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R&D and Components of Technical Change

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INTRODUCTION

Reflecting Solow's classic paper, it has now become an accepted proposition among economists that technical change makes an important contribution to the process of economic growth.[1] Over the last four decades attempts have been made to develop finer indices of technical change that would be useful for ascertaining multifactor productivity and for distinguishing among various types of technical change; eg. embodied, disembodied, neutral, non-neutral. In recent years, there has been progress in unravelling the sources of technical change itself to identify what factors contribute to the nature and type of technical change and, by inference, how to develop policies to further promote technical change. Freeman and Perez have hypothesized that there is a new techno-economic paradigm in place, which envisions the growth and decline of an economy as dependent upon the socio-economic institutions that promote or constrain the adjustment process relevant to the trajectories of new technologies.[2] One of the most important elements that has been identified, both as an explanation of the technical change and as an element of the new paradigm is the R&D component. An important question is how does R&D relate to technical change, particularly in manufacturing industries which comprise the high technology sector of the U.S.? Our paper attempts to address this question empirically.

The plan of the paper is as follows. The first section places R&D into perspective. Section 2 compares R&D in high tech with U.S. manufacturing. Section 3 obtains the coefficients of R&D in a translong cost function. These coefficients are interpreted in the last section and are presented along with our conclusions.

R & D IN THE U.S. ECONOMY

The U.S. economy had been growing comfortably during the 1950s and 1960s. However, this growth slowed down in 1970s and 1980s. There have been a number of studies that have tried to identify the reasons for this decline without unanimity. Jorgenson finds the culprit in energy prices.[3] Griliches wonders if the high growth rates in 1950s and 1960s were not unusual so that there is a question if the crime of slower growth was ever committed.[4] Bailey and Chakrabarti attribute the fault to 'missed' technological opportunities.[5] There is however agreement about two propositions: (i) there has been a slow down, and (ii) the R&D/GNP ratio has been declining in the U.S. Of course, it does not follow that (ii) is a cause of (i); at least not directly. On the other hand, these two phenomena appear to be related, even if it is not clear whether the relationship is indirect and whether they are both cause and effect.

The U.S. used to be the world leader in industrial production and devoted more than 3.00 percent of its GNP to R&D. The rationale for these large R&D expenditures was always couched in terms of their growth implications. As Table 1 shows, the share of R&D in U.S.

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TABLE 1
R&D—GNP Ratio

Year	France	W. Germany	Japan	U.S.
A: R&D—GNP Ratio				
1970	1.91	2.06	1.85	2.57
1975	1.80	2.22	1.96	2.20
1980	1.84	2.42	2.22	2.29
1985	2.31	2.67	2.77	2.69
B: Non Defense R&D—GNP Ratio				
1971	NA	2.03	1.83	1.65
1975	1.46	2.08	1.95	1.63
1980	1.43	2.30	2.21	1.79
1985	1.85	2.53	2.75	1.86

Source: Science and Engineering Indicators. 1987.

GNP has been declining since 1970 when this share was 2.57 percent. Ten years later it was 2.29. In 1985 it just about recovered the 1970 level. By comparison, other industralised countries have been spending more and more on R&D. During the same period, Japan's share grew from 1.85 percent in 1970 to 2.77 in 1985. In 1970, Japan's share was smaller than that of the U.S. In 1985, it is larger. Similarly West Germany raised its share from 2.06 in 1970 to 2.67 in 1985. In 1985, West Germany was spending as large a percentage of its GNP on R&D as the U.S. France has also increased its share, though by a lesser percentage.

Not only has the U.S. R&D/GNP share failed to keep pace with other countries, but U.S. spends much more of its R&D on defence and defence related activities. In earlier years, defence related technologies and R&D generated large spillover effects on commercial technologies. However, with the specialisation of scientific and technological advances, the spillover of large defence expenditures on commercial innovations and technologies has become limited. As a result, the U.S. share of non-defence R&D to GNP is much smaller and compares very unfavorably with that of the other industrial countries. As Table 1 points out, the share of the non-defence R&D expenditures in GNP in 1971 fell to 1.65. It has increased somewhat in recent years and is estimated at 1.86 for 1985. By comparison, the French ratio in 1985 of 1.85, was close to the U.S. ratio. West Germany on the other hand, has been spending more of its GNP on commercial R&D. In 1971, this ratio was 2.03 and 2.53 in 1985. Japan has also accelerated these expenditures at a fast rate. In 1971, the Japanese ratio was 1.83; which was close to that of the U.S. in 1985. By 1985, Japan had raised its ratio to 2.75 percent; a ratio which was higher than the 1985 U.S. ratio for total R&D. Interestingly, these patterns of R&D/GNP ratio are similar to the patterns of productivity growth and economic growth. They also seem consistent with lay person's view that the U.S. is losing its competitive strength vis-a-vis Japan and Germany.

R & D IN U.S. MANUFACTURING AND ITS HIGH TECH SECTOR

High Technology has become a well known term and one reads about it in all sorts of popular literature. While economists have undertaken to define high technologies there are serious questions both about the definition of the concept and its underlying principle and its measurement. Conceptually, high technology means that there are certain industries that are different from others in regard to their technological principles. What is different is that the new technologies are characterized by continuously falling prices; that is, their available supply must be sufficiently large to ensure falling supply price. Further, their technology spin-offs become embodied into other products and processes, thereby enlarging old markets and opening new ones.[6]

The usefulness, or motivation, to measure 'high-technology' products or industries derives from comparisons among traded goods. The implication is that the U.S. trade deficit in manufactures can only be remedied by a substitution of production from the 'low' to 'high' technology goods. If one examines trade data since 1965, it becomes apparent that the trade balance has been heavily influenced by the favorable trade balance in 'high tech' goods. For example, in 1980, the trade deficit in manufacturing would have been negative, but for the surplus in high tech goods which made the trade balance positive.[7] There is thus an interest in measuring high tech' products and industries.

There are a number of problems associated with the measurement of high tech. Experts differ about what constitutes the group of industries that may be termed high tech. The general perception among researchers is that high tech industries must involve some degree of technical sophistication. However, concensus is lacking about; (i) what is the required degree of sophistication?, (ii) whether the sophistication relates to the product or the processes or both? and (iii) what are the indices for identifying this sophistication?

A close look at published, and unpublished, research prepared by Federal and State government agencies who normally interested and involved in these issues, indicates that three criteria are generally used to classify industries as high tech. Two major classifications emerge: (a) those which reflect product-based definitions, and (b) those which reflect industry-based definitions.[8] Though there appear to be differences among definitions and, therefore, concepts of high tech, a closer look suggests major agreement about the core of the groups; differences appear only at the edges of the set. In the analysis that follows, we have utilized our own time series data for the high tech sector of U.S. manufacturing based on two criteria; (i) the number of scientists and engineers employed as a percent of total employment, and (ii) the R&D expenditure-shipment ratios. For an industry to be classified as high tech, the industry must lie above the average, based on both these criteria. Ours is thus a rather stringent criterion.[9] These series generated are for the period 1967–82, which covers two complete business cycles; 1969–73 and 1973–79. They encompass the 1967–69 upswing and the 1979–82 downswing. Thus, the period provides an "over the business cycle" view. Given these preliminaries, the R&D activity in the high tech sector can now be compared with that of U.S. manufacturing.

Table 2 display the rate of growth of R&D over the four periods and compares it with

TABLE 2
Growth Rates of Capital and R&D

	U.S. Manufacturing		High Tech Sector	
Period	Capital	R&D	Capital	R&D
1967–9	2.58	3.95	3.05	4.50
1969–73	2.49	2.67	3.77	2.54
1973–79	3.62	2.85	3.97	2.63
1979–82	3.78	4.68	5.83	3.88

Source: Estimated from data in Vandyopadhayaya (1987).

capital growth rates. Over the business cycle, R&D growth rates have been between 2.5 to 2.8 percent per year which is not very high. Looking at the growth rates of R&D for the high tech sector and comparing it with the manufacturing sector, we find that the growth rate for the manufacturing sector has been somewhat higher, except for the upswing of 1967–69. This picture reverses when one examines the growth rate of capital. Except for the upswing of 1967–69, the growth rates of capital in high tech sector have been higher than those of R&D. For U.S. manufacturing on the other hand this relationship is reverse; the growth rates of capital are lower compared to R&D except for the cycle of 1973–79. Yet, the growth rates of capital both in the high tech sector and the manufacturing have not been notably high; ranging only between 2.5 to 4.00 percent per year. Considering that the growth rate of capital is also not notably high, suggests that some growth is consistent even with a declining sector. This is what is expected *a priori*. Growth rates in manufacturing have been low for this period, and a large part of the growth that has taken place in high tech industries was accomplished by larger capital investments. This is also consistent with what has been going on in U.S. industries. "Low Tech" industries have, in general, been laying off workers and declining. For a variety of reasons, particularly the need for substitution as a result of the high price of oil some old industries have had to retool.[10] It is instructive to examine capital-output type ratios as displayed in Table 3 which summarizes the relevant intensities; R&D-output intensity, R&D-labor intensity, capital-output ratio, and capital-labor ratio for the manufacturing and the high tech sector for the four periods of analysis.[11]

The capital output ratio in U.S. manufacturing is in the range of 3.15 in the upswing to 3.77 over the 1973–79 cycle. The capital-labor ratio, on the other hand, is between 9.5 in the 1967–69 upswing and 14.3 in the downswing of 1979–82. The average capital-labor ratio for the whole period is 12. By comparison, the capital-labor ratio in high tech industries is much higher. The average value of this ratio for the whole period is 18 and fluctuates between 13 in the upswing and 22 in the downswing. For both manufacturing and the high tech sector the capital-output ratio has been rising over the two cycles of 1969–73 and 1973–79. The capital-output ratio in the high tech sector, on the other hand, is quite stable and low at around 2.2; much lower than in the manufacturing sector. This is consistent with the new techno-economic paradigm that implies that new high technologies do not need heavy capital investment; partly because they depend on inputs with a falling supply prices, and partly because the production is not yet at its peak level. The average size of the production unit in high tech sector is generally smaller.[12] Further examination of the high tech sector and its R&D to output and labor ratios yields an R&D-output ratio that is a shade higher than the

TABLE 3
R&D and Capital Intensity

	U.S. Manufacturing		High Tech Sector			
Period	K/O	K/L	K/O	K/L	R/O	R/L
1967–9	3.15	9.60	2.36	13.0	2.6	11.8
1969–73	3.25	10.6	2.20	15.8	2.51	13.9
1973–79	3.77	12.3	2.20	19.2	2.77	15.2
1979–82	3.54	14.3	2.22	22.1	3.16	15.5
1967–82	3.45	12.0	2.20	18.1	2.72	14.5

Source: Vandyopadhayaya (1987). K, O, R, L refer to Capital, Output, R&D, and Labor.

capital-output ratio.; the average value is 2.7 for the whole period compared to 2.2 for capital-output ratio. There has been a tendency for this ratio to go up slightly over the two cycles, which is higher in the downswing than is the upswing.[13] The R&D-labor ratio in high tech industries is also lower than the capital-labor ratios. However, both capital and R&D labor ratios seem to follow the same trend which is growth over the cycle and time.

R & D AND TECHNICAL CHANGE

There are various ways to analyze technical change which is defined generally to encompass both neutral or disembodied technical change and non-neutral or embodied technical change. The neutral technical change follows from the concept of shifts in the production function; biased or non-neutral technical change arises when the slope of the isoquants change. One way to analyse technical change, therefore, is to formulate a production function; output can be defined either as value added by manufacture or as gross output, including materials. Recent studies suggest that the gross output concept is more consistent with the data.[14] Similarly, the number of inputs vary. If the concept of gross output is used, then materials have to be counted among the inputs. Given the production function, one can derive a cost function based on the rather stringent assumptions about perfect factor markets and Shephard's Lemma. The form of the resulting cost function, depends in an essential way on the form of the production function. One of the more flexible forms which may be used is the translog form whose application is now standard.[15] It involves a large number of stringent assumptions which are accepted more out of convention than because one can make a case for them. These assumptions involve symmetry, homogeneity and homotheticity. Given these assumptions, and the Sheppard's Lemma, one can derive share equations for all the inputs. These are:

$$\mathbf{S} = \mathbf{a} + \mathbf{AiP}$$

Where **S** is a vector of input shares. In view of the restrictions on the related matrices of coefficients aj, one of the share equations is redundant and the order of **S**, therefore, is one less than that of **P**. The cost function and the shares equations form a system of simultaneous equations that can be estimated by simultaneous equation techniques.

We have information on the prices of capital, labor and materials, inputs and the total costs for the period 1967–82 for the high tech sector of the U.S. manufacturing. The parameters of the cost function for the three inputs can thus be estimated. Our interest here, however, is to analyse the character of technical change and its relationship to R&D. Accordingly, we define another variable, namely R, which stands for R&D expenditures. We argue that it is the R&D that is a source of technical change. This argument is very different from that made in the majority of studies on technical change. The general custom is to use a time trend, a sort of dummy variable, as a proxy for technical change. The use of the time trend dummy implies that the production, or its dual, the cost function, shifts with time and in a similar fashion, which is, of course, quite simplistic and involves heroic assumptions. Our contention is that changes in the production and cost functions are associated with the R&D expenditures. R&D provides a better approximation of, and its effect, technical change on the production function and costs.

To estimate the translog cost function we require four inputs; capital, labor, materials and R&D. In other words, our price vector has three elements; namely, price of capital, wage rate, and price of materials. Confronted with the choice between considering R&D as a variable and seeking its price as being similar to the price of capital, we chose not to follow this route,

TABLE 4
R&D and Components of Technical Change

Coefficient	U.S. Manufacturing	High Tech
ar	−.34	−.03
akr	−.04	.12
amr	.22	−.04
alr	−.18	−.16

Source: From estimates of the translog cost function.

because in that case it would have required that capital be redefined which would involve a nesting of the function for capital and R&D. Since our interest is in technical change, and not in the nature of capital and other inputs, we followed the route of defining the variable R&D as augmenting the price vector, just as time trend and other dummy variables do. In other words, in the formulation of the theory and the cost function, R&D does not appear as an argument. Once the theory has been formalised in terms of capital, labor and material inputs, then the R&D variable is used to analyse the shifts and other changes in the cost function caused by R&D or technical change. We have estimated this cost function by Zellner's Seemingly Unrelated Regression method.[16] These results are summarized in an Appendix available on request.

R & D AND COMPONENTS OF TECHNICAL CHANGE

For purposes of this analysis, the relevant coefficients of the estimated translog cost function are those associated with the variable R&D. These have been collected as Table 4. Four coefficients are of interest: namely *ar*, the first order coefficient of technical change and the three second order coefficients of technical change, *akr*, *amr*, and *alr*, relate to the interactions with capital, materials and labor respectively. Since we have similar results for the manufacturing sector, we have displayed these also so that they can be compared. Our expectation is that technical change should reduce costs. The first order coefficient *ar* will be negative since the value of *ar* is negative both for the high tech and manufacturing sectors. So far as the second order effects are concerned, the expectation is that the technical change in high technology is highly embodied in capital goods. In other words, there is expected to be complimentarity between capital and R&D or technical change. Since this is not generally expected in non-high technology industries, one would expect some differences between manufacturing and high tech industries. The results in Table 4 for *akr* are thus consistent with our expectations. For the high tech sector, *akr*, is positive. This implies that the R&D induced changes in the marginal cost of capital are positive. In other words, if the marginal cost of capital is negative, the effect of technical change is to reinforce this effect. On the other hand, if it is positive, technical change does not reduce it. By comparison, the effect of R&D in the 'mass-production' technologies is always to reduce the marginal cost of capital if the cost of capital is positive to start with. If the marginal cost is negative to start with, R&D induced technical change makes it positive. Opposite signs for the coefficient, *akr*, are thus fully consistent with the techno-economic paradigm.

NOTES

1. Solow (1957) estimated that technical change, defined as shifts in the production function, contributed as much as 90 percent to the growth of non farm U.S. economy for the period 1909–49.

2. Freema and Perez (1988).
3. Jorgenson (1988).
4. Griliches (1988).
5. Bailey and Chakrabarti (1988).
6. See Freeman and Perez (1988).
7. Diwan (1989) provides information on these issues.
8. For detailed discussion see Vandyopadhayaya (1987).
9. For details of the procedures and industries see Diwan and Vanddyopadhayaya (1987).
10. This was also the period when the environment laws were promulgated and involved in the investments for anti pollution purposes.
11. Harrod-Domar growth theory is based primarily on the concept of a capital-output ratio. Solow's neoclassical growth theory involves that there is no growth in capital-labor ratio.
12. Carlsson has analysed the data for the numerically controlled machines and founds a trend towards, what he calls, a downsizing process. Carlsson (1989). See also the evidence from Acs et al (1988) and Diwan (1989).
13. It is true that the downswing and upswing are in the economy as a whole and do not necessarily mean that the cycles for the high tech industries would be exactly the same. One would expect that the cycles for the high tech will be somewhat less pronounced and growth a little more accentuated. All the same, the business cycles in the economy will have influence on the high tech sector as well.
14. See Diwan and Chakraborty (1987).
15. Ibid.

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