# INFORMATION TECHNOLOGY AND THE G7 ECONOMIES

**by**

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## 1. Introduction.

In this paper I present new international comparisons of economic growth among the G7 nations – Canada, France, Germany, Italy, Japan, the U.K., and the U.S. These comparisons focus on the impact of investment in information technology (IT) equipment and software over the period 1980-2000. In 1998 the G7 nations accounted for nearly sixty percent of world output[1] and a much larger proportion of world investment in IT. Economic growth in the G7 has experienced a strong revival since 1995, driven by a powerful surge in IT investment.

The resurgence of economic growth in the United States during the 1990's and the crucial role of IT investment has been thoroughly documented and widely discussed.[2] Similar trends in the other G7 economies have been more difficult to detect, partly because of discrepancies among official price indexes for IT equipment and software identified by Andrew Wyckoff.[3] Paul Schreyer has constructed "internationally harmonized" IT prices that eliminate many of these discrepancies.[4]

Using internationally harmonized prices, I have analyzed the role of investment and productivity as sources of growth in the G7 countries over the period 1980-2000. I have subdivided the period in 1989 and 1995 in order to focus on the most recent experience. I have decomposed

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[1]See Angus Maddison (2001) for 1998 data for world GDP and the GDP of each of the G7 countries.
[2]See Dale Jorgenson and Kevin Stiroh (2000) and Stephen Oliner and Daniel Sichel (2000).
[3]See Wyckoff (1995)
[4]See Schreyer (2000). Alessandra Colecchia and Schreyer (2002) have employed these internationally harmonized prices in measuring the impact of IT investment.

growth of output for each country between growth of input and productivity. Finally, I have allocated the growth of input between investments in tangible assets, especially information technology and software, and human capital.

Growth in IT capital input per capita jumped to double-digit levels in the G7 nations after 1995. This can be traced to an acceleration in the rate of decline of IT prices, analyzed in my Presidential Address to the American Economic Association.[5] The powerful upswing in investment was most pronounced in Japan, but capital input growth in the U.S., Canada, and the U.K. was only slightly lower. France, Germany, and Italy also experienced double-digit growth, but lagged considerably behind the leaders.

During the 1980's productivity had disappeared as a source of growth for Canada, France, Germany, and Italy, while accounting for only sixteen percent of U.S. growth and thirty-one percent of growth for Japan. Productivity was the predominant source of growth only for the U.K. Between 1989 and 1995 productivity growth declined further in the G7 nations, except for Italy. Productivity growth was negative for Canada, France, and Germany, but remained positive for the U.S., the U.K., Italy, and Japan.

Productivity growth revived in all the G7 countries after 1995, again except for Italy. This resurgence was most dramatic in Germany, partly offsetting fifteen years of negative productivity growth, the aftermath of German reunification. However, productivity for Canada, France, Germany, and Italy in 2000 remained below the levels of 1980.

Japan exhibited the highest growth in output per capita among the G7 nations from 1980 to 1995. Japan's level of output per capita rose

[5]See Jorgenson (2001).

from the lowest in the G7 to the middle of the group. Although this advance owed more to input per capita than productivity, Japan's productivity growth far outstripped that for the other members of the G7, especially before 1989. Nonetheless, Japan's productivity remained the lowest among the G7 nations.

The United States and Canada had very similar levels of output per capita in 1980 with Canada holding a slight edge. Canada fell behind the U.S. during the 1980's and the U.S. led the G7 in output per capita during 1989-2000. The U.S. led the G7 countries in input per capita throughout the period 1980-2000, but U.S. productivity languished at levels below those of Canada, France, and Italy.

In Section 2 I outline the methodology for this study, based on my Presidential Address. I have revised and updated the U.S. data presented there through 2000. Comparable data on investment in information technology have been have been constructed for Canada by Statistics Canada.[6] Data for the four European countries – France, Germany, Italy, and the U.K. have been developed for the European Commission by Bart Van Ark, *et al*.[7] Finally, data for Japan have been assembled by myself and Kazuyuki Motohashi for the Research Institute on Economy, Trade, and Industry.[8] I have linked these data by means of the OECD's purchasing power parities for 1999.[9]

In Section 3 I consider the impact of IT investment and the relative importance of investment and productivity in accounting for economic growth among the G7 nations. Investments in human capital and tangible assets, especially IT equipment and software, account for the

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[6]See John Baldwin and Tarek Harchaoui (2002).
[7]See Van Ark, Johanna Melka, Nanno Mulder, Marcel Timmer, and Gerard Ypma (2002).
[8]See Jorgenson and Motohashi (2003)
[9]See OECD (2002). Current data on purchasing power parities are available from the OECD website: http://www.sourceoecd.org.

overwhelming proportion of growth. Differences in the composition of capital and labor inputs are essential for identifying persistent international differences in output and accounting for the impact of IT investment.

In Section 4 I consider alternative approaches to international comparisons. The great revival of interest in economic growth among economists dates from Angus Maddison's (1982) updating and extension of Simon Kuznets' (1971) long-term estimates of the growth of national product and population for fourteen industrialized countries, including the G7 nations. Maddison (1982, 1991) added Austria and Finland to Kuznets' list and presented growth rates covering periods beginning as early as 1820 and extending through 1989.

Maddison (1987, 1991) also generated growth accounts for major industrialized countries, but did not make level comparisons like those presented in Section 2 below. As a consequence, productivity differences were omitted from the canonical formulation of "growth regressions" by William Baumol (1986). This proved to be a fatal flaw in Baumol's regression model, remedied by Nazrul Islam's (1995) panel data model. Section 5 concludes the paper.

## 2. Investment and Productivity.

My papers with Laurits Christensen and Dianne Cummings (1980, 1981) developed growth accounts for the United States and its major trading partners -- Canada, France, Germany, Italy, Japan, Korea, The Netherlands, and the United Kingdom for 1947-1973. We employed GNP as a measure of output and incorporated constant quality indices of capital and labor input for each country. Our 1981 paper compared levels of output, inputs, and productivity for all nine nations.

I have updated the estimates for the G7 – Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States –

through 1995 in earlier work. The updated estimates are presented in my papers with Chrys Dougherty (1996, 1999) and Eric Yip (2001). We have shown that productivity accounted for only eleven percent of economic growth in Canada and the United States over the period 1960-1995.

My paper with Yip (2001) attributed forty-seven percent of Japanese economic growth during the period 1960-1995 to productivity growth. The proportion attributable to productivity approximated forty percent of growth for the four European countries - France (.38), Germany (.42), Italy (.43), and the United Kingdom (.36). Input growth predominated over productivity growth for all the G7 nations.

I have now incorporated new data on investment in information technology equipment and software for the G7. I have also employed internationally harmonized prices like those constructed by Schreyer (2000). As a consequence, I have been able to separate the contribution of capital input to economic growth into IT and Non-IT components. While IT investment follows similar patterns in all the G7 nations, Non-IT investment varies considerably and helps to explain important differences in growth rates among the G7.

**2.1. Comparisons of Output, Input, and Productivity.**

My first objective is to extend my estimates for the G7 nations with Christensen, Cummings, Dougherty, and Yip to the year 2000. Following the methodology of my Presidential Address, I have chosen GDP as a measure of output. I have included imputations for the services of consumers' durables as well as land, buildings, and equipment owned by nonprofit institutions. I have also distinguished between investments in information technology equipment and software and investments in other forms of tangible assets.

A constant quality index of capital input is based on weights that reflect differences in capital consumption, tax treatment, and the rate of decline of asset prices. I have derived estimates of capital input and property income from national accounting data. Similarly, a constant quality index of labor input is based on weights by age, sex, educational attainment, and employment status. I have constructed estimates of hours worked and labor compensation from labor force surveys for each country.

In Table 1 I present output per capita for the G7 nations from 1980 to 2000, taking the U.S. as 100.0 in 2000. Output and population are given separately in Tables 2 and 3. I use 1999 purchasing power parities from the OECD to convert output from domestic prices for each country into U.S. dollars. Per capita output in the U.S. and Canada was very similar in 1980 with Canada having a slight edge. The U.S. regained its lead among the G7 during the 1980’s and led throughout the 1990’s.

The four major European nations – the U.K., France, Germany, and Italy – had very similar levels of output per capita throughout the period 1980-2000 with Germany as the leader. Japan rose from last place in 1980 to fourth place among the G7 in 2000, lagging considerably behind the U.S. and Canada, but only slightly behind Germany. Japan led the G7 in the growth of output per capita from 1980-1995, but fell behind the U.S., Canada, the U.K., and France after 1995.

In Table 1 I present input per capita for the G7 over the period 1980-2000, taking the U.S. as 100.0 in 2000. I express input per capita in U.S. dollars, using purchasing power parities constructed for this study.[10] The U.S. was the leader among the G7 in per capita input throughout the period. In 2000 Japan ranked next to the U.S. with

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[10]The purchasing power parities for outputs are based on OECD (2002). Purchasing power parities for inputs follow the methodology described in detail by Jorgenson and Yip (2001).

Germany third and Canada fourth. France and Italy started at the bottom of the ranking and remained there throughout the period.

In Table 1 I also present productivity levels for the G7 over the period 1980-2000. Productivity is defined as the ratio of output to input, including both capital and labor inputs. Canada was the productivity leader throughout the period 1980-2000, despite the absence of productivity growth! Only the U.S., the U.K., and Japan made substantial gains in productivity. The level of productivity declined slightly in France and Italy and dropped precipitously in Germany after reunification.

I summarize growth in output and input per capita and productivity for the G7 nations in Table 4. I present growth rates of output and population for the period 1980-2000 in Tables 2 and 3. Output growth slowed in the G7 after 1989, but revived for all nations except Japan after 1995. Output per capita followed a similar pattern, but with negative growth for Canada during the period 1990-1995.

Japan led in growth of output and output per capita through 1995, but fell back to the middle echelon of the G7 after 1995. The U.K. led in productivity growth during the 1980's, when U.K. productivity growth outstripped the growth of input per capita. For all other countries and all other time periods the growth of input per capita exceeded growth of productivity by a substantial margin. Productivity growth in the G7 slowed during the period 1989-1995, except for Italy, where productivity slumped after 1995.

Germany led the G7 in growth of input per capita for the period 1980-1995, but relinquished leadership to the U.S. after 1995. Differences among input growth rates are smaller than differences among output growth rates, but there was a slowdown in input growth during 1989-1995 in the U.S., Canada, France, Italy, and Japan and an acceleration of growth in the U.K. and Germany. Growth of input per capita in the G7 increased after 1995, except in Germany and Japan.

**2.2. Comparisons of Capital and Labor Quality.**

A constant quality index of capital input weights capital inputs by property compensation per unit of capital. By contrast an index of capital stock weights different types of capital by asset prices. The ratio of capital input to capital stock measures the average quality of a unit of capital. This represents the difference between the constant quality index of capital input and the index of capital stock employed, for example, by Kuznets (1971) and Robert Solow (1970).

In Table 5 I present capital input per capita for the G7 countries over the period 1980-2000 relative to the U.S. in 2000. The U.S. was the leader in capital input per capita throughout the period. Germany led the remaining six countries in 1980, but was overtaken by Italy in 1989. Italy lagged behind the United States, but led the rest of the G7 through 2000. Japan was the laggard among the G7 in 1980, but surpassed the U.K. in 1989.

The picture for capital stock per capita has some similarities to capital input, but there are important differences. Capital stock levels do not accurately reflect the substitutions among capital inputs that accompany investments in tangible assets, especially investments in IT equipment and software. The U.S. led throughout the period in capital stock per capita as well as capital input, while Germany was second to the U.S. in capital stock. Japan and the U.K. lagged the remaining countries of the G7 throughout the period with Japan overtaking the U.K. in 1995.

The behavior of capital quality highlights the differences between the constant quality index of capital input and capital stock. There are important changes in capital quality over time and persistent differences among countries, so that heterogeneity in capital input must be taken into account in international comparisons of economic performance. Japan and the U.K. were the international leaders in capital quality throughout the period 1980-2000, while the U.S. ranked near the bottom, rising above Germany only in 1980.

I summarize growth in capital input and capital stock per capita, as well as capital quality for the G7 nations in Table 8. Italy was the international leader in capital input growth from 1980-1989, while the U.K. was the laggard. Japan led from 1989-1995, while Canada lagged considerably behind the rest of the G7. After 1995 Italy regained its earlier leadership. There was a slowdown in capital input growth in the G7 after 1989 and a revival after 1995 in the U.S., Canada, Germany, and Italy.

A constant quality index of labor input weights hours worked for different categories by labor compensation per hour. An index of hours worked fails to take quality differences into account. The ratio of labor input to hours worked measures the average quality of an hour of labor, as reflected in its marginal product. This represents the difference between the constant quality index of labor input and the index of hours worked employed, for example, by Kuznets (1971) and Solow (1970).

In Table 11 I present labor input per capita for the G7 nations for the period 1980-2000 relative to the U.S. in 2000. Japan was the international leader throughout the period and Italy the laggard. Labor input in Japan was nearly double that of Italy. The U.S. led the remaining G7 nations throughout the period. Canada was only slightly behind the U.K. in 1980, but ranked third among the G7 for the rest of the period, while the U.K. remained in fourth place. Germany lagged behind France in 1980, but rose of fifth place in 1989, while France fell to sixth.

The picture for hours worked per capita has some similarities to labor input, but there are important differences. Japan was the international leader in hours worked per capita. The U.S., Canada, and the U.K. moved roughly in parallel and Canada ranked second, except for 1995. Germany was the laggard in hours worked per capita until 1995, when Italy fell to the bottom of the G7. France remained above Italy throughout the period, but fell below Germany in 1995.

The behavior of labor quality highlights the differences between labor input and hours worked. Germany was the leader in labor quality throughout the period 1980-2000, but experienced a large decline after German reunification. The U.S. ranked second in labor quality, but Canada, France, and Japan approached U.S. levels in 2000. Labor quality levels in these three countries moved in parallel throughout the period. Italy was the laggard among the G7 in labor quality as well as hours worked.

I summarize growth in labor input and hours worked per capita, as well as labor quality for the period 1980-2000 in Table 12. Germany led the G7 nations in labor input growth until 1995, but relinquished leadership to France. Hours worked per capita fell continuously throughout the period 1980-2000 for Japan. Labor input growth was negative for the U.K. and France during the 1980's, for Canada during the periods 1989-1995, and for Germany and Japan after 1995. Hours worked per capita fell for the U.S., Canada, and the U.K. during the period 1989-1995 and moved in parallel throughout the period 1980-2000.

Growth in labor quality was negative for Germany throughout the period 1980-2000 and for the U.K. during the 1980's. Otherwise, labor quality growth was positive for the remaining G7 nations in all time periods. Japan was the leader during the 1980’s, relinquishing its lead to France during the 1990’s. Growth in labor quality and hours worked are equally important as sources of growth in labor input for the G7.

### 3. Investment in Information Technology.

Using data from Tables 1 and 2, I can assess the relative importance of investment and productivity as sources of economic growth for the G7 nations. Investments in tangible assets and human capital greatly predominated over productivity during the period 1980-2000. Productivity growth was negative for Canada, France, Germany, and Italy, while the U.S., the U.K., and Japan had positive productivity growth for this period. Productivity was the most important source of economic growth only for the U.K. and only during the 1980’s.

Similarly, using data from Table 5 I can assess the relative importance of growth in capital stock and capital quality. Capital input growth was positive for all countries for the period 1980-2000 and all three sub-periods. Capital quality growth was positive for the period as a whole for all G7 countries, except for the U.K. Although capital stock generally predominated in capital input growth, capital quality was also quantitatively significant, especially after 1995.

Finally, using data from Table 7 I can assess the relative importance of growth in hours worked and labor quality. Hours worked per capita declined for France and Japan, while labor quality rose in both nations during the period 1980-2000. For Germany labor quality declined, while hours worked rose during this period. For the U.S., Canada, the U.K., and Italy, both hours worked per capita and labor quality rose. I conclude that labor quality growth is essential to the analysis of growth in labor input.

### 3.1. Investment in IT Equipment and Software

The final step in the comparison of patterns of economic growth among the G7 nations is to analyze the impact of investment in information technology equipment and software. In Table 6 I present levels of IT capital input per capita for the G7 for the period 1980-2000, relative to the U.S. in 2000. The U.S. overtook Germany in 1989 and remained the leader throughout 2000, with Germany and Italy close behind. Japan lagged behind the rest of the G7 until 2000, when France fell into last place.

Table 6 reveals substantial differences between IT capital stock and IT capital input. The G7 nations began with very modest stocks of IT equipment and software per capita in 1980. These stocks expanded rapidly during 1980-2000. The U.S. led in IT capital stock throughout the period, while Japan, the laggard among the G7 in 1980, ranked second in 2000.

IT capital quality reflects differences in the composition of IT capital input, relative to IT capital stock. A rising level of capital quality indicates a shift toward short-lived assets, such as computers and software. This shift is particularly dramatic for the U.S., Canada, and Japan, while the composition of capital stock changed relatively less for the U.K., France, Germany, and Italy. Patterns for Non-IT capital input, capital stock, and capital quality largely reflect those for capital as a whole, presented in Table 5.

I give growth rates for IT capital input per capita, capital stock per capita, and capital quality in Table 9. The G7 nations have exhibited double-digit growth in IT capital input per capita since 1995. Japan was the international leader during this period with the U.S., Canada, and the U.K. close behind. Japan was also the leader in growth of IT capital input during the period 1980-1989, another period of double-digit growth in capital input. However, Japan fell behind Canada during 1989-1995, when growth slowed substantially.

Patterns of growth for IT capital stock per capita are similar to those for IT capital input for the four European countries. Changes in the composition of IT capital stock per capita were important sources of growth of IT capital input per capita for the U.S., Canada, and Japan. IT capital stock also followed the pattern of IT capital input with substantial growth during the 1980's, followed by a pronounced lull during the period 1989-1995. After 1995 the growth rates of IT capital stock surged in all the G7 countries, but exceeded the rates of the 1980's only for the U.S. and Japan.

Finally, growth rates for IT capital quality reflect the rates at which shorter-lived IT assets are substituted for longer-lived assets. Japan led in the growth of capital quality during the 1980's, but relinquished its lead to Canada in 1989. IT capital quality growth for the U.S., Canada, and Japan outstripped that for the four European countries for most of the period 1980-2000. Patterns of growth in Non-IT capital input per capita, Non-IT capital stock per capita, and Non-IT capital quality given in Table 10 largely reflect those for capital as a whole presented in Table 8.

Table 13 presents the contribution of capital input to economic growth for the G7 nations, divided between IT and Non-IT. The powerful surge of IT investment in the U.S. after 1995 is mirrored in similar jumps in growth rates of the contribution of IT capital through the G7. The contribution of IT capital input was similar during the 1980's and the period 1989-1995 for all the G7 nations, despite the dip in rates of economic growth after 1989. Japan is an exception to this general pattern with a contribution of IT capital comparable to that of the

U.S. during the 1980's, followed by a decline in this contribution from 1989-1995, reflecting the sharp downturn in Japanese economic growth.

The contribution of Non-IT capital input to economic growth after 1995 exceeded that for IT capital input for five of the G7 nations; the exceptions were the U.K. and Japan. The U.S. stands out in the magnitude of the contribution of capital input after 1995. Both IT and Non-IT capital input contributed to the U.S. economic resurgence of the last half of the 1990's. Despite the strong performance of IT investment in Japan after 1995, the contribution of capital input declined substantially; the pattern for the U.K. is similar.

### 3.2. The Relative Importance of Investment and Productivity.

Table 14 presents contributions to economic growth from productivity, divided between the IT-producing and Non-IT-producing industries. The methodology for this division follows Triplett (1996). The contribution of IT-producing industries is positive throughout the period 1980-2000 and jumps substantially after 1995. Since the level of productivity is higher in 1980 than in 2000 for Canada, France, Germany, and Italy, it is not surprising that the contributions of Non-IT-producing industries in these countries are predominantly negative.

Table 15 gives a comprehensive view of the sources of economic growth for the G7. The contribution of capital input alone exceeds that of productivity for most nations and most time periods. The contribution of Non-IT capital input predominates over IT capital input for most countries and most time periods with the U.K. and Japan after 1995 as exceptions. This can be attributed to the unusual weakness in the growth of aggregate demand in these countries. The contribution of labor input varies considerably among the G7 nations with negative contributions after 1995 in Germany and Japan and during the 1980's in France.

Finally, Table 16 translates sources of growth into sources of growth in average labor productivity (ALP). ALP, defined as output per hour worked, must be carefully distinguished from productivity, defined as output per unit of both capital and labor inputs. Capital deepening is the contribution of growth in capital input per hour worked and greatly predominates over productivity as a source of ALP growth for the G7 nations. Finally, the contribution of labor quality is positive, except for the U.K. and Germany in the 1980's and Germany after reunification.

## 4. Alternative Approaches

Edward Denison's (1967) pathbreaking volume, *Why Growth Rates Differ*, compared differences in growth rates for national income net of capital consumption per capita for the period 1950-62 with differences of levels in 1960 for eight European countries and the U.S. The European countries were characterized by much more rapid growth and a lower level of national income per capita. However, this association did not hold for all comparisons between the individual countries and the U.S. Nonetheless, Denison concluded:[11]

> Aside from short-term aberrations Europe should be able to report higher growth rates, at least in national income per person employed, for a long time. Americans should expect this and not be disturbed by it.

Maddison (1987, 1991) constructed estimates of aggregate output, input, and productivity growth for France, Germany, Japan, The Netherlands, and the United Kingdom for the period 1870-1987. Maddison (1995) extended estimates for the U.S., the U.K., and Japan backward to 1820 and forward to 1992. He defined output as gross of capital

[11]See Denison (1967), especially Chapter 21, "The Sources of Growth and the Contrast between Europe and the United States", pp. 296-348.

consumption throughout the period and constructed constant quality indices of labor input for the period 1913–1984, but not for 1870–1913.

Maddison employed capital stock as a measure of the input of capital, ignoring the changes in the composition of capital stock that are such an important source of growth for the G7 nations. This omission is especially critical in assessing the impact of investment in information technology. Finally, he reduced the growth rate of the price index for investment by one percent per year for all countries and all time periods to correct for biases like those identified by Wyckoff (1995).

### 4.1. Comparisons without Growth Accounts

Kuznets (1971) provided elaborate comparisons of growth rates for fourteen industrialized countries. Unlike Denison (1967), he did not provide level comparisons. Maddison (1982) filled this lacuna by comparing levels of national product for sixteen countries. These comparisons used estimates of purchasing power parities by Irving Kravis, Alan Heston, and Robert Summers (1978).[12]

Maddison (1995) extended his long-term estimates of the growth of national product and population to 56 countries, covering the period 1820–1992. Maddison (2001) updated these estimates to 1998 in his magisterial volume, *The World Economy: A Millennial Perspective*. He provided estimates for 134 countries, as well as seven regions of the world – Western Europe, Western Offshoots (Australia, Canada, New Zealand, and the United States), Eastern Europe, Former USSR, Latin America, Asia, and Africa.

Purchasing power parities have been updated by successive versions of the Penn World Table. A complete list of these tables

[12]For details see Maddison (1982), pp. 159–168.

through Mark 5 is given by Summers and Heston (1991). The current version of the Penn World Table is available on the Center for International Comparisons website at the University of Pennsylvania (CICUP). This covers 168 countries for the period 1950-2000 and represents one of the most significant achievements in economic measurement of the postwar period.[13]

**4.2. Convergence**

Data presented by Kuznets (1971), Maddison, and successive versions of the Penn World Table have made it possible to reconsider the issue of convergence raised by Denison (1967). Moses Abramovitz (1986) was the first to take up the challenge by analyzing convergence of output per capita among Maddison's sixteen countries. He found that convergence characterized the postwar period, while there was no tendency toward convergence before 1914 and during the interwar period. Baumol (1986) formalized these results by running a regression of growth rate of GDP per capita over the period 1870-1979 on the 1870 level of GDP per capita.[14]

In a highly innovative paper on "Crazy Explanations for the Productivity Slowdown" Paul Romer (1987) derived Baumol's "growth regression" from Solow's (1970) growth model with a Cobb-Douglas production function. Romer's empirical contribution was to extend the growth regressions from Maddison's (1982) sixteen advanced countries to the 115 countries in the Penn World Table (Mark 3). Romer's key finding was an estimate of the elasticity of output with respect to capital

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[13]See Heston, Summers, and Aten (2002). The CICUP website is at: http://pwt.econ.upenn.edu/aboutpwt.html.

[14]Baumol's "growth regression" has spawned a vast literature, recently summarized by Steven Durlauf and Danny Quah (1999, Ellen McGrattan and James Schmitz (1999), and Islam (2003). Much of this literature is based on data from successive versions of the Penn World Table.

close to three-quarters. The share of capital in GNP implied by Solow's model was less than half as great.

Gregory Mankiw, David Romer, and David Weil (1992) defended the traditional framework of Kuznets (1971) and Solow (1970). The empirical part of their study is based on data for 98 countries from the Penn World Table (Mark 4). Like Paul Romer (1987), Mankiw, David Romer, and Weil derived a growth regression from the Solow (1970) model; however, they augmented this by allowing for investment in human capital.

The results of Mankiw, David Romer, and Weil (1992) provided empirical support for the augmented Solow model. There was clear evidence of the convergence predicted by the model; in addition, the estimated elasticity of output with respect to capital was in line with the share of capital in the value of output. The rate of convergence of output per capita was too slow to be consistent with 1970 version of the Solow model, but supported the augmented version.

**4.2. Modeling Productivity Differences.**

Finally, Islam (1995) exploited an important feature of the Penn World Table overlooked in prior studies. This panel data set contains benchmark comparisons of levels of the national product at five year intervals, beginning in 1960. This made it possible to test an assumption maintained in growth regressions. These regressions had assumed identical levels of productivity for all countries included in the Penn World Table.

Substantial differences in levels of productivity among countries have been documented by Denison (1967), by my papers with Christensen and Cummings (1981), Dougherty (1996, 1999), and Yip (2001) and in Section 2 above. By introducing econometric methods for panel data Islam (1995) was able to allow for these differences. He corroborated the finding of Mankiw, David Romer, and Weil (1992) that the elasticity of output with respect to capital input coincided with the share of capital in the value of output.

In addition, Islam (1995) found that the rate of convergence of output per capita among countries in the Penn World Table substantiated the *unaugmented* version of the Solow (1970) growth model. In short, "crazy explanations" for the productivity slowdown, like those propounded by Paul Romer (1987, 1994), were unnecessary. Moreover, the model did not require augmentation by endogenous investment in human capital, as proposed by Mankiw, David Romer, and Weil (1992).

Islam concluded that differences in technology among countries must be included in econometric models of growth rates. This requires econometric techniques for panel data, like those originated by Gary Chamberlain (1984), rather than the regression methods of Baumol, Paul Romer, and Mankiw, David Romer, and Weil. Panel data techniques have now superseded regression methods in modeling differences in output per capita.

## 5. Conclusions.

I conclude that a powerful surge in investment in information technology and equipment after 1995 characterizes all of the G7 economies. This accounts for a large portion of the resurgence in U.S. economic growth, but contributes substantially to economic growth in the remaining G7 economies as well. Another significant source of the G7 growth resurgence after 1995 is a jump in productivity growth in IT-producing industries.

For Japan the dramatic upward leap in the impact of IT investment after 1995 was insufficient to overcome downward pressures from deficient growth of aggregate demand. This manifests itself in declining contributions of Non-IT capital and labor inputs. Similar downturns are visible in Non-IT capital in the U.K. and in labor input in Germany, but both were combined in Japan after 1995.

The conclusion from Islam's (1995) research is that the Solow (1970) model is appropriate for modeling the endogenous accumulation of tangible assets. It is unnecessary to endogenize human capital accumulation as well. The transition path to balanced growth equilibrium after a change in policies that affects investment in tangible assets requires decades, while the transition after a change affecting investment in human capital requires as much as a century.

Important changes in economic performance among the G7 can be rationalized on the basis of the neoclassical theory of economic growth, extended to incorporate persistent differences among nations. Productivity growth is exogenous, while investment is endogenous to the theory. Obviously, the relative importance of exogenous productivity growth has greatly diminished, so that a much more prominent role can be assigned to endogenous investment in tangible assets, especially IT equipment and software.

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