.40	37.15	2.50	-20.77

Note: The codes are (1) Low Income, (2) Lower Middle Income, (3) Upper Middle Income, and (4) High Income.

Source: Kumar and Russell (2002).

Kumar and Russell explain the case of Sierra Leone, saying Sierra Leone is poor because it is undercapitalized not because it does not use its meager capital efficiently. By 1990, Argentina's efficiency index stagnated at 0.65; Paraguay, Sierra Leone and the

United States maintained their scores of 1.00, with Hong Kong and Luxembourg joining their ranks.

The output per worker, for 1965 and 1990 measured in 1985 international prices, is shown in the fourth and fifth columns followed by percent changes between 1965 and 1990. This data reveals that the most prominent countries among the sample of 57 countries are Hong Kong, Japan, South Korea, Taiwan and Thailand with respective changes in output per worker in percentages of 251.1, 208.5, 424.5, 319.0 and 194.7. Other countries with some accomplishment are Greece, Ireland, Portugal, Spain and Turkey.

Kumar and Russell provide an interesting estimation of a decomposition of column 6 (growth of labor productivity for the 57 countries) between 1965 and 1990 shown in columns 7-9 of Table 1. The decomposition is made according to three components: technological change denoted efficiency, technological catch-up denoted technology and capital accumulation denoted deepening. The technological change is a reflection of shifts in the production frontier worldwide determined primarily by state-of-the-art technology, which is potentially transferable. The technological catch-up is a reflection of movement toward or away from the frontier as a country adopts best practice technologies to reduce technical inefficiencies. Capital accumulation depicts movement along the frontier. It is apparent from a cursory observation that the most important contribution to productivity improvement was capital accumulation. In many studies, physical and human capital are found to play prominent roles in labor productivity in contrast to the finding here of the prominent role of capital accumulation.

Table 2 is displayed in two panels depicting the mean (m) the standard deviation (S), the minimum, the maximum and the coefficient of variation (CV) for efficiency (Panel A) and output per worker (Panel B) for the groups of countries categorized by income for 1965 and 1990. On average, there seems to be little change in means of efficiency (Panel A) between 1965 and 1990. For all the 57 countries combined, the mean moved from 0.642 in 1965 to 0.658 in 1990, which is not statistically significant at the 5 percent significance level when using a test for equality of two means. The coefficient of variation CV (S/m) continually decreased as one moves up in the hierarchy of income.

For output per worker (Panel B), however, the changes between 1965 and 1990 are significant. Calculating the changes in means by the four group categories in percentages, the results are 14.7, 52.9, 86.0 and 71.0, indicating that productivity per worker was highest for the high-middle income countries, but in general coincided with the increasing levels of the group's income. For all the 57 countries combined, the increase was 67.4, which is statistically significant with a t-value = 3.66>1.96 for significance level α= 0.05. The coefficient of variation was also reduced in 1990 when moving up from the poorer nations to the richer nations, implying that richer nations tend more toward convergence as compared to poorer nations.

Table 2. Summary Information for Efficiency and Output per Worker

Panel A: Efficiency		1965					1990				
	n	m	S	Min	Max	CV	m	S	Min	Max	CV
Low	11	0.441	0.226	0.17	1.00	0.51	0.405	0.214	0.21	1.00	0.53
Low Middle	14	0.606	0.214	0.32	1.00	0.35	0.598	0.219	0.33	1.00	0.37
High Middle	7	0.647	0.246	0.38	1.00	0.38	0.593	0.119	0.36	0.74	0.20
High	25	0.747	0.146	0.45	1.00	0.20	0.822	0.109	0.60	1.00	0.13
All	57	0.642	0.220	0.17	1.00	0.34	0.658	0.228	0.21	1.00	0.34
Panel B: Worker Output		1965					1990				
	n	m	S	Min	Max	CV	m	S	Min	Max	CV
Low	11	2361	974	846	4005	0.41	2709	1244	1217	5315	0.46
Low Middle	14	5184	1663	2292	8162	0.32	7924	2873	4784	15871	0.36
High Middle	7	7247	4101	3055	12818	0.57	13481	3855	8632	18409	0.29
High	25	16225	5814	6189	28051	0.36	27745	5162	16637	37903	0.19
All	57	9735	7248	846	28051	0.74	16294	11336	1217	37903	0.69

Note: m= mean, S=standard deviation, CV= coefficient of variation.

Source: Kumar and Russell (2002) and calculations from Table 1.

A summary for the decomposition of change in output per worker by the four income levels is shown in Table 3, providing the mean (m), the standard deviation (S), the minimum, the maximum and the coefficient of variation (CV). The overall average of the 57 countries for total percentage change in worker productivity was 75.10 percent, of which 11.20 was due to change in efficiency, 6.14 was due to technological change and 59.21 resulted from capital deepening. This overall breakdown of averages indicates that the most important factor in productivity improvement was attributed to capital deepening, with technological progress and efficiency changes (technological catch-up) accounting in total for approximately 18 percent.

The capital deepening was most pronounced for the high-middle income group at 122.30 percent. The relatively small coefficient of variation for capital deepening for the four groups indicates that the effect of this factor was spread almost evenly (close to the mean) among the countries in each of the groups. While the contribution of change in efficiency (-3.72) and technology (-3.00) for the low-income group was on average negative, the contribution of capital deepening was positive at 43.90 percent.

Table 3. Decomposition of Percentage Change of Output per Worker

	n	m	S	Min	Max	CV
Total Percentage of Change						
Low	11	19.40	33.50	-33.90	80.50	1.73
Low Middle	14	60.14	50.70	-16.10	194.70	0.84
High Middle	7	146.06	162.50	4.60	424.50	1.11
High	25	88.10	56.60	7.40	251.10	0.64
All	57	75.10	79.80	-33.90	424.50	1.06
Contribution of Change in Efficiency						
Low	11	-3.72	24.59	-44.19	37.15	6.61
Low Middle	14	0.34	23.50	-32.02	54.90	69.12
High Middle	7	10.60	44.80	-35.50	94.00	4.23
High	25	24.00	56.20	-15.60	259.00	2.34
All	57	11.20	44.17	-44.19	259.00	3.94
Total Percentage of Change in Technology						
Low	11	-3.00	26.05	-57.74	24.16	8.68
Low Middle	14	4.96	7.47	-14.57	16.57	1.51
High Middle	7	3.25	3.78	-2.11	9.60	1.16
High	25	11.62	8.16	1.20	33.04	0.70
All	57	6.14	13.98	-57.40	33.04	2.28
Contribution of Change in Capital Deepening						
Low	11	43.90	46.00	-20.80	122.90	1.05
Low Middle	14	53.66	36.67	-1.00	108.32	0.68
High Middle	7	122.30	86.60	50.20	259.70	0.70
High	25	51.39	43.05	0.96	159.87	0.84
All	57	59.21	53.54	-20.80	259.70	0.90

Source: Kumar and Russell (2002).

Table 4. F-Test for Equality of Means of Efficiency Index and Output per Worker

	F-Test	P-Value
Efficiency Index (1965)	6.60	0.001
Efficiency Index (1990)	17.83	0.000
Worker Output (1965)	36.60	0.000
Worker Output (1990)	131.63	0.000
Change in Productivity	4.84	0.005
Efficiency Contribution	1.44	0.243
Technology Contribution	3.36	0.025
Capital Deepening Contribution	4.47	0.007

Source: Kumar and Russell (2002) and calculations from Table 1.

Table 4 provides the results of testing equality of means of the four groups of countries for the efficiency index and worker productivity for 1965 and 1990 as shown in Table 2 and the decomposition percentage change of worker output shown in Table 3 using analysis of variance. With one exception, efficiency contribution, the null hypothesis of equality is rejected with P-values ranging between 0.000 and 0.025. Of interest in Table 4, however, are the magnitudes of the F-ratios for efficiency and output per worker moving from 1965 to 1990. For efficiency, the F-ratios increased from 6.60 to 17.83, and for output per worker the ratio moved from 36.60 to 131.63. The indication here is that the gaps between the four hierarchies of income were widened between the two periods. Using the percent contribution of "between" and "within" variation to total variation expressed in Equation (1), the following display is revealing.

	Between Variation	Within Variation
Efficiency index		
1965	27.20	72.80
1990	50.52	49.48
Worker productivity		
1965	67.44	32.56
1990	88.17	11.83

The display provides evidence of the widening of gaps between the groups for efficiency and worker productivity for 1965-1990. A multiple comparisons procedure revealed that the widening of gaps between the four groups is attributed to movement of the high-income group of countries away from the rest.

For the percentage change of output per worker and the contribution to it from changes in efficiency, technology and capital deepening, the results in Table 4 indicate that the contribution from efficiency does not differ significantly between the four groups of income with P-value=0.243. Pursuing this line of analysis, single regression schemes were utilized, employing the percentage change in worker productivity as the dependent variable and the contribution of changes in efficiency, technology and capital deepening as the independent variables for each group in the income hierarchy as well as all the countries.

The results of this exercise again shows that the coefficient for capital deepening was statistically significant for the low-middle (P-value=0.024), upper-middle (P-value-0.000) and high-income (P-value=0.000) as well as all the countries (P-value=0.000). Neither the individual economies nor all countries had significant coefficient for technology, in line with Kumar and Russell, and only low-middle and all countries showed statistical significance for the efficiency coefficient, with respective P-values of 0.013 and 0.016. For low-income, none of the regression coefficients were significant.

Overall, based on the results of Tables 3 and 4, it can be concluded that capital

deepening was the most influential factor in promoting change in labor productivity generating a bimodal division of countries with the low-income ones on one side, and the middle (lower, upper) and high income on the other side. These observations are in conformity with Kumar and Russell's conclusion (P. 542) "that capital accumulation is the primary driving force in increasing labor productivity, and differences across countries in capital accumulation histories are primarily responsible for the emergence of the bimodal structure of the distribution of labor productivity."

Table 5. Convergence of Efficiency Index and Output per Worker

Panel A: Efficiency				
	b	t	p-value	r
Low	0.867	6.83	0.000	0.91
Low Middle	0.865	5.42	0.000	0.84
High Middle	0.349	2.36	0.066	0.72
High	0.239	1.62	0.118	0.32
All	0.819	9.58	0.000	0.79
Panel B: Worker Output				
	b	t	p-value	r
Low	1.017	3.94	0.003	0.80
Low Middle	1.030	2.60	0.023	0.60
High Middle	0.121	0.29	0.784	0.40
High	0.724	6.75	0.000	0.81
All	1.424	16.30	0.000	0.91

Note: Calculations by Equation (2).

Source: Kumar and Russell (2002).

Table 5 is a display of the results of Equation (2) dealing with convergence for the efficiency index and output per worker done for each of the four groups of economies as well as all the countries. All regularity conditions such as heteroskedasticity and normality were met when dealing with regression for all countries. The table provides the regression coefficient (b) and the t-values for its significance along with its p-values and the correlation coefficient (r) as an estimate (Equation 6) of ρ (Equation 5). For the efficiency index, $b<1.00$ for all the four groups, indicating convergence. For all countries, with b=0.819, the evidence points to convergence, especially when "1" is not included in the 95 percent confidence interval, $0.648<b<0.991$.

For output per worker, certainty of convergence is apparent for all income groups with the exception of low-income with b=1.017, which is slightly larger than 1. For all countries combined in one set, b=1.424, which is considerably larger than 1.00, substantiated further by observing that the 95 percent confidence interval for b ranges between b=1.248 and b=1.598. This result is similar in nature to studies on convergence

of per-capita income. Pritchett (1997) contends that the long-run growth rates in income - reflected in this paper in terms of growth of output per worker - of developing and developed countries tend to converge toward the richest among each group. The developing or less developed countries, Pritchett finds, tend to have slower growth rates than do the richer countries, producing divergence in relative income when all countries are grouped in one set. Similar observations were made by Barro (1991) and Mankiw, Romer and Weil (1992) who documented the presence of conditional convergence in terms of countries' own steady states.

Testing for statistical significance of the residual $(Y - Y')$ of Equation (7) by the t-test of Equation (7) produced the following array of countries delineating their accomplishments above expectation marked by (+) sign and accomplishments below expectation marked by (-) sign for one-sided significance levels $\alpha = .10$ with $t = \pm 1.28$ and $\alpha = .05$ with $t = \pm 1.645$.

Efficiency Index			
$\alpha = .10$		$\alpha = .05$	
(+)	**(-)**	**(+)**	**(-)**
Finland	Argentina	Hong Kong	Argentina
Hong Kong	Chile		
Israel	Dominican Republic		
Italy	Ivory Coast		
Luxembourg	Madagascar		
	Peru		
	Zambia		
Output per Worker			
$\alpha = .10$		$\alpha = .05$	
(+)	**(-)**	**(+)**	**(-)**
Hong Kong	Argentina	Hong Kong	New Zealand
Ireland	New Zealand	Japan	
Italy	Peru	South Korea	
Japan		Taiwan	
South Korea			
Spain			
Taiwan			

Table 6. Accounting of Efficiency Index

Country	X	Y	$Y - X$	Y'	$Y' - X$	$Y - Y'$	t
Argentina	1.00	0.65	-0.35	0.95	-0.05	-0.30	-2.22
Australia	0.76	0.82	0.06	0.76	0.00	0.06	0.46
Austria	0.85	0.73	-0.12	0.83	-0.02	-0.10	-0.72
Belgium	0.70	0.86	0.16	0.71	0.01	0.15	1.10
Bolivia	0.50	0.41	-0.09	0.54	0.04	-0.13	-0.95
Canada	0.79	0.93	0.14	0.78	-0.01	0.15	1.07
Chile	0.85	0.65	-0.20	0.83	-0.02	-0.18	-1.30
Colombia	0.41	0.45	0.04	0.47	0.06	-0.02	-0.14
Denmark	0.76	0.70	-0.06	0.76	0.00	-0.06	-0.40
Dom. Rep.	0.72	0.51	-0.21	0.72	0.00	-0.21	-1.53
Ecuador	0.38	0.36	-0.02	0.44	0.06	-0.08	-0.61
Finland	0.51	0.73	0.22	0.55	0.04	0.18	1.28
France	0.79	0.83	0.04	0.78	-0.01	0.05	0.36
Germany, West	0.69	0.78	0.09	0.70	0.01	0.08	0.58
Greece	0.55	0.60	0.05	0.58	0.03	0.02	0.12
Guatemala	0.81	0.73	-0.08	0.80	-0.01	-0.07	-0.48
Honduras	0.45	0.41	-0.04	0.50	0.05	-0.09	-0.66
Hong Kong	0.45	1.00	0.55	0.50	0.05	0.50	3.59
Iceland	0.96	0.87	-0.09	0.92	-0.04	-0.05	-0.36
India	0.37	0.41	0.04	0.44	0.07	-0.03	-0.19
Ireland	0.71	0.85	0.14	0.71	0.00	0.14	0.97
Israel	0.60	0.84	0.24	0.62	0.02	0.22	1.54
Italy	0.67	0.88	0.21	0.68	0.01	0.20	1.42
Ivory Coast	0.66	0.47	-0.19	0.67	0.01	-0.20	-1.46
Jamaica	0.56	0.52	-0.04	0.59	0.03	-0.07	-0.52
Japan	0.60	0.61	0.01	0.62	0.02	-0.01	-0.11
Kenya	0.26	0.29	0.03	0.35	0.09	-0.06	-0.41
Korea, South	0.43	0.61	0.18	0.49	0.06	0.12	0.90
Luxembourg	0.76	1.00	0.24	0.76	0.00	0.24	1.75
Madagascar	0.37	0.21	-0.16	0.44	0.07	-0.23	-1.64
Malawi	0.28	0.33	0.05	0.36	0.08	-0.03	-0.24
Mauritius	0.94	0.97	0.03	0.90	-0.04	0.07	0.48
Mexico	0.85	0.74	-0.11	0.83	-0.02	-0.09	-0.65
Morocco	0.74	0.86	0.12	0.74	0.00	0.12	0.86
Netherlands	0.84	0.88	0.04	0.82	-0.02	0.06	0.42
New Zealand	0.84	0.71	-0.13	0.82	-0.02	-0.11	-0.80
Nigeria	0.37	0.40	0.03	0.44	0.07	-0.04	-0.26
Norway	0.61	0.78	0.17	0.63	0.02	0.15	1.05
Panama	0.44	0.33	-0.11	0.49	0.05	-0.16	-1.18
Paraguay	1.00	1.00	0.00	0.95	-0.05	0.05	0.35

Peru	0.58	0.40	-0.18	0.61	0.03	-0.21	-1.49
Philippines	0.42	0.47	0.05	0.48	0.06	-0.01	-0.05
Portugal	0.67	0.78	0.11	0.68	0.01	0.10	0.70
Sierra Leone	1.00	1.00	0.00	0.95	-0.05	0.05	0.35
Spain	0.93	0.82	-0.11	0.90	-0.03	-0.08	-0.55
Sri Lanka	0.32	0.33	0.01	0.40	0.08	-0.07	-0.48
Sweden	0.81	0.76	-0.05	0.80	-0.01	-0.04	-0.27
Switzerland	0.84	0.86	0.02	0.82	-0.02	0.04	0.28
Syria	0.42	0.65	0.23	0.48	0.06	0.17	1.25
Taiwan	0.52	0.59	0.07	0.56	0.04	0.03	0.22
Thailand	0.44	0.56	0.12	0.49	0.05	0.07	0.48
Turkey	0.50	0.55	0.05	0.54	0.04	0.01	0.05
UK	0.99	0.95	-0.04	0.94	-0.05	0.01	0.04
USA	1.00	1.00	0.00	0.95	-0.05	0.05	0.35
Yugoslavia	0.69	0.59	-0.10	0.70	0.01	-0.11	-0.78
Zambia	0.42	0.29	-0.13	0.48	0.06	-0.19	-1.35
Zimbabwe	0.17	0.23	0.06	0.27	0.10	-0.04	-0.32

Note: $X = 1965, Y = 1990, Y' =$ expected (Equation (2)), $t = t$ – value by Equation (8)

Source: Kumar and Russell (2002).

Fuller summaries of the accounting produced by means of the identity of Equation (7) and the testing procedure of Equation (8) are displayed in Table 6 for the efficiency index and in Table 7 for output per worker. For each case, the table provides information on change between 1965 and 1990 $(Y - X)$, prediction from regression (Y') by Equation (2), difference between regression expectation and actual 1965 $(Y' - X)$, difference between actual 1990 and regression expectation $(Y - Y')$ and the testing for its significance (t) by Equation (8).

From Table 7 take as an example the case for Argentina for worker productivity. There was \$588 $(Y - X)$ increase between 1965 and 1990 with the expectation that productivity per worker would reach \$20,682 (Y'), which is \$7,864 $(Y' - X)$ above the 1965 level but a shortfall of \$-7276 $(Y - Y')$ by 1990. This shortfall is translated into a t-value = -1.55 by Equation (8), which is significant at the $\alpha = .10$ level.

Table 7. Accounting of Output per Worker

Country	X	Y	$Y - X$	Y'	$Y' - X$	$Y - Y'$	T
Argentina	12818	13406	588	20682	7864	-7276	-1.55
Australia	21246	30312	9066	32680	11434	-2368	-0.52
Austria	13682	26700	13018	21912	8230	4788	1.02
Belgium	17790	31730	13940	27760	9970	3970	0.86
Bolivia	4005	5315	1310	8137	4132	-2822	-0.60
Canada	22245	34380	12135	34102	11857	278	0.06
Chile	10169	11854	1685	16911	6742	-5057	-1.08
Colombia	5989	10108	4119	10961	4972	-853	-0.18
Denmark	17955	24971	7016	27995	10040	-3024	-0.65
Dom. Rep.	4544	6898	2354	8904	4360	-2006	-0.43
Ecuador	4993	9032	4039	9543	4550	-511	-0.11
Finland	13938	27350	13412	22277	8339	5073	1.08
France	17027	30357	13330	26674	9647	3683	0.79
Germany, West	17282	29509	12227	27037	9755	2472	0.53
Greece	7721	17717	9996	13427	5706	4291	0.91
Guatemala	5784	7435	1651	10669	4885	-3234	-0.69
Honduras	3633	4464	831	7607	3974	-3143	-0.67
Hong Kong	6502	22827	16325	11691	5189	11136	2.38
Iceland	15010	24978	9968	23803	8793	1175	0.25
India	1792	3235	1443	4986	3194	-1751	-0.38
Ireland	10322	24058	13736	17129	6807	6929	1.48
Israel	12776	23780	11004	20623	7847	3158	0.67
Italy	14163	30797	16634	22597	8434	8200	1.75
Ivory Coast	2674	3075	401	6242	3568	-3167	-0.68
Jamaica	5336	5146	-190	10031	4695	-4885	-1.04
Japan	7333	22624	15291	12874	5541	9750	2.08
Kenya	1377	1863	486	4396	3019	-2533	-0.55
Korea, South	3055	16022	12967	6784	3729	9238	1.98
Luxembourg	21238	37903	16665	32668	11430	5235	1.14
Madagascar	2220	1561	-659	5596	3376	-4035	-0.87
Malawi	846	1217	371	3640	2794	-2423	-0.52
Mauritius	6496	10198	3702	11683	5187	-1485	-0.32
Mexico	11536	17012	5476	18857	7321	-1845	-0.39
Morocco	4428	6770	2342	8739	4311	-1969	-0.42
Netherlands	20628	31242	10614	31800	11172	-558	-0.12
New Zealand	23658	25413	1755	36113	12455	-10700	-2.36
Nigeria	1481	2082	601	4544	3063	-2462	-0.53
Norway	17233	29248	12015	26967	9734	2281	0.49
Panama	6020	7999	1979	11005	4985	-3006	-0.64
Paraguay	3910	6383	2473	8002	4092	-1619	-0.35

Peru	8162	6847	-1315	14054	5892	-7207	-1.54
Philippines	3326	4784	1458	7170	3844	-2386	-0.51
Portugal	6189	16637	10448	11246	5057	5391	1.15
Sierra Leone	2640	2487	-153	6194	3554	-3707	-0.80
Spain	12451	26364	13913	20160	7709	6204	1.32
Sri Lanka	3337	5742	2405	7186	3849	-1444	-0.31
Sweden	20870	28389	7519	32145	11275	-3756	-0.82
Switzerland	23660	32812	9152	36116	12456	-3304	-0.73
Syria	7634	15871	8237	13303	5669	2568	0.55
Taiwan	4394	18409	14015	8691	4297	9719	2.08
Thailand	2292	6754	4462	5698	3406	1056	0.23
Turkey	3765	8632	4867	7795	4030	837	0.18
UK	16645	26755	10110	26130	9485	625	0.13
USA	28051	36771	8720	42367	14316	-5596	-1.27
Yugoslavia	5320	10007	4687	10009	4689	-2	0.00
Zambia	3116	2061	-1055	6871	3755	-4810	-1.03

Note: X=1965, Y= 1990, Y´ = expected (Equation 2), t = t-value by Equation (8)

Source: Kumar and Russell (2002).

The schemes followed in Tables 6 and 7 resulting from the model depicted in Equations 2, 7 and 8 are akin to that of Jones (1997) in his study of convergence. Jones compared GDP per worker relative to the United States for a large number of countries in 1960 and 1990 so that departure of a country from the 45-degree line indicates changes in the income distribution. Instead, this paper, by utilizing the suggested model, provides an estimate for the difference between the expected accomplishment in the efficiency index and output per worker (Y') for each country in 1990 as compared to actual (Y) in 1965. In contrast, Jones has found, as was done in this paper, that a number of OECD economies and newly industrialized countries have not reached their steady state level of 1990 and that divergence in the bottom level of income distribution can be expected to continue.

Of interest, finally, is to relate through regression methodology the differential effects of productivity per worker ($Y - Y'$) shown in column 6 of Table 7 with the contribution from changes in efficiency, technology and capital deepening shown in columns 7-9 of Table 1. None of the four groups or all countries had significant regression coefficient relating to technology. In other words, technology could not provide a statistically adequate explanation for the differential effect. Similarly, the effects of efficiency and capital deepening were only significant with respective P-values of 0.020 and 0.000 when all the countries were grouped in one sample. These results are consistent with the broad findings of this paper, in conformity with Kumar and Russell, in that the rate of technological catch-up in improving worker productivity was minor throughout the periods 1965 and 1990.

4. CONCLUSIONS

Cordina (2004) reports that convergence in total factor productivity in recent years is in general larger in developed countries than in developing countries and that convergence between these groups is occurring, though at a very slow pace. Kumar and Russell followed this path of research by constructing an efficiency index and estimating output per worker for 57 countries at various levels of economic development for 1965 and 1990. Their research also provided estimation of the percent contributions to percentage change of output per worker between 1965 and 1990 due to change in efficiency, change in technology and capital deepening, concluding that capital deepening was the most influential factor to explain the change of output.

This paper, by utilizing Kumar and Russell's rich findings on efficiency index and output per worker as well as the contribution to growth of output between 1965 and 1990, provided further insights to their work by splitting the 57 countries into four groups according to levels of income, a procedure deemed useful as shown in the introductory section of this paper. Analysis of variance was used to test for equality of means and regression methodology to test for convergence. In particular, the paper provided - in Tables 6 and 7 - the differential effect (Equation 7) depicting estimates of differences between what was observed for each country in 1965 and what was expected of that country in 1990, for the efficiency index and output per worker. Countries with statistically significant differential effects were identified.

The conclusion of this paper is that inter-country dispersion between the four economies were widened in 1990 as compared to 1965 for both the efficiency index and output per worker. It was also found, with the exception of efficiency, that the contribution to growth of output for technology and capital deepening differ between the groups. Convergence was found to prevail for the efficiency index for each of the groups as well as for all the countries in contrast to output per worker where divergence prevailed, especially when the countries were grouped into one set.

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