BROOKINGS DISCUSSION PAPERS IN INTERNATIONAL ECONOMICS

No. 132

PRODUCTIVITY GROWTH: DISCUSSION AND TWELVE SECTOR SURVEY

Philip Bagnoli

April 1997

Philip Bagnoli is an economist with the Economic Studies and Policy Analysis Division of the Department of Finance in Ottawa. This work was undertaken while he was a resident Research Associate in the Economic Studies Program of the Brookings Institution. This project has received financial support from the U.S. Environmental Protection Agency through Cooperative Agreement CR-818579-01-0 and from the National Science Foundation through grant SBR-9321010. The author thanks Warwick McKibbin and Peter Wilcoxen for comments on earlier drafts and Barry Bosworth and Charles Schultze for helpful discussions.

PRODUCTIVITY GROWTH:
DISCUSSION AND TWELVE SECTOR SURVEY

ABSTRACT

This paper surveys productivity growth at a sectoral level for the United States and other countries. We begin with a discussion of the definition and measurement of productivity growth followed by a review of empirical work undertaken in its measurement.

We then take a close look at factors influencing productivity growth in twelve sectors: electric utilities; gas utilities; petroleum refining; coal mining; crude oil and gas extraction; other mining; agriculture, fishing and hunting; forestry and wood products; durable manufacturing; non-durable manufacturing; transportation; and services. The paper reports differential productivity growth rates for these industries for the United States and for subsets of these industries for other countries.

Philip Bagnoli
Department of Finance, Ottawa, ON.
The Brookings Institution, Washington, DC.

I. Introduction

Almost four decades have elapsed since Solow (1957) argued that productivity growth was a major factor in the growth of national output. Since that time much analysis has been conducted into the sources of productivity growth and into the factors that affect its magnitude. Subsequent studies have enhanced his original 2-factor model to account for a larger number of inputs and a change in the quality of those inputs: the *Solow residual* is now much smaller than originally calculated -- though its economic importance remains considerable. Some of the more careful and detailed of the subsequent studies (e.g. Denison [1974], Maddison [1987] or Jorgenson, Gollop and Fraumeni [1987]) suggest that the remaining residual accounts for about one quarter of growth for the period beginning in the late 1940's. At least one study which tries to account for the input of students' time into building human capital (Jorgenson and Fraumeni [1992]) puts the residual growth at about one sixth of total growth during that period.

Diewert (1992) undertook a critical review of the metrics used in gauging productivity growth. He provides strong theoretical arguments for well known criticisms of some of the traditional techniques of measuring productivity growth and suggests that index number theory might be the only foundation for providing reasonable measures of productivity growth.

This paper will outline these as well as other major issues that must be addressed in productivity analysis and summarizes the results of previous work done in this area. Our intention is to provide an introduction to the current state of research in productivity analysis (future work will then take this basis as a point of departure). We begin in the next section (II) with a simple illustration of productivity growth and its measurement followed by a discussion of conceptual and empirical issues in attempting to measure productivity growth. The following section (III) will provide a literature review and detail elements of some of the important work that has been done. Section IV then surveys historical factors in productivity growth in a 12 sector disaggregation[1], followed by the final section (V) which concludes by illustrating the implications of historical productivity growth on the twelve sectors.

II. Background

Traditionally, three basic approaches have been used in measuring total factor productivity (TFP) growth. These are based on: (1) production functions; (2) cost functions; and (3) inference through index numbers. The approach used by Solow (1957) to argue that technological progress was an important component of economic growth was based on the first method and can be illustrated with the following production function:

$$Y = f(K_P, K_H, M) \tag{1}$$

Where: *Y is output,*
K_P is physical capital,
K_H is human capital,
M is materials.

TFP growth occurs when changes in output *Y* cannot be attributed to changes in one of the three inputs[2], i.e.:

$$\dot{Y} - f_{K_P}\dot{K}_P - f_{K_H}\dot{K}_H - f_M\dot{M} > 0 \tag{2}$$

At the level of the aggregate economy when output is aggregated to one good the materials input is very small and is generally ignored: it is dominated by the value-added attributable to physical and human capital in the final product; moreover, the total volume of material inputs does not show large changes

[1]The disaggregation corresponds to the sectors of the GCUBED model, see McKibbin and Wilcoxen (1995).

[2]The measure given by equation (2) has become known as the Solow residual. An alternative view of the residual is given by Real Business Cycle theorists who treat it as a random variable and thus argue that productivity shocks are the sources of fluctuations in economic activity (see Prescott [1987]).

over time (at a sectoral level, however, materials are the dominant input for most industries).

Equation (2), however, has drawbacks as a measure of productivity gains. It is sensitive to both the measurement of aggregate inputs as well as the correct parameterization of the production function. Take, for example, a Cobb-Douglas function; if Gross Domestic Product (GDP) is the output measure then we have,

$$Ln(\pi_t) = Ln(GDP_t) - \beta_k Ln(Physical\ Capital_t) - \beta_l Ln(Human\ Capital_t) \tag{3}$$

Increases in π_t measure TFP gains, while β_k and β_l are parameters. The measurement of TFP gains is clearly sensitive to the accuracy of measured changes in physical and human capital and, as well, the accuracy with which the parameters β_k and β_l have been measured. The problem of measuring β_k and β_l can be overcome with the aid of the following assumptions:

(1) *competitive markets,*
(2) *constant returns to scale,*
(3) *no externalities which create a wedge between social and private marginal costs.*

These assumptions allow us to use cost shares (i.e. deflated nominal factor returns) in place of the Cobb-Douglas parameters so that we have:

$$\dot{\pi}_t = G\dot{D}P_t - s_k \dot{k}_{P_t} - s_l \dot{k}_{H_t} \tag{4}$$

where s_k and s_l are the capital and labor cost shares, respectively and k_{P_t} and k_{H_t} are physical and human capital, respectively.

This equation is no longer parametric, it holds for any form of the production function that satisfies the three assumptions given above. It is, therefore, a powerful tool in productivity measurement which has come into widespread use. As we shall see, however, there are still important caveats that must be acknowedged. The remainder of this section will first discuss some additional conceptual issues in measuring productivity growth followed by more specific discussions of data measurement issues, international productivity comparisons, and the use of cost functions and index numbers to measure productivity growth.

Many authors specify the production function with a measure of labor input (e.g. number of hours worked) and then make adjustments for changes in the quality of labor so as to get a measure of human capital (see Denison [1962]). Some authors, however, do not (e.g. Glaser [1992]). This inconsistency stems from differences in the objectives of researchers: authors who use the correction are attempting to carefully account for changes in output that are linked to measurable changes in inputs (growth accounting), those who do not are measuring a rough approximation of welfare by looking at changes in the amount of output that can be obtained for a given unit of labor input -- i.e. how much material goods do we get for our efforts.

Inherent in the distinction just made is the notion that, for growth accounting, human and physical capital must be treated symmetrically. That is, human capital is built through investment -- requiring the postponement of consumption -- in acquiring skills much the same way physical capital is built by accumulated investment in physical equipment. Both types of capital are subject to depreciation, with human capital depreciation occurs slowly since the stock is reduced only through the withdrawl of labour services. It is this distinction that lead Jorgenson and Fraumeni (1992) conclude that residual growth is only one sixth of output growth in the post-war period when we account for student's time in building human capital.

Pushing this argument further leads us to acknowledged that output growth which is the result of research and development (R&D) -- leading to improvements in physical and human capital -- is in fact a return to the investment made in R&D. This can be distinguished from output growth that occurs through the pure synergy of labor working with capital and producing additional output with no *investment* in acquiring new knowledge. A growth accounting effort, therefore, that fully accounted for changes in inputs would have to account for returns to R&D. This treatment of R&D as a factor of production leads to the observation that firms invest in it until its marginal cost equals the value of its contribution to revenues. The residual, therefore, after accounting for the cost of R&D would imply that TFP measured primarily gains in output that were unaccounted for elsewhere; that is, it would measure quasi-rents originating in a capital/labour synergy or in excess returns to improvements in production technologies.

It should be emphasized that equation (4) is highly aggregated. To write such an equation for the aggregate economy requires not only the three assumptions outlined earlier[3] (which made equation (4) operational) but also other restrictive assumptions which are embodied in an aggregate production function. For example, since the economy produces many goods which are aggregated into a total measure of output, the aggregate production function will have many underlying sectoral production functions which must be identical replicates of the aggregate. It is not sufficient that the sectoral capital shares be equal on average to the aggregate capital share, they must be identical to the aggregate (recall that logarithms are not additive, i.e. $\log\{a+b\} \neq \log\{a\}+\log\{b\}$).

Turning to the measurement of π_t (as specified in equation 4), we begin by highlighting that, as was pointed out by Nordhaus (1987), economists have made considerable effort in measuring the rate of productivity growth but little has been done to explain the determinants of that growth rate. Models of endogenous growth (e.g. Romer [1990]) elucidate the process which creates productivity growth but do not provide explanations as to the magnitude of that growth rate; and, by implication, do not explain changes in productivity growth rates. Recent history has shown periods of high productivity growth where its average rate was .8% of GDP per year for more than two decades followed by a period of virtually no productivity growth at all. A critical transition from high productivity growth to low growth

[3]Denison (1962) provides some justification for making the assumptions previously outlined and concludes that these assumptions are tenable for the aggregate economy but are less tenable at high levels of disaggregation

seems to have occurred during the late 1960's to early 1970's (see Nordhaus, [1972] and Denison [1979]). While many anecdotal as well as empirical arguments have been suggested regarding the sources of that change, none has been found to be convincing[4].

a. Data Problems and the Measurement of a Residual

As was mentioned earlier, current estimates of TFP growth are smaller than they initially were but they remain economically very significant. The basis on which these estimates are made, however, remains the subject of some discussion among researchers -- Denison (1962) and Christensen and Jorgenson (1969) made important contributions in measuring labor and capital inputs but there remain limitations created by the lack of adequate data. Consider the level of detail necessary to adequately measure the sources of labor productivity: the amount of human capital being used for specific tasks should be known so as to control for changes in the quantity of human capital being applied to the task. Changes in human capital include changes in the level of training and education of labor and their costs should be excluded from the TFP measurement because they represent an investment: any additional output resulting from that investment cannot be considered a TFP gain if it just covers the cost of the investment.

In the past, changes in human capital have been approximated by changes in the number of years of formal schooling of the population. While this measure may in fact be correlated with the quality of the labor input the correlation may be imperfect. Indeed, Mulligan and Sala-i-Martin (1995) make this argument and show that, using their "optimal" estimates of human capital, the 1980's were a period where the average stock of human capital and the average number of years of formal education actually moved in different directions -- thus giving opposing answers to the question of whether increased dispersion in

[4]Krugman (1994) suggests that a technological catchup at the end of the war was responsible for the exceptional growth rate and was largely exhausted by late 1960's. Jorgenson (1984) suggests its principle cause was the oil price shock.

human capital may have contributed to the increased dispersion in incomes[5].

The foregoing observations are also applicable to changes in the quality of the capital input. Measurement of changes in capital should account for technological improvements that were being embodied in new capital stocks (see Solow [1960]) since the additional output from the technological improvement is a return to the investment made in obtaining the technology (R&D). Furthermore, to get a true measure of the sources of TFP growth this data would have to be available for a complete business cycle to eliminate cyclical factors (e.g. labor hoarding which would distort labor input measurements).

Another source of limitations created by the data is that output cannot always be measured in a cost efficient manner and must therefore be estimated. This problem is most common in the service sectors, especially those relating to financial services. Since the output of many service sector industries varies from firm to firm and is not always priced directly (e.g. most bank transactions are not individually priced but are paid for through the interest spread on loans and deposits), gathering exact data that could be used for TFP measurement is not feasible. In these industries output is sometimes measured as the value of the inputs -- often it is measured simply as the value of the labor input. The working premise is that productivity improvements accrue to the inputs in the form of higher returns. As a result, in the banking sector productivity improvements would, by definition, be non-existent. More generally, however, in industries where input markets are competitive while output markets are not this technique will fail to measure TFP changes because the gains will accrue to the owners of the firm (which can still be measured but only if the analysis is sufficiently detailed). Output markets may not be competitive in times technological change where new technologies create quasi-rents for innovating firms (some argue that the economy is dominated by monopolistic competition, see Akerlof, Dickens and Perry, 1996, and the references therein). Furthermore, since the output price is often not being measured correctly (see

[5]It has been suggested that formal schooling serves as a screening mechanism to identify individuals with specialized characteristics who are then channeled into professions by a self-selection process. If this is the case then formal education will be a good indicator primarily of how the screening process works and only secondarily of the quality of labor.

CBO [1995] for a discussion of problems with the Consumer Price Index), changes that go primarily to consumers in increased consumer surplus are also not being captured; for example, when neutral productivity improvements allow an industry to produce more output with the same inputs but demand elasticity is near unity there may be little change in revenues in spite of an increase in output. If the output price index is not carefully measured the changes could be completely missed in productivity analysis even though the industry would have undergone significant changes in output.

The implication of the foregoing remarks is that the elements that go into the production function for estimating TFP growth may have considerable error in their measurement. As was outlined earlier, any errors in measuring inputs poses problems for the measurement of TFP growth.

b. Non-stationary Inputs and Outputs

As is discussed in Feenstra and Markusen (1994) and Diewert (1992) new inputs and outputs not only cause mis-measurement of productivity growth but also raise questions about the usefulness of the exercise. The nature of the problem is easily understood by considering equation (2) and asking what would be the value of a measure between two time periods where the human capital could be measured consistently over time but the units of measure of capital and output had changed. They would, in essence, be two different economies which can only be compared by looking at the level of welfare attained per unit of human capital.

Perhaps the best means of dealing with this problem is to emphasize short term measures of TFP growth and make less use of long term TFP. Unfortunately, short-term TFP calculations have their own problems in dealing with business cycle issues.

Cross-Country Studies

International comparisons of TFP growth are particularly difficult because of the onerous data requirements. We have argued that the data requirements for analysis of TFP growth can be heavy when one is looking for the source of TFP growth in an economy that produces many goods and services which change over time. To conduct the same study across economies further requires that the data be consistently defined across a number of national sources. For the system of national accounts (SNA) a common definition exists and is adhered to by most of the world's national statistical agencies. However, for other data collected this is not always true; for example, most OECD countries report employment data which cannot be directly compared.

Another source of difficulties that arises in making international comparisons is that of selecting units of measurement. Since different economies tend to produce a different mix of goods and services -- which change over time -- it is not possible to simply compare the number of units being produced across countries. Fortunately, the apparatus necessary to compare national outputs has been developed considerably by a number of international organizations starting from the initial work of Heston and Summers (1980). Both the OECD and the IMF now pay special attention to obtaining indices of national output through the use of purchasing power parity (PPP) measurements (the OECD has a somewhat longer tradition of calculating PPP's). In spite of considerable effort, however, these numbers still provide measurements which fail to inspire confidence. The OECD and IMF indices often differ considerably and the OECD numbers tend to vary by uncomfortably large amounts across base years.

A third problem in making international comparisons is with the periods chosen. As was mentioned earlier, it is important to avoid periods where the business cycle might distort the measurements of TFP growth. This problem becomes even more difficult to overcome when many countries are involved because it is very unlikely that a starting and end point can be found where all countries will be at the same point in the business cycle. While this problem cannot be completely eliminated its effect can be minimized by choosing as long a period as possible, thereby distributing the measurement error over many years.

Index Numbers and Cost Functions

The discussion thus far took the production function as its point of departure, it then quickly moved to more restrictive but non-parametric form based on cost shares. The change was necessary because the production function is not econometrically identified in its unresticted form. For the parameters to be identified would require that stringent *a priori* restrictions be imposed (for a broader discussion see Diewert [1992]). As was mentioned earlier, however, there are alternatives in measuring TFP growth. A less restrictive strategy involves the use of cost functions. By assuming cost minimizing behavior and using *Shephard's Lemma* the number of parameters that must be estimated while retaining generality in the functional form can be reduced. The remaining problem with the cost function technique (which is also a problem with production function techniques) is that many parameterizations of the cost functions are possible, all of which are valid but each of which is likely to give different rates of TFP growth. Since little formal criteria exists for choosing among the alternatives, in general researchers choose one that best suits the task at hand. In many cases, however, this leads to measurements which can not be directly compared to other studies.

The most promising technique for measuring TFP growth is through the use of index numbers (Diewert [1979]). Index numbers are better suited to measuring TFP growth for two related reasons: first, most indices have a commonality in their construction so there is less contradiction with the measured values than there is with production or cost function based measurements. Second, indices do not force a particular structure on the data. This latter point is important but it may also be considered a drawback of index numbers. For example, when one is trying to account for the sources of growth, an index number provides little guidance as to how the allocation of increases in output should be divided among the inputs.

III. Literature Review

a. aggregate analysis

Table I

(1) structural change
(2) convergence to technology leader
(3) foreign trade effects
(4) economies of scale
(5) energy price shocks
(6) natural resource discovery
(7) costs of government regulation and crime
(8) labor hoarding
(9) capacity utilization effects

Source: Maddison (1987)

In spite of the problems just discussed a number of studies have undertaken a comparison of productivity growth on an international scale. One of the earliest studies was Denison (1967) where sources of growth in the United States and nine European countries were compared for the period 1950 to 1962. Denison essentially applies on an international scale the techniques he developed in earlier work (e.g. Denison [1962]) to analyze the US economy. Similar to his earlier work -- and to Solow (1957) -- the results he obtains suggest that "Advances of knowledge" was a major contributor to growth in the US and the European countries in a disaggregation that included nineteen different factors. In that work, however, Denison argues that changes in Advances of knowledge should only be measured for the most advanced economy. His reasoning is that other countries which are behind the technology leader will in general be catching up to the best practice of the leader, therefore, much of the residual that would be measured as Advances of knowledge in those countries would simply reflect implementation of existing best practice -- in other words, “adoption of knowledge”.

Maddison (1987) reviews comparative growth studies and outlines the essentials of growth accounting with an illustrative long term analysis of growth in four European countries, Japan and the United States. He divides inputs into three categories (Capital, Labor and Other Factors) and then demonstrates how successive refinements to quality change in those inputs reduces the measured to 25% of actual growth. residual . Table I lists his Other Factors. As is obvious from the table, some of the factors that might be associated with productivity growth are included as part of that input. The residual that is measured, therefore, is more a statement of unmeasurable effects than it is a measure of productivity change. Moreover, what is uncomfortably clear in his work is that TFP growth that is measured as a residual is critically dependent of the measurement and definition of the inputs. Maddison concludes that the full model can explain, on average, approximately 75% of the growth in Europe, Japan and the U.S. that occurred between 1913 and 1950, leaving a significant role for the residual "TFP" growth. He points out, however, that the ability of the model to explain growth varies across countries and across time periods.

Additional studies in productivity growth are found in Table II where we present a summary of GDP growth rates and the measured TFP growth for a number of major countries and regions. With a few notable exceptions, we find that there is surprising agreement among results. This occurs in spite of our earlier comments regarding the techniques and objectives of researchers.

Recently, new databases have been developed in the Penn World Tables and for projects at the World Bank which -- when combined with recent improvements in the International Labor Organization (ILO) databases -- make more rigorous analysis possible beyond the conventional few industrialized countries. Bosworth, Collins and Chen (1995) use the data on human and physical capital to look at the extent to which growth outside the industrialized regions is in factor deepening rather than productivity growth. They tentatively conclude that in most cases it is the mobilization of resources that accounts for growth. In an interesting application of computable general equilibrium modeling Chenery, Robinson and Syrquin (1986) examine the importance of various policy and institutional settings for the development process. Part of their survey of empirical work is presented in Table II.

Gordon (1995) attempts to examine a tradeoff between TFP growth and unemployment in the Group of Seven countries. He develops a consistent database of hours worked by pooling together data from various sources. Some of his empirical results are also found in Table II.

Table II: Studies of Economy-Wide Growth in a Range of Countries

	Maddison (1989)						Gordon (1995) (a)						Bosworth/Collins/Chen (1995)				
Country	Period	GDP Growth	TFP Growth	Cont. Capital	Cont. Labor		Period	Output Growth	TFP Growth	Cont. Capital	Cont. Labor		Period	GDP Growth	TFP Growth	Cont. Capital	Cont. Labor
U.S.	1950-73	3.65	1.49	1.02	1.14	*	1960-73	3.12	1.35	0.95	0.82	*	1960-70	3.61	0.90	0.98	1.73
	1973-84	2.42	0.25	0.84	1.33	*	1973-79	2.69	-0.14	1.31	1.52	*	1970-80	2.96	-0.50	0.97	2.49
							1979-92	2.29	0.38	1.17	0.74	*	1980-86	2.71	0.90	0.78	1.03
													1986-92	2.24	0.60	0.77	0.87
Japan	1950-73	9.29	5.47	2.37	1.45	*	1960-73	7.72	---	---		*	1960-70	10.12	5.00	4.17	0.95
	1973-84	3.72	1.99	1.00	0.73	*	1973-79	3.29	1.29	1.86	0.14	*	1970-80	4.52	0.50	2.78	1.24
							1979-92	3.98	1.63	1.83	0.52	*	1980-86	3.66	1.10	1.52	1.04
													1986-92	4.07	1.00	1.74	1.33
France	1950-73	5.13	3.69	1.07	0.37	*	1960-73	5.62	3.64	1.49	0.49	*	1960-70	5.64	2.50	2.32	0.82
	1973-84	2.32	1.47	1.20	-0.35	*	1973-79	3.84	2.39	1.52	-0.07	*	1970-80	3.66	0.80	1.76	1.10
							1979-92	2.59	1.57	0.99	0.03	*	1980-86	2.42	0.50	1.09	0.84
													1986-92	2.61	0.80	0.95	0.86
Germany	1950-73	5.92	4.14	1.59	0.19	*	1960-73	5.27	3.43	1.88	-0.04	*	1960-70	4.34	2.20	1.81	0.33
	1973-84	1.72	1.48	1.01	-0.77	*	1973-79	3.95	2.69	1.55	-0.29	*	1970-80	2.93	1.20	1.23	0.50
							1979-92	4.40	1.44	1.57	1.39	*	1980-86	2.11	0.60	0.91	0.60
													1986-92	6.64	1.40	1.75	3.49
U.K.	1950-73	3.02	1.98	0.98	0.06	*	1960-73	3.36	2.32	1.15	-0.12	*	1960-70	2.82	1.10	1.57	0.15
	1973-84	1.10	1.19	0.76	-0.85	*	1973-79	2.43	1.16	1.11	0.16	*	1970-80	2.21	0.20	1.15	0.86
							1979-92	1.51	1.22	0.13	0.17	*	1980-86	3.41	1.60	0.91	0.89
													1986-92	1.30	0.00	0.89	0.41
Canada							1960-73	3.02	2.30	0.72		*	1960-70	4.73	1.60	1.16	1.97
							1973-79	1.27	0.36	0.91		*	1970-80	4.70	0.20	1.46	3.04
							1979-92	1.41	-0.04	1.45		*	1980-86	3.31	0.60	1.38	1.33
													1986-92	2.02	-0.50	1.50	1.02
Italy							1960-73	6.71	5.56	1.15		*	1960-70	5.72	3.60	1.99	0.13
							1973-79	1.99	2.63	-0.64		*	1970-80	3.89	1.70	1.34	0.85
							1979-92	1.90	1.71	0.19		*	1980-86	2.31	0.20	0.97	1.14
													1986-92	2.39	0.70	0.88	0.81
Australia													1960-70	5.14	1.10	1.77	2.27
													1970-80	3.64	0.80	1.48	1.36
													1980-86	3.24	0.50	1.11	1.63
													1986-92	3.10	0.60	1.00	1.50
China	1950-73	5.84	0.49	2.74	2.61								1960-70	3.60	1.30	0.76	1.54
	1973-84	6.85	2.10	2.35	2.40								1970-80	4.91	0.80	2.58	1.53
													1980-86	8.49	4.00	3.06	1.44
													1986-92	7.69	2.50	3.70	1.50
Korea	1950-73	7.49	2.84	1.84	2.81	*							1960-70	6.83	0.60	4.19	2.04
	1973-84	7.38	1.42	3.03	2.93	*							1970-80	7.64	0.80	5.20	1.64
													1980-86	7.49	2.50	3.41	1.57
													1986-92	7.59	1.90	4.29	1.39
Taiwan	1950-73	9.32	3.51	2.32	3.49								1960-70	9.63	1.40	5.75	2.48
	1973-84	7.63	1.23	2.83	3.57								1970-80	8.06	1.10	4.88	2.07
													1980-86	4.50	1.80	2.10	0.60
													1986-92	5.90	2.50	2.80	0.60
India	1950-73	3.69	-0.05	1.84	1.90								1960-70	4.09	0.50	2.28	1.31
	1973-84	4.29	0.50	1.37	2.42								1970-80	3.57	-0.20	2.01	1.76
													1980-86	5.35	1.80	1.96	1.59
													1986-92	5.35	1.50	2.22	1.63
Argentina	1950-73	3.78	1.38	1.05	1.35								1960-70	4.02	1.10	1.89	1.03
	1973-84	0.69	-1.58	0.62	1.65								1970-80	3.35	-0.10	2.16	1.29
													1980-86	-0.59	-2.00	0.37	1.05
													1986-92	1.85	1.10	-0.20	0.95
Brazil	1950-73	6.75	2.13	2.15	2.47								1960-70	5.11	1.60	2.10	1.41
	1973-84	4.33	-1.97	2.90	3.40								1970-80	7.24	2.40	3.34	1.51
													1980-86	2.19	-1.10	1.58	1.72
													1986-92	-0.09	-2.60	1.02	1.48
Chile	1950-73	3.67	1.60	1.06	1.01								1960-70	4.16	1.40	1.62	1.13
	1973-84	1.24	-0.92	0.58	1.58								1970-80	1.67	0.00	0.43	1.24
													1980-86	-0.22	-1.90	0.37	1.31
													1986-92	6.75	3.80	1.66	1.29
Mexico	1950-73	6.38	1.91	2.06	2.41								1960-70	6.34	1.70	2.96	1.68
	1973-84	4.55	-0.64	2.28	2.91								1970-80	4.93	0.40	2.73	1.80
													1980-86	-0.07	-3.50	1.55	1.88
													1986-92	1.99	-0.90	0.82	2.07
USSR	1950-73	5.05	0.50	2.76	1.79	*											
	1973-84	2.16	-1.40	2.00	1.56	*											

Notes: CCJ: Christensen, Cummings and Jorgenson (1995),Ah: Aluwalia (1985), Y: Young (1994).
References for E: Elias (1978), El: Elias (1990), and D: Dougherty (1991) are found in Barro and Sala-i-Martin (1995)
(a) Gordon reports Nonfarm Private Business Sector. For Italy and Canada Output/Hour is reported.
* Labor is measured in hours worked
Growth in Labor Force is proxied by growth in population in Chenery/Robinson/Syrquin (1995) and Barro/Sala-i-Martin (1995) for non-OECD countries
In calculations for Chenery/Robinson/Syrquin (1995) and Barro/Sala-i-Martin (1995) a labor share of 0.7 was used for OECD economies and 0.6 for non-OECD economies..

Table II (continued): Studies of Economy-Wide Growth in a Range of Countries

	Chenery/Robinson/Syrquin (1995)						Barro/Sala-i-Martin (1995)					
Country	Period	GDP Growth	TFP Growth	Cont. Capital	Cont. Labor		Period	GDP Growth	TFP Growth	Cont. Capital	Cont. Labor	
U.S.	1960-73	4.30	1.30	1.66	1.34	CCJ	1960-90	3.10	0.41	1.40	1.29	D
Japan	1960-73	10.90	4.50	4.77	1.63	CCJ	1960-90	6.81	1.96	3.87	0.98	D
France	1960-73	5.90	3.00	2.63	0.27	CCJ	1960-90	3.50	1.45	2.03	0.02	D
Germany	1960-73	5.40	3.00	2.81	-0.41	CCJ	1960-90	3.20	1.58	1.88	-0.26	D
U.K.	1960-73	3.80	2.10	1.78	-0.08	CCJ	1960-90	2.49	1.30	1.31	-0.12	D
Canada	1960-73	5.10	1.80	2.20	1.10	CCJ	1960-90	4.10	0.46	2.29	1.35	D
Italy	1960-73	4.80	3.10	2.07	-0.37	CCJ	1960-90	4.10	1.97	2.02	0.11	D
Australia												
China												
Korea	1960-73	9.70	4.10	2.42	3.18	CCJ	1966-90	10.32	1.20	4.77	4.35	Y
Taiwan	1955-60	5.24	3.12	1.07	1.05	Ch	1966-90	9.10	1.80	3.68	3.62	Y
India	1960-79	6.24	-0.18	2.50	3.92	Ah						
Argentina	1960-74	4.10	0.70		3.40	E	1940-80	3.60	1.10	1.55	0.95	El
Brazil	1960-74	7.30	1.60		5.70	E	1940-80	6.40	1.85	3.25	1.30	El
Chile	1960-74	4.40	1.20		3.20	E	1940-80	3.80	1.50	1.30	1.00	El
Mexico	1960-74	5.60	2.10		3.50	E	1940-80	6.30	2.30	2.55	1.45	El
USSR												

In an interesting footnote to productivity studies, Costello (1993) constructs a simple two-factor model which is used to study TFP in five OECD countries (United States, Canada, Germany, United Kingdom and Italy). She finds that country specific cross-industry correlations are important, more important in fact than industry specific cross-country correlations. This finding is interesting because it weakens the argument for real business cycle models. If technology shocks were the main source of real fluctuations then the cross-industry correlations should be more important than the cross-country correlations, presumably because technology shocks are disbursed within an industry more efficiently than they are across industries.

Costello makes use of the commonality of cross-country studies to argue that within her model the results she obtains are consistent with shocks that come from excluded factors such as human wealth, nation-specific labor hoarding, or national infrastructure.

b. disaggregated analysis

An important disaggregated analysis of productivity growth is found in Jorgenson, Gollop and Fraumeni (1987) where national output in the U.S. is allocated to 51 sectors for the period 1949 to 1979. The significance of the study is in the considerable effort that was expended in building the necessary database to study a four factor (KLEM) production function in translog form. Table III summarizes the growth in sectoral output and its sources as presented in their work. There are surprising aspects of the table that are worth noting. First, as can be seen from the table there is substantial variation across sectors. The rate of TFP growth would appear not to be driven by technological progress that improves productivity in all sectors, but rather it seems to be sector specific -- and not even operable in some sectors (a number of sectors show negative productivity growth). Furthermore, the variation in growth rates for sectoral output attests strongly to the critique of *aggregate* analysis found in Jorgenson [1988]. Table III shows that the interesting aspect of sources of growth is found in the details more than in the whole.

Table III

Growth in sectoral output and its sources, 1949-1979 (average annual rates)

Industry	Rate of output growth	Intermediate input	Capital input	Labor input	Productivity growth
Agricultural production	0.0216	0.0128	0.0040	-0.0097	0.0146
Agricultural services	0.0297	0.0173	0.0068	0.0111	-0.0055
Metal mining	0.0142	0.0075	0.0127	-0.0004	-0.0056
Coal mining	0.0038	0.0112	0.0069	-0.0116	-0.0027
Crude petroleum and natural gas	0.0213	0.0291	0.0104	0.0031	-0.0214
Nonmetallic mining and quarrying	0.0409	0.0153	0.0178	0.0039	0.0038
Contract construction	0.0271	0.0169	0.0022	0.0074	0.0006
Food and kindred products	0.0281	0.0134	0.0018	-0.0002	0.0131
Tobacco manufacturers	0.0072	0.0116	0.0039	-0.0015	-0.0068
Textile mill products	0.0345	0.0157	0.0026	-0.0030	0.0192
Apparel and other fabricated textile products	0.0264	0.0130	0.0016	0.0009	0.0109
Paper and allied products	0.0401	0.0322	0.0054	0.0041	-0.0016
Printing and publishing	0.0323	0.0176	0.0023	0.0066	0.0058
Chemicals and allied products	0.0591	0.0329	0.0091	0.0050	0.0121
Petroleum and coal products	0.0271	0.0422	0.0024	0.0005	-0.0179
Rubber and misc. plastic products	0.0477	0.0259	0.0062	0.0113	0.0043
Leather and leather products	-0.0047	-0.0023	0.0005	-0.0054	0.0025
Lumber and wood products except furniture	0.0288	0.0245	0.0045	-0.0011	0.0009
Furniture and fixtures	0.0373	0.0281	0.0029	0.0038	0.0026
Stone, clay, and glass products	0.0382	0.0281	0.0057	0.0038	0.0007
Primary metal industries	0.0128	0.0154	0.0023	0.0011	-0.0059
Fabricated metal industries	0.0350	0.0200	0.0037	0.0062	0.0050
Machinery, except electrical	0.0417	0.0240	0.0062	0.0080	0.0036
Elec. machinery, equipment, and supplies	0.0580	0.0262	0.0058	0.0102	0.0158
Trans. equipment and ordnance. except motor vehicles	0.0559	0.0408	0.0013	0.0100	0.0039
Motor vehicles and equipment	0.0451	0.0285	0.0053	0.0022	0.0091
Professional photographic equipment and watches	0.0569	0.0217	0.0102	0.017	0.0081
Misc. manufacturing industries	0.0340	0.0243	0.0037	0.0015	0.0046
Railroads and rail express services	0.0053	-0.0046	0.0019	-0.0108	0.0187
Street rail., bus lines, and taxicabs	-0.0217	-0.0063	0.0036	-0.0044	-0.0147
Trucking services and warehousing	0.0488	0.0222	0.0072	0.0078	0.0116
Water transportation	0.0040	0.0058	0.0011	-0.0019	-0.0009
Air transportation	0.0957	0.0421	0.0103	0.0153	0.0281
Pipelines, except natural gas	0.0493	0.0133	0.0282	-0.0014	0.0093
Transportation services	0.0268	0.0488	0.0034	0.0049	-0.0304
Telephone, telegraph, and misc. comm. services	0.0688	0.0077	0.0234	0.0087	0.0290
Radio and television broadcasting	0.0132	-0.0064	0.0185	0.0216	-0.0205
Electric utilities	0.0628	0.0227	0.0275	0.0034	0.0092
Gas utilities	0.0531	0.0403	0.0106	0.0024	-0.0001
Water supply and sanitary services	0.0328	-0.0031	-0.0001	0.0048	0.0312
Wholesale trade	0.0425	0.0064	0.0090	0.0127	0.0145
Retail trade	0.0293	0.0091	0.0043	0.0056	0.0103
Finance,insurance, and real estate	0.0493	0.0341	0.0031	0.0076	0.0044
Services. exc. private households and institutions	0.0377	0.0286	0.0064	0.0078	-0.0052
Private households	0.0491	0.0000	0.0499	-0.0008	0.0000
Institutions	0.0373	0.0146	0.0105	0.0182	-0.0059
Federal public administration	0.0173	0.0000	0.0000	0.0173	0.0000
Federal government enterprises	0.0141	0.0000	0.0000	0.0141	0.0000
State and local educational services	0.0457	0.0000	0.0000	0.0457	0.0000
State and local public admin.	0.0362	0.0000	0.0000	0.0362	0.0000
State and local enterprises	0.0363	0.0000	0.0000	0.0363	0.0000

Source: Jorgenson, Gollop and Fraumeni (1987)

An analysis conducted by Englander and Mittelstadt (1988) examined aggregate TFP growth for twenty OECD countries. Their analysis lacked some of the qualitative refinements made by earlier studies; however, that shortcoming was offset by the international scope of their comparison. In their work, TFP is the residual after accounting simply for the increase in gross capital stocks and the number of people employed (using fixed weights for the inputs). As such, their productivity measure captures quality changes in labor and changes in other inputs such as energy and resources). Nonetheless, since the same assumptions are made for all countries the study can provide some indication of the extent to which other factors had differential effects. Since the work is disaggregated by sector for all countries it permits some insight into difference in the sources of underlying sectoral growth. Table XIII in section V (on page 40) includes some of the results of their study. There we find a wide divergence in TFP in many sectors across the OECD countries. That wide divergence, once we have controlled for employment, capital and technology, suggests that TFP is affected in important ways by other forces.

An important and in-depth look at measurement problems and data reliability in using national accounts data to measure productivity growth is found in Baily and Gordon (1988). There has always been an acknowledgment that national accounts data do not fully measure economic activity and, by corollary, fail to correctly measure productivity improvements. There are, however, two issues that need to be distinguished. First, inaccurate measurement of the *level* of economic activity would lead to mis-measurement of the level of productivity of any factor input. Next, inaccurate measurement of *changes* in economic activity -- caused by a poor correspondence between the true underlying rate of growth and the growth of economic transactions actually measured -- would cause a mis-measurement of rates of productivity growth. This distinction must be made because a strong defense of the current measurements is that while they may not provide a full accounting of the level of economic activity, they are comprehensive enough to provide an accurate gage of the rate of change of economic activity; that is, the omitted factors are either too small to be distorting the growth rate or changes in those factors correspond closely to the mean of changes in the other factors which are measured accurately. Baily and Gordon

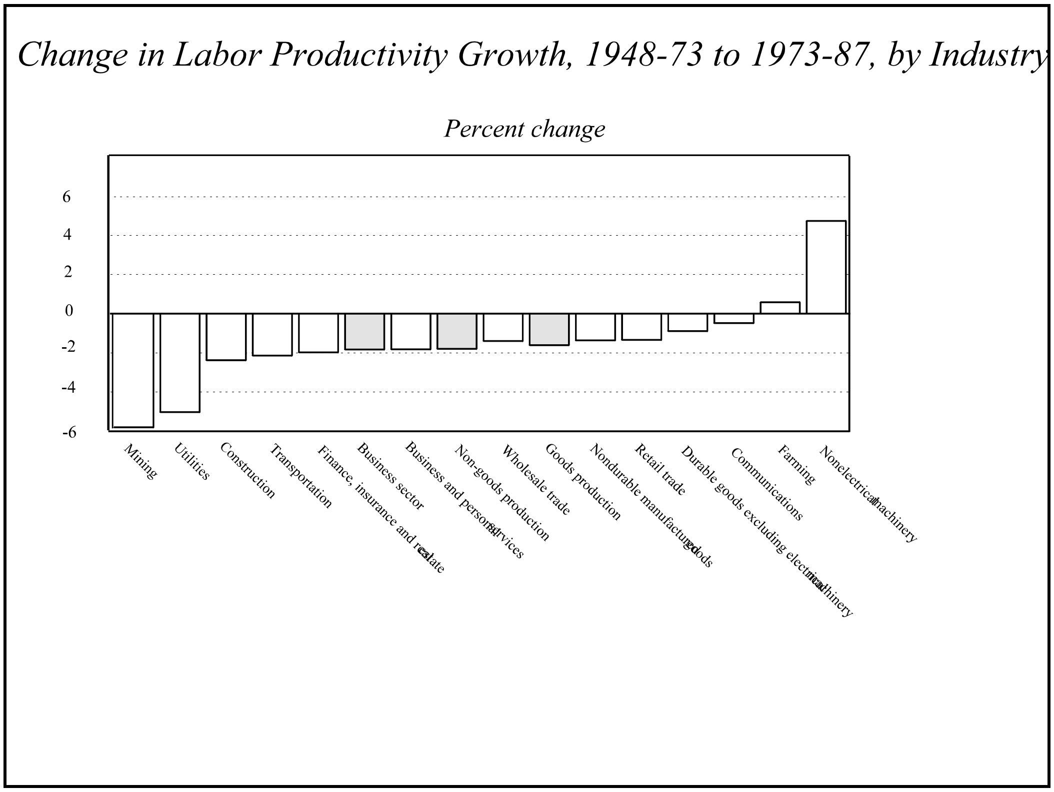

Figure I, *Source*: Baily and Gordon (1988)

provide a wide ranging treatment of measurement issues in average labor productivity by looking at four areas and focus on how those areas may result in the mis-measurement of productivity growth. They also provide convincing evidence of the aggregate nature of the change in productivity that occurred during the early 1970's. Figure I illustrates that in a sixteen sector disaggregation of the U.S. economy all but one sector experienced a major downturn at that time. The pervasive nature of the change seen in the figure suggests that its source was common to all sectors. This figure, therefore, provides a strong counter-argument to those who claim that aggregate productivity analysis cannot provide useful information about TFP growth.

c. biases in technical change

Biases in technical change are an important area of study because they demonstrate the economy's ability to both create and respond to relative price changes. For example, we would expect that a factor of production that is becoming more expensive over time would be substituted away in the production process. But we might also expect that there will be improved technological efficiencies in using that input (i.e. biased technical change). Empirical studies find considerable evidence to suggest that technical change is not neutral -- as we can see from table IV of U.S. aggregate growth.

Table IV
Biases in technical change

Study	Period	Input	Factor Augmentation	
Yuhn	1962-1981	K	17.1%	
	private, non-farm	L	4.9%	*
		E	-4.4%	
		M	1.9%	
Brown-De Cani	1980-1950	K	Labor-saving	
	private, non-farm	L	Labor-using	
David-van de Klundert	189-1960	K	1.6%	*
	aggregate	L	2.3%	*
Ferguson	1929-1963	K		
	manufacturing	L	1.5%	*
Kalt	1929-1967	K	-0.01%	
	aggregate	L	2.2%	*
May-Denny	1947-1971	K	3.8%	
	manufacturing	L	2.2%	*
		M	-0.2%	
Panik	1929-1966	K	Labor-saving	
	aggregate	L		
Sato	1909-1960	K	1.3%	*
	private, non-farm	L	2.0%	*
Wilkinson	1899-1953	K	Labor-saving	
		L		

Source: Yuhn (1991), Note: * statistically significant.

They find a predominance of labor-saving (i.e. Harrod-neutral) technical change at an aggregate level. The range of values for the rate of labor saving is from 1.5% to 2.3%. The May and Denny (1979) study uses a translog production function for estimation while the others use either a constant elasticity of substitution function or a variant thereof.

In a sectoral study that appears to contradict many of the results shown in Table IV, Jorgenson and Fraumeni (1981) find that in a 35 sector disaggregation of the U.S. economy all but four sectors are labor using while all but eleven are capital using. Since most sectors exhibit this characteristic it is unlikely that the differences arise in the aggregation. One possible explanation for the contradictory results may be in the measurement of labor. Jorgenson and Fraumeni use an adjustment for labor quality while the studies cited above do not. In estimation, when no adjustment is made for labor quality there will be a bias toward finding labor-augmenting technical change if the changes in labor quantity are correlated with the changes in labor quality. This correlation may result from improvements in labor quality changing the relative price of leisure thereby inducing a partial substitution away from leisure. This would, of course, have to dominate any income effect resulting from improvements in labor quality -- the post-World War II period does show simultaneous increases in labor quality and labor-force participation rates.

Looking at the Japanese economy Kuroda, Yoshioka and Jorgenson (1984) find that in a 30 sector disaggregation of the Japanese economy technical change is labor saving in all sectors and material using in all sectors except Food & Kindreds and Petroleum. It is also energy saving in 26 sectors but energy using in the Machinery and Finance sectors. With respect to the capital input it is capital using in 22 sectors but capital saving in 7 sectors. These results refer to the period from 1960 to 1970. The findings differ somewhat from those in the U.S. but we note that Japan had different circumstances. For example, labor supply growth in the U.S. was much faster than it was in Japan -- in the U.S. the female participation rate increased considerably from the late 1960's. As well, immigration created considerable increases the general population.

Notice again that the tendency of sectors in both countries to exhibit a high degree of similarity of biases in technical change implies that aggregation can provide useful information regarding the aggregate effect of technical change.

IV. TFP Growth in a 12 Sector Disaggregation

As was mentioned earlier, our interest in productivity growth is focused on the 12 sector disaggregation found in the GCUBED model[6]. In this section we survey historical factors affecting

[6]See McKibbin and Wilcoxen (1995).

productivity in each of those sectors:

Table V.

1	Electric Utilities
2	Gas Utilities
3	Petroleum Refining
4	Coal Mining
5	Crude Oil and Gas Extraction
6	Mining
7	Agriculture
8	Forestry and Wood Products
9	Durable Manufacturing
10	Non-durable Manufacturing
11	Transportation
12	Services

1. Electric Utilities

Productivity growth in electric utilities is consistent with the view that much of the rapid productivity gain of the post-World War II period can be attributed to technological advances that occurred during the war -- making the subsequent slowdown inevitable as that technology was fully developed[7]. As is outlined in Gordon (1992) the basic technology used to generate electricity was mature by the end of the war but the design of turbines that fully utilized advances in metallurgy and advances in knowledge of optimal temperature and pressure ranges could only be implemented in succeeding generations of turbines (considerable learning-by-doing was occuring). By the late 1960's, however, scale economies had not only been exhausted but they had actually been exceeded. Many of the very large turbines built during the 1960's were subject to higher rates of maintenance outages than were their smaller predecessors. Thus during the decade that followed, labor productivity growth levelled off and even showed some decline as the newer equipment proved less reliable than the older equipment. The following table illustrates this point nicely:

[7]Baumol (1986) outlines this view.

TABLE VI. Selected Characteristics of New Plants and All Plants, Selected Intervals, 1948-1987

	Average Annual Number of Plants		Output per Employee (millions KWH)		Average Capacity		Average Utilization Rate (percent)	
	New (1)	All (2)	New (3)	All (4)	New (5)	All (6)	New (7)	All (8)
1948-50	11	70	8.20	6.03	85	139	64	62
1951-53	10	105	11.01	8.13	121	168	67	64
1954-56	9	137	20.39	10.63	259	219	59	59
1957-59	8	157	22.53	12.18	221	254	65	54
1960-62	5	174	29.68	14.63	325	324	62	51
1963-65	8	188	29.50	18.95	347	381	61	53
1966-68	6	203.	39.15	23.54	651	462	59	57
1969-71	6	216	33.90	26.00	578	561	48	57
1972-74	8	240	30.87	27.78	862	681	44	53
1975-77	11	260	30.40	27.16	749	769	42	47
1978-80	8	270	18.82	25.09	818	834	42	47
1981-83	5	228	20.33	26.06	794	1009	46	47
1984-85	4	197	18.46	25.71	946	1174	46	47
1986-87	2	194	12.77	25.56	921	1195	35	47

Source: Gordon (1992)

The relevant data is shown in the column labeled Output per Employee. There we see that after 1968 the output of new plants begins to fall dramatically to a level almost one third lower by the time the oil crises occurred[8]. Part of this story is obviously explained in the last column labeled Average Utilization Rate where we see that plants began operating at lower capacity than they had been in earlier periods, however, the fall in output per employee is larger than the fall in utilization rates.

The Bureau of Labor Statistics looked at TFP growth in the utilities services sector for the period 1948 to 1988 (Glaser [1993]). They chose to split the period at 1973 and, not surprisingly, found a substantial slowdown after 1973, particularly in the use of capital and labor. The results are a useful complement to Gordon’s work because they show the extent to which the oil price shocks affected the input composition of the utility services sector and thus allows us to have a sense of how important the oil price shock was relative to the slowdown resulting from the general exhaustion of technological advances; for example, the marked slowdown in capital and labor productivity growth relative to energy

[8]After the oil crisis labor productivity data would be affected by increased demand for coal. That is, since the oil crisis made coal cheaper than oil, demand for coal increased. Coal requires a greater labor input for handling and transportation so that , beginning in 1973, measures of labor output would not be very indicative of changes in technology for electric utilities.

and materials productivity growth that they illustrate suggests that the former (capital and labor) were substituted for the latter to a very high degree following the relative price change. Such a large substitution would have dominated the technology growth slowdown, suggesting that productivity growth in those sectors is more closely related to the oil price shock than it is to alternative influences.

Using the data that underlie table IV we obtain the following TFP growth measure for the electric utilities:

Total Factor Productivity Growth

	1950-59	1960-69	1970-79
Electric Utilities	2.0	2.4	-1.7

Source: Author's calculation from Jorgenson, Gollop and Fraumeni (1987)

Jorgenson and Kuroda (1992) estimate that total factor productivity growth in a combined utilities sector (electric and gas) was -1.1 for the 1980-85 period.

2. Gas Utilities

Gas utilities in the U.S. have long been subjected to regulation. That regulation was, in the past, flexible enough to permit significant increases in total factor productivity -- Aivazan, et. al. (1987) estimate that TFP growth during 1953-1979 averaged 3.33% per year. However, Sickles and Streitwieser (1992) report that after the partial deregulation of 1978 with the Natural Gas Policy Act (NGPA) there were no further increases in productivity. One explanation for this observation would be that firms chose to move to a new long run equilibrium by increasing prices and allowing demand to fall. When output fell productivity increases would have been difficult to obtain because the nature of gas pipeline transmission does not allow capital to be easily withdrawn -- the most likely outcome would have been productivity decreases. Therefore, it is possible that technology continued to improve but its effects were offset by falling output. That firms chose to allow prices to rise and demand to fall is consistent with the state of known recoverable reserves where the ratio of current consumption to known reserves is approximately nine years: with this level of reserves firms may have chosen to begin collecting scarcity rents on the reserves.

If this conjecture is correct then we should not expect future productivity growth to be very rapid in these sectors. For the world as a whole, however, the picture is somewhat different. The ratio of current consumption to known recoverable reserves is approximately 64 years for all countries combined (assuming easy transportation of liquefied natural gas). But, unlike the U.S., much of the world remains unexplored. Most of the known reserves exist in a few countries (the former U.S.S.R. countries have approximately 42% of known world reserves) and there is potential for substantial productivity improvements within those countries.

Using the data that underlie table IV we obtain the following total factor productivity growth measure for the gas utilities:

Total Factor Productivity Growth

	1950-59	1960-69	1970-79
Gas Utilities	0.3	0.8	-1.8

Source: Author's calculation from Jorgenson, Gollop and Fraumeni (1987)

Jorgenson and Kuroda (1992) estimate that total factor productivity growth in a combined utilities sector (electric and gas) was -1.1 for the 1980-85 period.

3. Petroleum Refining

Petroleum refining is one of the few industries where little has changed in the past 50 years. The basic technique of catalytic cracking for refining of high octane gasoline (which, along with jet fuel and diesel oil, comprise the bulk of refined petroleum products) was discovered in the early part of this century and has been subject to only minor improvements in plant design. As a result, TFP growth has been slow in that industry for some time.

Both Hibdon and Mueller (1990) and Shoesmith (1988) find evidence of **U**-shaped long run cost curves for refineries, suggesting that there is an optimum scale to which firms have been moving. Hibdon and Mueller (1990) in particular find evidence of a very stable trend to an optimum scale which appears unchanged during the period of their examination 1947-84.

Looking back to table IV we see that a broader grouping titled Petroleum and Coal Products Productivity as a whole suffered a decline for the period 1949-79. Jorgenson and Kuroda (1992) also estimate total factor productivity growth in the same combined sector and obtain a growth rate of 4.1 percent per annum for the 1980-85 period. Using the data that underlie table IV we have interpolated the following total factor productivity growth measure for the petroleum refining industries:

Total Factor Productivity Growth

	1950-59	1960-69	1970-79
Petroleum Refining	0.1	0.1	0.1

Source: Author's interpolation from Jorgenson, Gollop and Fraumeni (1987)

4. Coal Mining

The coal mining industry in the U.S. presents an interesting study in productivity analysis. For the first decade and a half after the second world war it experienced positive TFP growth (Jorgenson, Gollop and Faumeni [1987]) and continued to experience positive labor productivity growth until 1969 (Sider [1983]). That period was followed, however, by a long sustained fall in both measures of productivity which, during the 1970's, became quite severe.

While causal relationships are always difficult to establish, there are two major events which affected the coal mining industry which are suggestive of possible explanations for the slowdown. The first is the Coal Mine Health and Safety Act of 1969 (CMHSA) which mandated a number of operational changes in mining activity with the goal of reducing occupational hazards for coal miners[9]. The second is the oil price shock of 1973-74. Both of these events would be expected to reduce productivity: the

[9]These operational changes had substantial cost implications for the mining companies -- Kruvant, Moody and Valentine, [1982] estimate that temporarily disabling injuries were reduced at a marginal cost of $75,000 -- which have not, as yet, been shown to have yielded large benefits in terms of occupational safety: both Sider (1983) and Kruvant, Moody and Valentine (1982) find a positive relationship between changes mandated by CMHSA and temporarily disabling injuries but find no relationship between CMHSA and permanently disabling injuries or death.

CMHSA because resources had to be diverted away from mining and into support activity; the oil shock because all mines that previously were unprofitable to operate suddenly became viable and were pressed into service. There are, however, other factors which would be important in any projection of future TFP growth rates. In their firm level study Kruvant, Moody and Valentine (1982) find that geological factors dominate other factors as coal extraction proceeds. Therefore, while productivity is likely to improve over the short run, the long term trend will be to stagnate or fall after the turn of century if new and easily accessible deposits are not found.

Using the data that underlie table IV we obtain the following total factor productivity growth measure for the coal mining industry:

Total Factor Productivity Growth

	1950-59	1960-69	1970-79
Coal Mining	3.6	1.9	-5.2

Source: Author's calculation from Jorgenson, Gollop and Fraumeni (1987)

Jorgenson and Kuroda (1992) estimate that total factor productivity growth in a combined mining sector (all mining activity) was -.9 for the 1980-85 period.

5. Crude Oil and Gas Extraction

Crude oil and natural gas extraction have been influenced by two factors which generally work to offset each other but which, in the past, have produced improvements in total factor productivity. The dominant factor in the past has been technology improvements which have been felt in everything from geological exploration to bookkeeping with personal computers. Opposing this trend has been the increasing cost of finding and extracting crude oil and natural gas both in the U.S. and elsewhere. In the U.S. all of the areas that have traditionally been oil producing regions are now in decline with even Alaska already showing declining production levels (see Friedman, [1992]). Moreover, since enhanced recovery techniques tend to be labor intensive (relative to simply putting a wellhead on a new reservoir and controlling the flow), there is likely to be an inverted relationship between productivity and output price; that is, if prices increase then marginal wells will be brought back on-line with enhanced recovery techniques so productivity may actually fall. On the other hand, falling prices would eliminate many of the enhanced recovery wells currently in operation thereby increasing productivity.

Since the global consumption-to-known-recoverable-reserves ratio is currently 95+ years[10] it seems unlikely that scarcity will create any long term secular increases in prices in the near future. Therefore modest continuing increases in productivity should continue for some time.

Using the data that underlie table IV we obtain the following total factor productivity growth measure for the crude oil and gas extraction industry:

Total Factor Productivity Growth

	1950-59	1960-69	1970-79
Crude Oil & Gas Extraction	0.2	1.3	-7.9

Source: Author's calculation from Jorgenson, Gollop and Fraumeni (1987)

6. Mining

The mining industry has in general shown a pattern similar to that of electric utilities -- discussed earlier. Technological innovations which had occurred rapidly in excavation and transportation equipment, as well as in metallurgy, were understood well enough that their consequence could be somewhat foreseen by the early 1950's. The implementation of these innovations could, however, only occur over new generations of equipment where the engineering problems could be solved in stages until full exploitation of the technology occurred. In other words, it was understood that larger excavation and hauling capacities were possible with the technologies already in place; however, since the optimal capacity was not known, it would have to be discovered by incrementally building ever larger equipment. Thus, dump trucks which had capacities of between 22 and 34 tons in the 1950's achieved capacities of 170 tons by the mid-1980's (see Stollery [1985]). The leveling off of capacity increases suggests that

[10]This compares to the current-consumption-to-known-recoverable-reserves ratio of 35 years which existed in 1974 at the time of great concern regarding oil supplies.

either larger trucks were not feasible with existing truck building technology or that larger trucks provided no additional benefit to mine operation (i.e. other equipment could not handle the additional haulage). In either case it will be observed that productivity growth slowed because technological innovations were largely exploited.

Undoubtedly the most important component in mining productivity is the quality of the ore being mined. Productivity is measured in terms of a final product which is often a refined ore; therefore, a deterioration in the input ore grade would, by itself, lower productivity of other factors. A typical scenario for mine activity is that excavation begins at the center of a deposit where the ore is at its highest purity, as that ore is used up mining will continue until the rising marginal cost created by deteriorating ore grade surpasses the price of the refined product.

On a national scale a somewhat different process will be at work. The geologically most accessible deposits will first be found and exploited. Over time a fairly complete geological map will be created and diminishing returns to further exploration will become severe. This will be accompanied by an overall deterioration of the *average* quality of ore being mined. If international sources of higher quality ore become available then this scenario need not have any implications for the price of the refined ore. These international sources will, however, slow down the productivity decline by shrinking the domestic industry -- firms which are experiencing a deterioration in ore quality will be forced out of business sooner.

The process just outlined appears to be operational in the United States. Geological surveys of the United States are more complete than for any other large country in the world. For many minerals the U.S. has already achieved the theoretical predictions of McKelvey's formula[11] and diminishing returns to exploration are occurring. Indeed, oil and gas exploration in the U.S. is a prime example of this phenomenon.

---

[11] See McKelvey (1961).

Using the data that underlie table IV we obtain the following total factor productivity growth measure for the mining industries:

Total Factor Productivity Growth

	1950-59	1960-69	1970-79
Mining	0.4	0.2	-1.2

Source: Author's calculation from Jorgenson, Gollop and Fraumeni (1987)

Jorgenson and Kuroda (1992) estimate that total factor productivity growth in a combined mining sector (all mining activity) was -.9 for the 1980-85 period.

7. Agriculture, Fishing and Hunting

Agriculture is perhaps a prime industry with which to illustrate, by opposite example, a phenomenon which has been dubbed the *Baumol effect*. The urbanization of America, which began in the 19th century, had by the end of the Second World War already had its greatest impact. Yet, at the end of the war agriculture still represented some 9% of U.S. output. By 1985, after some 38 years of total factor productivity growth which averaged 1.6% per year it had been reduced to 1.9% of U.S. output (see US Department of Commerce [1975], US Department of Commerce [1988], and Jorgenson and Gollop [1992]). This is not an industry which contracted in absolute size, but rather its productivity growth was so rapid that it required a continually diminishing share of the economy's resources to produce an ever increasing amount of output.

In the future, productivity growth in agriculture may not have as profound an effect on total output in the U.S. as it has had in the past but there is little reason to believe that productivity growth will not continue. Moreover, there is considerable scope for rapid productivity improvements in agriculture in the non-industrialized world where simply applying current best-practice would yield considerable labor productivity gains[12]. In summary, agricultural productivity growth on a global scale can be predicted to

[12]This comment does not imply that current techniques in those countries are suboptimal. Given relative costs (i.e. the costs of labor and capital) in those countries those techniques are likely to be rational choices.

continue at its postwar rate for a long time to come.

Using the data that underlie table IV we obtain the following total factor productivity growth measure for the agricultural sector:

Total Factor Productivity Growth			
	1950-59	1960-69	1970-79
Agriculture	1.7	2.1	0.7

Source: Author's calculation from Jorgenson, Gollop and Fraumeni (1987)

Jorgenson and Kuroda (1992) estimate that total factor productivity growth in the agricultural sector 4.9 percent per annum for the 1980-85 period.

9. Durable Manufacturing

Table VII shows TFP growth in U.S. manufacturing industries for selected periods from two datasets. Both productivity studies measure total factor productivity based on the standard KLEM factor input model. The method used to calculate the labor input, however, differs in the two models. The BLS measures simply hours of labor worked while Jorgenson and Kuroda measure labor input by using hours worked which they adjust for quality changes through the use of wage data. In other words, Jorgenson and Kuroda would measure more use of higher wage labor as a change in the quality of the labor input. The measured differences are important as can be seen in tables VII and IX.

Table VII

	BLS				**Jorgenson and Kuroda**		
Industry	**1949-88**	**1960-70**	**1970-80**	**1980-85**	**1960-70**	**1970-80**	**1980-85**
Total Manufacturing	1.3	1.40	0.89	1.34			
Durable goods	1.3	1.46	1.07	1.44			
Lumber and wood products	1.6	3.53	1.04	-0.53	1.24	-0.62	1.11
Furniture and fixtures	0.6	0.54	1.29	0.20	0.54	1.13	0.24
Stone, clay, and glass products	0.7	0.53	-0.08	0.79	0.76	0.20	1.48
Primary metal industries	-0.2	-0.03	-0.71	-0.54	0.27	0.45	0.84
Fabricated metal products	0.6	0.44	0.26	0.39	0.69	0.43	0.32
Machinery, except electrical	1.7	1.22	1.90	3.31	0.98	1.53	2.13
Electrical and electronic equip.	2.1	2.86	2.58	1.43			
Transportation equipment	1.0	0.89	0.84	1.01			
Instruments and related products	1.4	1.30	1.29	0.86			

	BLS				Jorgenson and Kuroda		
Miscellaneous manufacturing	1.1	1.10	-0.51	2.56	0.62	-0.34	-0.25

Source: BLS Multifactor Productivity Dataset, Gullickson (1992), Jorgenson and Kuroda (1992).

The failure to account for changes in labor quality should result in the BLS overestimating total factor productivity growth. As we see in table VIII this is generally true:

Table VIII 1960-85 difference in total factor productivity growth rates between BLS and Jorgenson and Kuroda (positive numbers imply larger BLS growth rate).

Durable goods		Non-durable goods	
Lumber and wood products	1.25	Food and kindred products	0.17
Furniture and fixtures	0.06	Tobacco manufactures	
Stone, clay, and glass products	-0.34	Textile mill products	0.61
Primary metal industries	-0.86	Apparel and related products	
Fabricated metal products	-0.15	Paper and allied products	0.22
Machinery, except electrical	0.48	Printing and publishing	0.38
Electrical and electronic equip.		Chemicals and allied products	0.60
Transportation equipment		Petroleum products	
Instruments and related products		Rubber and misc. plastic products	0.23
Miscellaneous manufacturing	0.69	Leather and leather products	0.46

The difference between the two studies are significant and imply a substantial improvement in labor quality for the given periods.

10. Non-durable Manufacturing

Table IX provides a look at non-durable manufacturing in the U.S. for several time periods from the two datasets just discussed. The pattern is not much different from that of the durable goods industries. It suggests that the 1970's were a period of unusually low productivity and that the 1980's have seen something of a return to earlier rates of growth.

Table IX

	BLS				Jorgenson and Kuroda		
Industry	**1949-88**	**1960-70**	**1970-80**	**1980-85**	**1960-70**	**1970-80**	**1980-85**
Non-durable goods	1.0	1.09	0.52	1.03			
Food and kindred products	0.6	0.68	0.21	1.14	0.61	0.22	0.42
Tobacco manufactures	0.0	1.29	-0.09	-3.74			
Textile mill products	1.6	1.86	1.81	0.81	1.40	0.78	0.76
Apparel and related products	1.1	0.43	2.06	0.71			
Paper and allied products	1.0	0.73	0.64	1.87	1.02	0.16	1.15
Printing and publishing	0.3	0.56	0.06	-0.14	-.25	0.18	-0.67
Chemicals and allied products	1.8	1.55	0.29	1.70	1.52	-1.25	1.85
Petroleum products	0.4	0.64	0.08	-0.37			

Rubber and misc. plastic products	1.0	1.10	0.26	3.23	1.85	0.04	1.02
Leather and leather products	0.4	0.07	1.47	-0.73	0.48	-0.15	-0.59

Source: BLS Multifactor Productivity Dataset, Gullickson (1992), Jorgenson and Kuroda (1992).

11. Transportation

The existence of a large database can by itself create a significant literature as researchers take advantage of the database to test ideas and techniques. The transportation sector is often cited as a case-in-point. Although the transportation industry (comprising principally of rail, trucking and airline transportation) is a small part of total economic activity, its significant database, accumulated under a long period of regulation, has drawn a disproportionate amount of interest from economists. This is advantageous for our purposes since it provides a large reservoir of high quality work from which to draw on.

A recent addition to that literature is Gordon (1991) where an extensive discussion of data published by the Bureau of Labor Statistics and also the data tabulated from the National Income and Product Accounts is provided. Both these sources have provided either total factor productivity estimates or average labor productivity estimates for some time. He finds that both data sources have strengths and weaknesses so that an optimal strategy would involve combining data from both sources.

As with most sectors of the economy, productivity appears to have slowed some time during the early 1970's. Unlike other sectors, however, the transportation sector underwent a major change in the institutional setting in which it operates. Deregulation in 1979 resulted in a new routing structure in the airline industry and an overhaul of much of the inter-city trucking industry. To some extent, however, these changes have failed to live up to the promise of deregulation. Gordon (1991) finds that total factor productivity in airline and trucking has performed poorly since those industries were deregulated and that only rail transport has shown any marked improvement[13]. An interesting question that arises is whether

[13]Note, however, that this is only one dimension with which to measure the success of deregulation.

the change in the institutional environment would simply have caused a level divergence of productivity from its fully competitive realization or if it would have caused a divergence of growth rates. This is an important issue because in the former case there is still much to be learned from the historical series whereas the latter case implies that we can only learn from the post-1979 data.

Gordon's preferred measure of total factor productivity gives the following result:

Table X. Total Factor Productivity in Transportation, 1948-87

	1948-59	**1959-66**	**1966-73**	**1973-79**	**1979-87**	**1948-73**	**1973-87**	**1948-87**
Total Factor Productivity *Annual Growth, Cyclically Adjusted*	2.02	3.63	1.78	1.67	2.05	2.40	1.89	2.22

Source: Gordon (1991)

It would appear from this table that the post-1979 period was not atypical of historical experience in the transportation sector as a whole. Indeed, there appears to be a slight recovery of productivity growth through the 1980's. There is, therefore, a dichotomy between the performance of the deregulated industries and transportation as a whole.

Using the data that underlie table IV we obtain the following total factor productivity growth measure for the transportation industries:

Total Factor Productivity Growth

	1950-59	1960-69	1970-79
Transportation	1.4	0.6	0.5

Source: Author's calculation from Jorgenson, Gollop and Fraumeni (1987)

From Jorgenson and Kuroda (1992) we estimate that total factor productivity growth in the transportation sector was .82 percent per annum for the 1980-85 period.

12. Services

Service sector productivity is not as well measured as is manufacturing productivity but -- as is outlined in Baily and Gordon (1988) -- it can still be a useful source of information. Moreover, the size of the service sector makes it a dominant determinant of overall productivity levels -- suggesting that perhaps we should be less sanguine about the accuracy of aggregate productivity growth.

The measurement problems that exist in the services sector are well known and have been documented elsewhere. The most notable problem is that the output of some service industries is not very well defined, e.g. government, finance, insurance, and real estate. The question that arises is how to quantify and value the output of sectors which act as intermediaries in transactions. For example, how does one measure productivity in the insurance industry? Should we measure TFP growth on the basis of number of insurance policies written, or number of claims processed, or perhaps even the total value of insured products. Even in other service sectors such as medical, personal, etc. (where output is no more tangible but where it may be more easily quantified), productivity is difficult to measure because there is a continuum of products and prices that makes finding a homogeneous category of goods which can be consistently measured over time very difficult. In the case of medical services, for example, questions arise regarding the <u>definition</u> of output. Should it be number of patients seen or number of procedures performed, or perhaps even number of illnesses treated? All of these numbers will give different measures of output and almost certainly different rates of TFP growth.

The current practice in many of these problem sectors is to measure output by the value of the labor input. Obviously this precludes any meaningful analysis of TFP since it biases downward productivity measures. Baily and Gordon (1988) argue, however, that these sectors are small relative to total GDP (they show that even if we remove these sectors from the productivity measures we still get a significant slowdown in the early 1970's). Nevertheless, other sources of bias may be manifesting themselves in the data. Table (XI) shows that at least two of the services sectors had large slowdowns through the 1980's. Since this was a period of increased computer use in those industries one would expect that either firms were investing unwisely or that a measurement problem exists.

Other problems are known to exist in measuring productivity in services which are of varying degrees of importance. For example, there are many changes which have occurred in services which increase consumer surplus without increasing productivity -- some changes may even reduce productivity while increasing consumer surplus. The retail trade industry is a case-in-point. The extension of hours of operation into late evenings and Sundays provided greater flexibility for shoppers but reduced the sales volume per salesperson.

The previously mentioned continuity of quality and price for service sector output is perhaps the most important distinguishing feature of services relative to manufactured goods. For example, goods such as automobiles are available only in discreet units of predefined quality. While the selection may seem large enough to roughly approximate a continuous choice of attributes it is nonetheless much smaller than the range of attributes available in services. An important reason for this phenomenon is that with services the labor input can be more easily adjusted than it can with manufactured goods. There is thus more ability to price discriminate by suppliers by making quality adjustments for individual customers. They can also change the base quality of their product in response to changes in market conditions -- something a large manufacturing plant would have to incur adjustment costs to achieve. The implications of this observation for productivity analysis can be significant. If the quality of services is relatively easy to change then getting the price index right becomes crucial to getting a correct TFP measure. But price indices, as currently constructed, at best capture general movements in the underlying prices and almost certainly do not capture the subtle movements that productivity analysis would require.

Total factor productivity in the major service sectors has, nonetheless, been estimated for the 1948-85 period by the American Productivity Center (see Kendrick [1987]).

Table XI. Total Factor Productivity in Services, 1948-85

Total Factor Productivity *Annual Growth*	**1948-73**	**1973-79**	**1979-85**	**1948-85**	**Share of GCUBED Service Sector Output**
Communications	4.9	2.4	1.3	3.9	6.7
Trade	2.5	0.4	0.8	1.9	41.3
Finance and Insurance	1.1	-0.7	-2.0	0.3	10.0
Real Estate	1.3	1.4	-3.2	0.6	10.8
Services	0.7	0.4	0.8	0.7	31.2

Source: Kendrick (1987)

The estimates for the sectors that comprise services in GCubed are given in table XI. They imply a sectoral productivity growth (1948-85) of 1.4 percent annually for the GCubed Services sector. The treatment of labor input in this table follows that of the Bureau of Labor Statistics in counting unadjusted hours worked, thus changes in labor quality are treated as productivity increases rather than as increases in the labor input.

Summary

The preceding discussion has outlined factors affecting productivity growth in a twelve sector aggregation of the economy. We summarize productivity growth in those sectors by presenting a table of the growth rates calculated from Jorgenson, Gollop and Fraumeni (1987) and Jorgenson and Kuroda (1992):

Table XII. US Total Factor Productivity Estimates

	1950-59*	1960-69*	1970-79*	1980-85**
Electric Utilities	2.0	2.4	-1.7	-1.1
Gas Utilities	0.3	0.8	-1.8	-1.1
Petroleum Refining (2)	0.1	0.1	0.1	4.1
Coal Mining	3.6	1.9	-5.2	-0.9
Crude Oil & Gas Extraction	0.2	1.3	-7.9	
Mining	0.4	0.2	-1.2	-0.9
Agriculture	1.7	2.1	0.7	4.9
Forestry & Wood Products				
Durable Manufacturing		1.0	0.6	1.1
Non-Durable Manufacturing		0.7	0.2	0.4
Transportation	1.4	0.6	0.5	0.8
		1948-73	1973-79	1979-85
Services		1.8	0.5	0.1

The Durable Manufacturing sector shown in table XII omits Electrical Equipment, Transportation Equipment and Precision Instruments for the years 1980-85. The Non-durable Manufacturing sector omits Tobacco Manufactures, Apparel and other fabricated textile products and Petroleum and Coal products, again for the 1980-85 period.

V. Implementation of Productivity Growth in a 12 sector aggregation (The GCUBED Model)

The previous sections discussed productivity growth in various sectors of the US economy. It would be useful to have a similar set of results for other countries so that international comparisons could be made. Unfortunately, researchers in other countries have not shown as keen an interest as their U.S. counterparts in measuring productivity growth so there is less work from which we can draw -- a partial exception is found in Japan. The table on the following page (Table XIII) brings together estimates of TFP growth from a number of studies to create a matrix of growth rates for the 12 sectors previously discussed in a multi-region setting.

A stylized fact of technical change is that it has been Harrod-neutral in much of the post-world war II era. We now translate the productivity growth of those studies to a Harrod-neutral measure of technical change and combine it with labor force growth. Using the notation of section II and making the assumptions outlined there we have:

$$\dot{\pi}_{TFP} = \dot{y} - (s_k \dot{k}_P + (1 - s_k)\dot{k}_H) \qquad (7)$$

where s_k is the cost share of physical capital. The alternative formulation which is more explicity Harrod-neutral is given by:

$$\dot{y} = s_k \dot{k}_P + (1 - s_k)(\dot{\pi}_{LATC} + n) \qquad (8)$$

Table XIII. 12 Sectors

Source	Country	Period	Electric Utilities	Gas Utilities	Petroleum Refining	Coal Mining	Crude Oil & Gas Extraction	Mining	Agriculture	Forestry & Wood Prod	Durable Manuf.	Non-durable Manuf.	Transp.	Services
EM	**U.S.**	1970-83						-4.28	-0.38		1.49	1.16	1.65	0.37
JGF		1950-60	2.00	0.30	1.65	3.60	0.20	0.41	1.70		0.36	1.70	1.11	0.70
JGF		1960-70	2.40	0.80	1.90	1.90	1.30	0.21	2.10		0.99	0.90	0.55	-0.08
JGF		1970-79	-1.70	-1.80	-8.50	-5.20	-7.90	-1.05	0.70		0.33	-0.30	0.58	0.29
JK		1960-70	2.11	2.11	1.62			1.08	1.18		0.36	0.73	1.09	0.40
JK		1970-80	-1.47	-1.47	-4.56			-5.58	0.67		0.56	0.19	1.00	0.07
JK		1980-85	-1.67	-1.67	3.42			0.05	4.43		1.04	0.50	0.25	0.27
BLS		1960-70									1.46	1.09		
BLS		1970-80									1.07	0.52		
BLS		1980-85									1.44	1.03		
G		1960-73	1.54	1.54				0.34	0.23		1.97	1.97	2.53	0.38
G		1973-79	0.21	0.21				-0.99	-1.10		0.64	0.64	1.20	-0.95
G		1979-92	0.72	0.72				-0.48	-0.59		1.15	1.15	1.71	-0.44
EM	**Japan**	1970-83						1.60	-0.74		2.62	0.66	1.15	0.55
JK		1960-70	3.22	3.22	-1.36			1.66	0.45		1.86	0.93	3.06	1.49
JK		1970-80	-2.99	-2.99	-3.89			1.72	-1.64		0.80	0.19	0.49	0.05
JK		1980-85	0.60	0.60	-1.29			0.30	-0.27		0.20	0.29	1.19	0.81
EM	**Germany**	1970-83						-2.43	3.08		1.60	0.62	0.52	1.37
EM	**France**	1970-83							1.97		0.89	2.06	0.85	0.85
EM	**U.K.**	1970-83						8.22	2.55		1.32	0.51	1.70	0.11
EM	**Italy**	1970-83							2.12		1.11	1.52	0.77	-0.13
EM	**Canada**	1970-83							0.17				1.77	
S		1957-79						-4.66						
RP		1967-80	0.94	0.94		-1.02		-0.04	-0.14	2.43	0.70	0.51	2.29	1.02
EM	**Belgium**	1970-83							2.50		0.51	3.27	-0.88	1.06
EM	**Denmark**	1970-83							3.26		0.83	2.68	-0.98	0.88
EM	**Finland**	1970-83						0.62	1.44				2.03	
EM	**Norway**	1970-83							2.68		1.17	-0.48	2.46	0.34
EM	**Sweden**	1970-83						-2.62	1.22		2.84	-1.58	1.76	1.09
EM	**Australia**	1970-83							2.95				2.52	
M	**China**	1980-85	-3.71			0.80	-0.82							
K		1961-85									7.00	7.00		
A	**India**	1960-85			-0.13						-0.12	-0.14		
E	**Brazil**	1950-80							2.55		2.25	2.25		
E		1960-80												
E	**Argentina**	1950-80							0.44		1.05	1.05		
E		1960-80												
E	**Mexico**	1950-80							1.84					
Z	**Africa**	1960-80							1.60					0.30

E: Elias (1992)
M: McGuckin et. al. (1992)
JGF: Jorgenson, Gollop and Fraumeni (1987)
RP: Rao and Preston (1984)
A: Ahluwalia (1991)
K: Kuan et. al. (1988)
JK: Jorgenson and Kuroda (1995)
S: Stollery (1985)
Z: Zind (1992)
EM: Englander & Mittlestadt (1987)
G: Gordon (1995)
BLS: Bureau of Labour Statistics Database

Table XIV

Sector	Output Growth	Contrib. of Capital	Contrib. of Labor	Contrib. of Interm. Input	TFP Growth	Equivalent LATC
Electric Utilities	6.28	2.75	0.34	2.27	0.92	6.75
Gas Utilities	5.31	1.06	0.24	4.03	-0.01	0.64
Petroleum Refining	2.71	0.24	0.05	4.22	-1.79	-14.35
Coal Mining	0.38	0.69	-1.16	1.12	-0.27	-0.30
Crude Oil & Gas Extraction	2.13	1.04	0.31	2.91	-2.14	-17.05
Mining	2.63	1.50	0.15	1.10	-0.14	-0.02
Agriculture	2.20	0.42	-0.86	1.30	1.36	6.26
Forestry & Wood Products	2.88	0.45	-0.11	2.45	0.09	1.13
Durable Manufacturing	3.94	0.44	0.57	2.49	0.44	2.11
Non-durable Manufacturing	3.54	0.37	0.20	1.93	1.03	4.80
Transportation	2.93	0.52	0.07	1.39	0.94	3.93
Services	4.05	0.59	0.78	2.21	0.46	1.97

Source: Authors' calculations from data presented in Jorgenson, Gollop and Fraumeni (1987)

Where n is labor force growth. From this we get:

$$\dot{\pi}_{LATC} = (\dot{y} - s_k \dot{k}_P)/(1 - s_k) - n \tag{9}$$

implying:

$$\dot{\pi}_{LATC} = \dot{\pi}_{TFP}/(1 - s_k) - n \tag{10}$$

In Tables XIV and XV we have calculated this adjusted productivity growth term. In Table XIV we use the data found in Jorgenson, Gollop and Fraumeni (1987) to perform this calculation on their sectoral results[14]. The fourth column provides the recalculated Harrod-neutral labor-augmenting technical change. In general the energy sectors have had slower productivity growth than the non-energy sectors which, as is shown in Bagnoli, McKibbin and Wilcoxen (1995), has important implication for future economic development if the trend should continue. To get Table XV we used population, labor force and hours worked data to perform this calculation for the studies of Table II.

[14]See Appendix II for a sectoral mapping and for details of the aggregation.

Table XV

Maddison (1989)			Gordon (1995)			BCC (1995)			CRS (1986)			BS (1995)		
Country	**Period**	**Equiv. LATC**	**Country**	**Period**	**Equiv. LATC**	**Country**	**Period**	**Equiv. LATC**	**Country**	**Period**	**Equiv. LATC**	**Country**	**Period**	**Equiv. LATC**
U.S.	1950-73		U.S.	1960-73	1.93	U.S.	1960-70	2.14	U.S.	1960-73	1.86	U.S.	1960-90	0.48
	1973-84	0.09		1973-79	-0.20		1970-80	0.29						
				1979-92	0.54		1980-86	1.14						
							1986-92	0.86						
Japan	1950-73		Japan	1960-73		Japan	1960-70	7.29	Japan	1960-73	7.47	Japan	1960-90	3.04
	1973-84	2.91		1973-79	1.84		1970-80	1.57						
				1979-92	2.33		1980-86	2.00						
							1986-92	1.86						
France	1950-73		France	1960-73	5.20	France	1960-70	4.00	France	1960-73	3.91	France	1960-90	1.38
	1973-84	0.87		1973-79	3.41		1970-80	1.86						
				1979-92	2.24		1980-86	1.29						
							1986-92	1.86						
Germany	1950-73		Germany	1960-73	4.90	Germany	1960-70	3.57	Germany	1960-73	3.41	Germany	1960-90	1.41
	1973-84	0.62		1973-79	3.84		1970-80	2.00						
				1979-92	2.06		1980-86	1.00						
							1986-92	2.14						
U.K.	1950-73		U.K.	1960-73	3.31	U.K.	1960-70	1.57	U.K.	1960-73	2.57	U.K.	1960-90	1.17
	1973-84	-0.12		1973-79	1.66		1970-80	1.00						
				1979-92	1.74		1980-86	2.86						
							1986-92	0.29						
			Canada	1960-73	3.38	Canada	1960-70	2.57	Canada	1960-73	1.30	Canada	1960-90	0.06
				1973-79	0.53		1970-80	1.43						
				1979-92	-0.06		1980-86	1.14						
							1986-92	-0.57						
			Italy	1960-73	8.18	Italy	1960-70	5.71	Italy	1960-73	4.24	Italy	1960-90	2.56
				1973-79	3.87		1970-80	2.86						
				1979-92	2.51		1980-86	1.00						
				1979-92			1986-92	1.57						
						Australia	1960-70	2.57						
							1970-80	1.14						
							1980-86	1.00						
							1986-92	1.00						
China	1950-73	3.15				China	1960-70	2.83						
	1973-84	6.03					1970-80	2.17						
							1980-86	7.67						
							1986-92	5.17						
Korea	1950-73	7.19				Korea	1960-70	2.67	Korea	1960-73	9.81	Korea	1966-90	7.62
	1973-84	5.66					1970-80	2.33						
							1980-86	5.50						
							1986-92	4.50						
Taiwan	1950-73	11.67				Taiwan	1960-70	3.33	Taiwan	1955-60	6.95	Taiwan	1966-90	9.03
	1973-84	8.00					1970-80	3.33						
							1980-86	4.00						
							1986-92	5.17						
India	1950-73	-9.08				India	1960-70	1.33	India	1960-79	6.21			
	1973-84	2.63					1970-80	0.33						
							1980-86	3.50						
							1986-92	3.17						
Argentina	1950-73	2.88				Argentina	1960-70	2.33	Argentina	1960-74	5.28	Argentina	1940-80	2.05
	1973-84	-1.45					1970-80	0.33						
							1980-86	-3.00						
							1986-92	2.17						
Brazil	1950-73	4.81				Brazil	1960-70	3.00	Brazil	1960-74	9.50	Brazil	1940-80	2.59
	1973-84	0.08					1970-80	4.17						
							1980-86	-1.17						
							1986-92	-3.67						
Chile	1950-73	2.18				Chile	1960-70	2.67	Chile	1960-74	5.25	Chile	1940-80	2.35
	1973-84	-0.47					1970-80	0.50						
							1980-86	-2.67						
							1986-92	6.83						
Mexico	1950-73	4.23				Mexico	1960-70	3.50	Mexico	1960-74	~~6.42~~	Mexico	1940-80	3.17
	1973-84	1.24					1970-80	0.83						
							1980-86	-4.83						
							1986-92	0.17						
USSR	1950-73	2.39												
	1973-84	-0.64												

Note: BCC- Bosworth, Collings and Chen; CRS-Chenery, Robinson and Syrquin; BS-Barro and Sala-i-Martin

The GCUBED model uses a CES production function so that unit elasticity is not imposed on the data. When implementing the LATC illustrated in table XIV in a parameterized model with fixed shares we need to be aware of some pitfalls. To illustrate further, we specify Harrod-neutrality in a CES function:

$$Y = [K_P^{-\rho} + (\pi_{LATC} K_H)^{-\rho}]^{-1/\rho} \tag{12}$$

In this case, letting q be the price of output and w and r be the wage and the price of capital, respectively, we use the profit maximization conditions: :

$$r/q = (Y/K_P)^{(1+\rho)} \quad and \quad w/q = (Y/\pi_{LATC} K_H)^{(1+\rho)} \tag{13}$$

Productivity growth becomes:

$$\dot{\pi}_{LATC} = \frac{\dot{Y} - r/q\dot{K}_P - w/q\dot{K}_H}{wK_H/q\pi_{K_H}} \tag{14}$$

Now, in the CES production function *1/(1+ρ)* is the elasticity of substitution. Equations (13) and (14), therefore, imply that for a given change in output and inputs the measurement of productivity growth is related to the elasticity. It can be shown that this relationship has a tendency to be negative (the relationship is negative for the U.S. and is most likely to be negative in industrialized countries) so that as the elasticity becomes larger the rate of productivity growth that is calculated will decrease. This result is important for single country studies where measurement of the level of productivity growth is desired but it is even more important in comparative studies across very different economies where the substitution elasticities may differ. Researchers find elasticities of substitution much less than one for the industrialized countries (see Yuhn [1991] for a survey of U.S. empirical work). De La Grandville (1989), however, has proposed that the elasticity of substitution might be closer to unity in the developing countries -- or at least higher than in industrialized countries. Some empirical work has supported this proposition (see Yuhn [1991]). In other words, studies which do cross-country TFP calculations using Cobb-Douglas production functions are, at the very least, obliged to provide some justification for their assumption of unit elasticity because there is a potentially strong bias in the results originating in that assumption.

IV. Concluding Remarks

This paper reviewed some issues in productivity measurement from a growth accounting perspective. We illustrated the basic techniques of productivity growth measurement and surveyed both aggregate and sectoral measurements undertaken by other authors. It was pointed out that there are numerous areas of weakness in the measures so there is reason to be skeptical that any one measure of productivity growth accurately reflects economic changes. However, as was pointed out in Baily and Gordon (1988), the current measurements are accurate enough to provide a rough of gauge of actual productivity growth.

The sectoral productivity growth survey that we undertook provides some interesting observations on the components of aggregate growth. It was argued in Jorgenson (1987) that changes in the allocation of factors of production can have important influences on growth rates without requiring any changes in either composition or quantity of the factors. The reason for this is that movement of factors from low to high value sectors will, by itself, give you measured increases in output. We saw in the sectoral data considerable differences in productivity growth among sectors so there is scope for this phenomenon to be occuring. We also saw, however, that productivity growth and other sectoral indicators can be greatly affected by one-time or transitory events -- undermining arguments regarding the importance of observed sectoral differences. The obvious conclusion we draw from this is that a careful analysis should combine both sectoral and aggregate data with a strong emphasis on eliminating short-term influences when the sectoral differences have important long-term implications.

References

Akerlof, G. A., W. T. Dickens and G. L. Perry (1996), "The Macroeconomics of Low Inflation," *Brookings Papers on Economic Activity*.

Aivazian, V. A., J. L. Callen, M.W. Chan and D. C. Mountain (1987), "Economies of Scale Versus Technological Change in the Natural Gas Transmission Industry," *Review of Economics and Statistics*, vol. 69(3), August, pp. 356-61.

Ahluwalia, I.J. (1985), "Industrial Growth in India: Performance and Prospects", *Journal of Development Economics*, vol. 23, no. 1, September, pp. 1-18.

Ahluwalia, I.J. (1991), *Productivity and Growth in Indian Manfacturing*, New York: Oxford University Press.

Baily, M.N. and R. J. Gordon (1988), "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power," *Brookings Papers on Economic Activity*, pp. 347-420.

Barro, R., and Sala-i-Martin (1995), *Economic Growth*, New York, N.Y.: McGraw-Hill.

Baumol, W. J. (1986), "Productivity Growth, Convergence, and Welfare: What the Long-run Data Show," *American Economic Review*, Vol. 76, no. 5, pp. 1072-85.

Bosworth, B., S. M. Collins and Y. Chen (1995), "Accounting for Differences in Economic Growth," Conference paper: *Structural Adjustment Policies in the 1990's: Experience and Prospects*, November 5-6, (1995). Institute for Developing Economies, Tokyo, Japan.

Chenery, H., S. Robinson and M. Syrquin (1986), *Industrialization and growth: A Comparative Study*, New York: Oxford University Press.

Christensen, L. R., and D. W. Jorgenson (1969), "The Measurement of U.S Real Capital Input, 1929-1967," *Review of Income and Wealth*, Series 15, no. 4, pp. 293-320.

Christensen, L. R., D. Cummings and D. W. Jorgenson (1980), "Economic Growth, 1947-1973: An International Comparison" In *New Developments in Productivity Measurements*, eds. John W. Kendrick and Beatrice Vaccara, 595-698. NBER Studies in Income and Wealth, vol. 41, New York: Columbia University Press

Costello, D. M. (1993), "A Cross-Country, Cross-Industry Comparison of Productivity Growth," *Journal of Political Economy*, vol. 101(2), pp. 207-222.

Denison, E. F. (1962), *Sources of Economic Growth and the Alternatives Before Us*. New York: Committee for Economic Development

Denison, E. F. (1967), *Why Growth Rates Differ*, Washington, D.C.:The Brookings Institution.

Denison, E. F. (1979), *Accounting for Slower Growth: The United States in the 1970's*, Washington, D.C.: The Brookings Institution.

Diewert, W. E. (1976), "Exact and Superlative Index Numbers," *Journal of Econometrics*, vol. 4, pp. 115-145.

Diewert, W. E. (1992), "The Measurement of Productivity," *Bulletin of Economic Research*, vol. 44(3), pp.163-98.

De La Grandville, O. (1989), "In Quest of the Slutsky Diamond," *American Economic Review*, vol. 79(3), June, pp. 468-81.

Elias, V.J. (1992), *Sources of Growth: A Study of Seven Latin American Economies*, San Francisco: ICS Press.

Englander, A. S., and A. Mittelstadt (1988), "Total Factor Productivity: Macroeconomic and Structural Aspects of the Slowdown," *OECD Economic Studies*, No. 10, spring, pp. 7-56.

Feenstra,R.C., and J. R. Markusen (1994), "Accounting for Growth with New Inputs" *International Economic Review* vol. 35(2), May, pp. 429-47.

Friedman, B. L. (1992), "Productivity in Crude Oil and Natural Gas Production," *Monthly Labor Review*, March, pp.9-17.

Glaser, G. L. (1993), "Multifactor Productivity in the Utility Services Industries," *Monthly Labor Review*, May, pp. 34-49.

Gordon, R. J. (1991), "Productivity in the Transportation Sector," NBER Working Paper No. 3815, February.

Gordon, R. J. (1992), "Forward into the Past: Productivity Retrogression in the Electric Generating Industry," NBER Working Paper No. 3988, February.

Gordon, R. J. (1995), "Is There a Tradeoff Between Unemployment and Productivity Growth," NBER Working Paper No. 5081, April.

Gullickson, W. (1992), "Multifactor Productivity in Manufacturing Industries," *Monthly Labor Review*, October, pp.20-32.

Summers, R., and A. Heston (1980), "International Comparisons of Real Product and Its Composition: 1950-77," *Review of Income and Wealth*, vol. 26(1), March, pp. 19-66.

Hibdon, J. E. And M. J. Mueller (1990), "Economies of Scale in Petroleum Refining, 1947-1984: A Survivor Principle-Time Series Analysis," *Review of Industrial Organization*, vol. 5(3), pp. 25-43.

Jorgenson, Dale W., (1984), "The Role of Energy in Productivity Growth," In Kendrick, John W., ed, *International Comparisons of Productivity and Causes of the Slowdown*, Cambridge: Ballinger, pp.270-323.

Jorgenson, Dale W., (1988), “Productivity and Postwar U.S. Economic Growth,” *Journal of Economic Perspectives*, vol. 2(4) Fall, pp. 24-41.

Jorgenson, D. W., and B. M. Fraumeni (1981), “Relative Prices and Technical Change”,in *Modelling and Measuring Natural Resource Substitution,* eds. E. R. Bernst and B. C. Field, Cambridge: MIT Press.

Jorgenson, D. W., and B. M. Fraumeni (1992), “Investment in Education and U.S. Economic Growth”, *Scandinavian Journal of Economics,* vol. 94, Supplement. pp. 51-70.

Jorgenson, D. W., and F. M. Gollop (1992), “Productivity Growth in U.S. Agriculture: A Postwar Perspective”, *American Journal of Agricultural Economics,* pp. 745-50.

Jorgenson, Dale W., Frank M. Gollop, and Barbara M. Fraumeni, (1987), *Productivity and U.S. Economic Growth,* Cambridge, Harvard University Press.

Jorgenson, D. W., and M. Kuroda (1992), “Productivity and International Competitiveness in Japan and the United States, 1960-1985”, *The Economic Studies Quarterly,* vol. 43(4), pp. 313-325.

Kendrick, J. W. (1987), “Service Sector Productivity,” *Business Economics*, vol. 22(2), pp. 18-24.

Krugman, P.R. (1994) “Competitiveness: A Dangerous Obsession,” *Foreign Affairs*, 73(2), March-April, pp. 28-44.

Kruvant, W. J., C. E. Moody, Jr. and P. L. Valentine (1982), “Sources of Productivity Decline in U.S. Coal Mining, 1972-1977,” *The Energy Journal*, vol. 3(3), pp. 53-70.

Kuan, E., et. al., (1988), “Prodcutivity Changes in Chinese Industry, 1953-1985”, *Journal of Comparative Economics*, vol. 12, pp. 570-591.

Kuroda, M., K. Yoshioka and D. W. Jorgenson (1992), “Relative Price Changes and Biases of Technical Change in Japan”, *The Economic Studies Quarterly,* vol. 35(2), pp. 116-38.

May, J. D., and M. Denny (1979), “Factor-Augmenting Technical Progress and Productivity in U.S. Manufacturing,” *Internatinoal Economic Review*, vol. 20, pp. 759-74.

Maddison, A. (1987), “Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment”, *Journal of Economic Literature*, vol. 25, June, pp. 649-98.

Maddison, A. (1989), *The World Economy in the 20th Century*, OECD, Development Centre Studies.

Mark, J. A. (1982), “Measuring Productivity in Service Industries,” *Monthly Labor Review,* June, pp.3-8.

McGuckin, R. H., et. al., (1992), “Post-Reform Productivity Performance and Sources of Growth in Chinese Industry: 1980-85," *Review of Income and Wealth,* Series 38, Numer 3. September.

McKelvey, V. E. (1960). "Relation of Reserves of the Elements to Their Crustal Abundance."

American Journal of Science, Vol. 258-A, pp. 234-41.

McKibbin, W. J. and P. J. Wilcoxen (1995). "The Theoretical and Empirical Structure of GCUBED", *Brookings Discussion Papers in International Economics*, No. 118, The Brookings Institution.

Millward, R. (1990), "Productivity in the UK Services Sector: Historical Trends 1856-1985 and Comparisons with the USA 1950-85," *Oxford Bulletin of Economics and Statistics,* vol 52(4), pp.423-36.

Mulligan, C. B. and X. Sala-i-Martin (1995). "Measuring Aggregate Human Capital," NBER Working Paper No. 5016, February.

Nerlove, M. (1965), *Estimation and Identification of Cobb-Douglas Production Functions*, Chicago: Rand-McNally.

Nordhaus, W.D. (1972) "The Recent Productivity Slowdown," *Brookings Papers on Economic Activity*, pp. 493-536.

Nordhaus, W.D. (1988) "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power: Comment," *Brookings Papers on Economic Activity*, pp. 421-24.

Rao, P.S. and R.S. Preston (1983), "Interfactor substitution and total factor productivity growth: Evidence from Canadian industries," Economic Council of Canada, Discussion Paper No. 242.

Romer, P.M. (1990), "Endogenous Techonological Change," *Journal of Political Economy*, vol. 95(5), pp. 71-102.

Shoesmith, G. L. (1988), "Economies of Scale and Scope in Petroleum Refining", *Applied Economics*, vol. 20, December, pp. 1643-52.

Sickles, R. C., and M. L. Streitwieser (1992), "The Structure of Technology, Substitution, and Productivity in the Interstate Natural Gas Transmission Industry under the NGPA of 1978," *Bureau of the Census Center for Economic Studies Discussion*, Working Paper 92-9, August.

Sider, H. (1982) "Safety and Productivity in Underground Coal Mining" *The Review of Economics and Statistics*, vol. 65(2), May, pp. 225-33.

Solow, Robert M., (1957), "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, vol. 39(3), 1957, August, pp. 312-20.

Solow, Robert M., (1960), "Investment and Technical Progress," in *Mathematical Models in the Social Sciences, 1959*, eds. Arrow, K.J., S. Karlin and P. Suppes, Stanford: Stanford University Press

Stollery, K. R. (1985), "Productivity Change in Canadian Mining 1957-1979", *Applied Economics*, vol. 17, pp. 543-558.

Young, A. (1994), "Lessons from the East Asian NICS: A Contrarian View", *European Economic Review*, vol. 38, April, pp. 964-73.

Yuhn, K. H. (1991), "Economic Growth, Technical Change Biases, and the Elasticity of Substitution: A Test of the De La Grandville Hypothesis," *Review of Economics and Statistics*, vol. 73(2), pp. 340-46.

Zind, R. G., (1992), "Factors Contributing to Productivity Growth in the LDCs", *Economic Notes*, vol. 21, no. 1, pp. 120-136.

Appendix I

Jorgenson, Gollop and Fraumeni (1987) use a 51 sector disaggregation which we were required to aggregate into 12 sectors. To accomplish this we begin with:

$$y_i = g(k_i, \pi_i l_i, m_i) \qquad for\ i = 1\ to\ 51.$$

Where k is capital, l is labor, m is material and π is labor augmenting technical change. Using the assumptions outlined earlier we can write:

$$\dot{y}_i = \dot{tfp}_i + s_i^k \dot{k}_i + s_i^l(\dot{\pi}_i + \dot{l}_i) + s_i^m \dot{m}_i \qquad for\ i = 1\ to\ 51.$$

where, for example, s_i^k implies the cost share of capital in industry i. Define x to represent an aggregate subset of the 51 industries (there are 12 unique aggregations). Now define s_x^i to be the revenue share of industry i in the aggregate industry x (of which i is an element), that is:

$$s_x^i = \frac{p_i y_i}{\sum_{j = elements\ of\ x} p_j y_j}$$

Output changes in the aggregate industry x can now be written as:

$$\begin{aligned}
\dot{y}_x = & \sum_{i = elements\ of\ x} s_x^i \dot{tfp}_i + \quad (sector\ agg.\ tfp) \\
& \sum_{i = elements\ of\ x} s_x^i s_i^k \dot{k}_i + \quad (sector\ agg.\ contribution\ of\ k) \\
& \sum_{i = elements\ of\ x} s_x^i s_i^l (\dot{\pi}_i + \dot{l}_i) + \quad (sector\ agg.\ contribution\ of\ l) \\
& \sum_{i = elements\ of\ x} s_x^i s_i^m \dot{m}_i . \quad (sector\ agg.\ contribution\ of\ m)
\end{aligned}$$

Since JGF report the contribution of each factor for each industry we can simplify further with:

$$\dot{y}_x = \sum_{elements\ of\ x} s_x^i \dot{tfp}_i + \sum_{elements\ of\ x} s_x^i c_i^k + \sum_{elements\ of\ x} s_x^i s_i^l (\dot{\pi}_i + \dot{l}_i) + \sum_{elements\ of\ x} s_x^i c_i^m$$

where c_i^j is the contribution of factor j in industry i. This equation forms the basis for the calculations reported in table XIV.