WORKING PAPER

TECHNICAL PROGRESS AND NEW
LOGISTICS TECHNOLOGIES

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by

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FOREWORD

Connected to manufacturing change there have been structural changes in the industry, which have become possible through new transportation and communication technologies. It has been claimed that the efficiency increase in logistics, e.g. in transportation and warehousing -- due to the just-in-time production philosophy --, largely explains the productivity growth. This paper tries to assess the problem and shows that, in fact, there exists a relationship between logistic improvements and economic growth. The paper is thus a valuable contribution to our work, as it provides new ideas on the issue of economic growth and technological change.

Prof. F. Schmidt-Bleek	Prof. J. Ranta
Program Leader	Project Leader
Technology, Economy, Society	Computer Integrated Manufacturing

ABSTRACT

The objective of this paper is to study new developments in logistics technologies as a prerequisite and as a consequence of technical progress in the case of the United States. Logistics is used here to denote all systematic actions aimed at bringing materials form primary producers through all intermediate steps to the end user, i.e. logistics includes transportation, handling, storage, as well as all related information processing.

The rapid growth of transport and communication output or productivity contributes to overall economic growth. The growth and spread of logistics technologies is likely to change the nature of modern economies.

The nature of the effects of new logistics technologies can be characterized by their indirect and overall impact on productivity of the whole economy. By improving the efficiency of the chain from producer to end user it contributes to that part of the growth rate that *can not* be explained by the increase in capital and labor inputs solely.

This study shows that the unexplained residual of conventional production functions, i.e. the growth accounted to technical progress can be explained, at least partly, by factors expressing changes in logistic structures and their performance.

Using the data given by N.E. Terleckyj (1984), who analyses the growth of the U.S. communication industry, we extend our focus to transport sector as well, and following the traditional line of production literature this paper present estimates concerning the role of logistics factors in explaining the rate of growth.

1. Objectives and background

The objective of this paper is to study new developments in logistics technologies as a prerequisite and as a consequence of technical progress in the case of the United States. Logistics is used here in accordance with the definition of S. Wandel and R. Hellberg (1987) to denote all systematic actions aimed at bringing materials form primary producers through all intermediate steps to the end user, i.e. logistics includes transportation, handling, storage, as well as all related information processing.

The rapid growth of transport and communication output or productivity contributes to overall economic growth. The growth and spread of logistics technologies is likely to change the nature of modern economies by the end of this century [1)] justifying the term *information economy* in the sense that most work performed will deal with production, processing, storing, interpretation and transformation of information.

Logistics costs represent a rather significant part of total value added in modern economies even now. In 1980 the estimated share of logistics costs in value added amounted to 31.8 percent in Swedish material sectors (see. L. Sjöstedt and S. Wandel (1987)).

The nature of the effects of new logistics technologies can be characterized by their indirect and overall impact on productivity of the whole economy. By improving the efficiency of the chain from producer to end user it contributes to that part of the growth rate that *can not* be explained by the increase in capital and labor inputs solely. This residual in case of the United States takes approximately six-sevenths of the growth rate.[2)]

This study shows that the unexplained residual of conventional production functions, i.e. the growth accounted to technical progress can be explained, at least partly, by factors expressing changes in logistic structures and their performance. Although,

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[1)] The dynamic properties of changes in communication and transport sector of the U.S. are analysed in several context by N. Nakicenovic (1986,1978) and N. E. Terleckyj (1984).

[2)] Our estimate in this study is 85 % for the period 1950-1982. S. Fabricant (1954) has estimated that over the period 1871-1951 about 90 percent of the increase in output per capita was attributable to technical progress. R. M. Solow (1957) indicates that in the period 1909-1949 about seven-eighths (88 %) of the growth rate is traceable to technical change. There are a number of studies dealing with this problem reviewed by C. Kennedy and A. P. Thirwall (1972).

the idea that logistic factors might be very important in such changes in productivity that are not attributable to increase in direct physical inputs, is quite straightforward, we could find only one publication in this line. N.E. Terleckyj (1984) analyses the growth of the U.S. communication industry. Using the data generated by his research we extend our focus to transport sector as well, and following the traditional line of production literature this paper present estimates concerning the role of logistics factors in explaining the rate of growth.

2. Technical progress and the aggregate production function

Capital accumulation had long been taken as the dominant determinant of economic growth. Not only was it the belief of the classical economists like Ricardo and Marx that productivity is increased principally where capital/labor ratio is increased , it was also the general belief of economists in the forties and fifties. The evidence found by S. Fabricant(1954) has however drastically changed this view. R. M. Solow (1957) by formulating the problem opened a new perspective in quantitative studies of technical progress. He found that the increase in productivity is far greater than what can be accounted for by increase in capital/labor ratio. Indeed in the period 1950-1982 we found that 85 % of the increases in productivity cannot be explained by increases in capital/labor ratio (see footnote 2). To this unexplained growth Solow gave the name technological change.

We used Solow's model to explain production and technical change is based on production function, F , characterized by *constant returns to scale*:

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

where Y represents output and K and L represent capital and labor inputs in physical units. The variable t for time appears in F to allow for technical change as an unspecified expression for any kind of shifts in the production function. We define the *share* of capital input and labor input in the value of output by:

$$v_K = \frac{Y}{K} \tag{2}$$

$$v_L = \frac{Y}{L}. \tag{3}$$

Necessary conditions for producer equilibrium are given by equalities between the value shares of each input and the *elasticity* of output with respect to that input:

$$v_K = \frac{\partial lnF}{\partial K} \tag{4}$$

$$v_L = \frac{\partial lnF}{\partial L} \tag{5}$$

Finally, we can define the *rate of technical change*, w, as rate of growth of output with respect to time, ***holding inputs constant***:

$$w = \frac{\partial lnF}{\partial t} \tag{6}$$

Under constant returns to scale the rate of technical change can be expressed as the rate of growth of the output less a weighted average of the rates of growth of capital and labor inputs, where the weights are given by the corresponding value shares: [3]

$$\frac{d\ln F}{dt} = \frac{\partial \ln F}{\partial K}\frac{d\ln K}{dt} + \frac{\partial \ln F}{\partial L}\frac{d\ln L}{dt} + \frac{\partial \ln F}{\partial t} \tag{7}$$

It is convenient to use the special case of *neutral* technical change.[4] Shifts in the production function are defined as neutral if they leave marginal rates of substitution untouched but simply change the output attainable from given inputs. In that case the production function takes the special form:

$$Y = A(t)f(K, L), \tag{8}$$

where the multiplicative factor $A(t)$ measures the cumulated effect of shifts over time. Differentiate (8) totally with respect to time and divide by Y one obtains

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + A\frac{\partial f}{\partial K}\frac{\dot{K}}{Y} + A\frac{\partial f}{\partial L}\frac{\dot{L}}{Y}, \tag{9}$$

where dots indicate time derivatives.

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[3] We note that expressions $\frac{d\ln K}{dt}$, $\frac{d\ln L}{dt}$, $\frac{\partial \ln F}{\partial t}$ are Divisia quantity indexes of capital input, labor input and of technical change. These indexes were used by F. Divisia (1925, 1928, 1952). The Divisia index of technical change was introduced by R. Solow (1957) and it has been discussed by F. M. Gollop and D. W. Jorgenson (1980), C. Hulten (1973), D. W. Jorgenson and Z. Griliches (1967, 1971).

[4] Tests for determining the type of technical progress are published in M. J. Beckman and R. Sato (1969). We performed several test for our data. The test results given in Annex II, although are not too decisive, but at least does not exclude the possibility of ***Hicks neutrality***. Hicks neutrality means that technical progress is ***product augmenting***. The shifts in the production function are pure scale changes, leaving marginal rates of substitution unchanged at given capital/labor ratios. (C. Kennedy and A. P. Thirwall (1972)). Hicks neutrality leads to the form given by equation (8) (see M. J. Beckmann and R. Sato (1969) p. 90.)

Now using the conditions for producer equilibrium of form (4) and (5) in equation (9) - note that $\frac{\partial F}{\partial K} = A\frac{\partial f}{\partial K}$, $\frac{\partial \ln F}{\partial \ln K} = \frac{\partial F}{\partial K}\frac{K}{F}$, $F(K, L, t) = A(t)f(K, L)$ in this case - we get:

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + v_K\frac{\dot{K}}{K} + v_L\frac{\dot{L}}{L}. \tag{10}$$

From (10) we can express the rate of technical progress:

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - v_K\frac{\dot{K}}{K} - v_L\frac{\dot{L}}{L}, \tag{11}$$

where the variables on the right hand side of equation (11) all are observable. The growth rate of GDP, $\frac{\dot{Y}}{Y}$, the share of inputs in the value of GDP, v_K and v_L, and the growth rates of inputs, $\frac{\dot{K}}{K}$ and $\frac{\dot{L}}{L}$ can be calculated from data given in Table 1 and Table 7 in Annex I.

3. Application to the U.S.: 1950-1982

In order to calculate the rate of technical progress defined by equation (11) as a residual we should either estimate the parameters v_K and v_L defined by (4) and (5), or we should take them from other sources. After so many years of intense empirical investigations concerning the values of these parameters that started with the paper of C. W. Cobb and P. H. Douglas (1928) we may summarize that the actual value of the parameters v_K and v_L must lie somewhere in the intervals $(\frac{1}{4}, \frac{1}{3})$ and $(\frac{2}{3}, \frac{3}{4})$, respectively. The estimates given by O. Eismont and H. Ross (1985) based on the data for period 1960-1982 and using special corrections for the income from self employment are $v_k = 0.75, v_L = 0.25$. Using these values in estimating $WT2$ the estimated rate of technical progress (w) defined by equation (6) and (10) is shown in Fig. 1. Our own calculation based on the data presented in Table 7 gave $v_K = 0.65, v_L = 0.35$. The rate of technical progress given by this calculation ($WT1$) is shown together with the first one in Fig. 2. to indicate, that the difference is negligible.

From the estimates of (WT's) we can get the multiplicative factor $A(t)$, which measures the cumulated effect of shifts in the production function. These multiplicative factors, $AT1$ and $AT2$, referring to $WT1$ and $WT2$, are shown in Fig. 3. together with the index of the labor productivity ($1960 = 100$).

In the remaining part of the analysis we used $WT2$ and $AT2$. Noticing that tendencies and the specification properties of the two calculations mentioned above are very similar.

Returning now to the aggregate production function, our starting point, it is worth to mention that all these calculations aimed at to separate $A(t)$ and $f(K,L)$ in equation (8).

Under our assumption the production function can be reformulated as follows:

$$\frac{Y}{L} = A(t)f(\frac{K}{L},1)\,. \tag{12}$$

Having isolated $A(t)$, we have now the opportunity to investigate the nature of the causal part of the production function as well. In order to illustrate the shape of $f(\frac{K}{L},1)$, the scatter of $\frac{Y}{A(t)L}$ against $\frac{K}{L}$ is shown in Fig. 4. The shape of this relationship is remarkable, supporting the hypotheses that there might exist an aggregate production function connecting output to inputs.

4. The determinants of technical progress

After using alternative methods to measure the rate of technical progress we found that technical progress has played an important role in the growth of the U.S. during the period 1950-1982. However, the estimation of the rate of technical progress has so far been confined to the assumption of exogenous technical progress that just appears like manna falling from heaven; it is costless and does not depend on other economic variables. It is perhaps true that many of the factors that govern the rate of technical progress are outside the usual boundaries of economics. Nevertheless, the treatment of technical progress as entirely exogenous is clearly unrealistic.

Specifying the multiplicative factor, $A(t)$, in eq.(8) as solely depending from time we estimated the following equation for the period 1950-1982:[5)]

$$\begin{aligned} \ln A &= 0.018 + 0.013\,t \\ &\quad\;(1.59) \quad (24.70) \end{aligned} \tag{13}$$

$$R^2 = 0.950 \quad DW = 0.32\,,$$

where $\ln A$ is log of $A(t)$, the cumulated technical factor, and t is time. The DW - statistics is far outside the acceptable region indicating errors in specification.

Including the square of time (t^2) into this equation, the result over the same period is:

5) Figures in parentheses indicate absolute values of t-statistics.

$$\ln A = -0.080 + 0.022t - 0.0002t^2$$
$$(5.14) \quad (11.74) \quad (4.79) \tag{14}$$
$$R^2 = 0.971 \qquad DW = 0.51$$

The error in specification of this equation is evident from not only the devastating value of D-W test but also because the negative coefficient of t^2 indicates, that as time goes on we would have to face not only a slowdown in growth but after a while there would be a permanent negative growth. In more sophisticated approaches there might be room for time as an explanatory variable, but only using it together with other endogenous factors (see W. Krelle (1987)). All these results indicate that there must be some factors that influence the rate of technical progress in important ways. Since the publication of R. M. Solow (1957), some attempts have been made to construct macro-economic models with the assumption of endogenous technical progress. C. Kennedy and A. P. Thirwall (1972) gives an overview of the developments in this respect prior to 1971 with references to 294 papers.

Here we come out with the idea to explain it with logistics factors and it is hard to believe that among many results of the past three decades unknown to us there would not be similar ones. As E. K. Y. Chen (1979) notes (p.90), extremely little has been done to *test* the *endogenous* technical progress hypotheses. This is especially astonishing when we at the same time observe the ever-increasing empirical work based on the assumption of *exogenous* technical progress, that cannot survive even the simplest test procedures.

The purpose of the remaining part of this paper is to test an endogenous technical progress hypotheses based on factors connected with logistics.

Before doing so, we shall briefly review the literature on endogenous technical progress. We shall however confine this review to literature on the testable hypotheses that are related to our approach.

Kaldor-Eltis model

It was N. Kaldor (1957) who first introduced the notion that technical progress is to be explained by the process of investment. Further results were published by W. A. Eltis (1971, 1973) where he related the technological progress to enterpreneurial decisions on research and development (R&D) expenditures. The framework of their approach can be summarised in the following general specification.

$$A(t) = A_0 e^{\lambda t}, \tag{15}$$

where $A(t)$ is the level of technology (the multiplicative factor that measures the cumulated effect of shifts over time, and represents the ***technical progress function*** which can be specified for estimation purposes using various functional forms of investment, share of investment in GDP, change of capital/labor ratio or any economic variable supposed to influence technical progress.

Learning by doing

Learning as a process of acquiring knowledge has long been studied by psychologists and management scientists. However, it was not until K. J. Arrow's (1962) paper that the concept of learning by doing was incorporated into a macroeconomic model. Arrow's aim was to build up a neoclassical growth model in which at least part of technical progress does not depend on the time as such but develops out of experience gained within the production process itself. Based on earlier ideas of P. J. Verdoorn (1951), N. Kaldor and others, Arrow related technical progress to experience, and chose cumulative gross investment as the index of experience, arguing that the appearance of new machines that brings about new problems to solve and new perspectives at the same time provides stimulation to innovation. (R. U. Ayres (1984,1987) describes the development of the idea of learning by doing.)

The notion of learning by doing can be incorporated in the following form:

$$A_t = A_0 G_t^c, \tag{16}$$

where G_t is the index of learning, measured by cumulative gross investment, and c is the learning coefficient, or in other words it is the elasticity of A_t with respect to the index G_t.

Many combination of equations[6] (15) and (16) could be used for estimation procedures. In the present paper we bring logistics factors into the explanation of endogenous technical progress. The results are not significantly different using either the form (15) or the form (16) as a framework for specification in that respect, that in both cases these factors have considerable explanatory power.

[6] For example: $A_t = A_0 e^{\lambda t} G_t^c$ could give a framework for several specification variants.

5. Data, Specification and Empirical Results

The result of testing endogenous technical progress originating from logistics factors depend to a large extent on how we measure the changes in logistics. The choice of explanatory variables is not too big if we prefer to have long time series of factors related to technological progress generating activities in transport and communication sectors of the U.S. Consequently, the selection of explanatory variables is admittedly *ad hoc*.

The driving force of new logistics technologies is undoubtedly in the sphere of information processing. This is made clear by the amounts of private and government R & D spending, which are much higher relative to output in communication (9.3 percent in 1980) than in the business sector as a whole (2.8 percent N. E. Terleckyj (1984) p.119.) Relatively long time series for private ($RDEXC$) and government ($RDEXG$) R & D expenditures in U.S. electrical equipment and communication industries were completed by Terleckyj, reproduced in Table 5. These were used as proxies for contributing factors from communication sectors to the growth of the U.S. economic performance.

From the sphere of transportation, as the other important component of logistics we used two additional explanatory variables. One of them is the share of transport equipment investments in gross capital formation ($SITR$, given in Table 4). The other one was motivated by the results of N. Nakicenovic (1986) , who showed how the advancement of the motor vehicle production and use in the U.S. opened a road to technological change.[7] We used the share of motor vehicles in total intercity freight traffic ($SMOTO$, given in Table 2) to indicate this link.

The estimated equation is a specified form of equation (15):

$$\begin{aligned}\ln AT = & -0.629 + 0.108 RDEXC + 0.0507 RDEXG_{-3} + \\ & \;\;(4.25) \quad\; (8.31) \qquad\qquad\quad (3.53) \\ & +0.0165 SITR + 0.0188 SMOTO \\ & \;\;(3.11) \qquad\qquad\quad (3.08)\end{aligned} \tag{17}$$

$$R^2 = 0.959 \qquad DW = 1.11\,,$$

where in the case of $RDEXG$ the subscript indicates a time lag of 3 years. The goodness of fit is demonstrated in Fig. 5. The value of DW statistics now are inside

[7] Results of a parallel research reported in P. Dimitrov and S. Wandel (1988) also demonstrated the importance of road transport for logistic performance.

the interval where it is inconclusive, although positive autocorrelation can be rejected at 1 % level of significance ($d^{0.01}_{23,4}$: $d_L = 0.77, d_U = 1.53$). To test the reliability of the estimates and the specification we performed the following test procedures:

To test normality of the residuals the Jarque-Bera LM test was used. The presence of autocorrelation (of different order) was tested by Durbin's m and by Godfrey's LM tests. To trace the time where structural change in the parameters might have occurred the Quandt-ratios were calculated and using the results of this procedure the Chow test was applied to check for structural change. The presence of heteroscedasticity was checked by using the Goldfeld-Quandt and the usual F-test. The constancy of the parameters was checked by the Breusch-Pagan LM test. As a general diagnostic test Remsey's RESET tests were applied and finally, as a test for functional misspecification the Godfrey-Wickens LM test was applied. For a detailed description of the test procedures mentioned and for the actual values of the test statistics see Annex II.

To summarize these tests, we can draw the conclusion that the inclusion of the explaining variables considered in our analysis is justified by the results but on the other hand there might be some other important explaining factors not considered here.

The t-values shows that all of the coefficients are significant. The significance of lagged R & D expenditures of government might indicate, that the effect of government R & D expenditures lags some years in comparison to the effects of private R & D expenditures. This is quite plausible if we take into consideration that the government-funded R & D performed in universities and in institutions often needs longer gestation period to be implemented in production.

Using equation (16) as another framework for the specification we get:

$$\begin{aligned} \ln AT = &-0.516 + 0.230 \ln RDEXC + 0.072 \ln RDEXG_{-3} + \\ &\;(7.95) \quad (10.83) \qquad\qquad\quad (2.96) \\ &+0.114 \ln SITR + 0.399 \ln SMOTO \\ &\;(2.78) \qquad\qquad (4.06) \end{aligned} \tag{18}$$

$$R^2 = 0.977 \qquad DW = 1.33$$

(Note, that the difference between (17) and (18) is that here the explanatory variables are in log form.)

The result of estimations (17) and (18) provides more or less the same conclusions. The goodness of fit in graphical illustration cannot be distinguished. Results of some test statistics are better in case of equation (18) (for example the LM test for autocorrelation) but we do not see much reason to prefer (18) against (17). Both support that the variables chosen for logistics factors significantly affect the rate of technical progress. It is evident in the light of the test results that there must be other factors as well, perhaps not all observable, that should be included in the specification. Nevertheless, to treat the technical progress as an, at least partly endogenous process makes a great difference in describing what is going on in reality. These results also indicate that logistics factors if we interpret them widely enough to include many sides of the relations between producer and user, are good candidates, if not the best ones, in endogenizing technical progress.

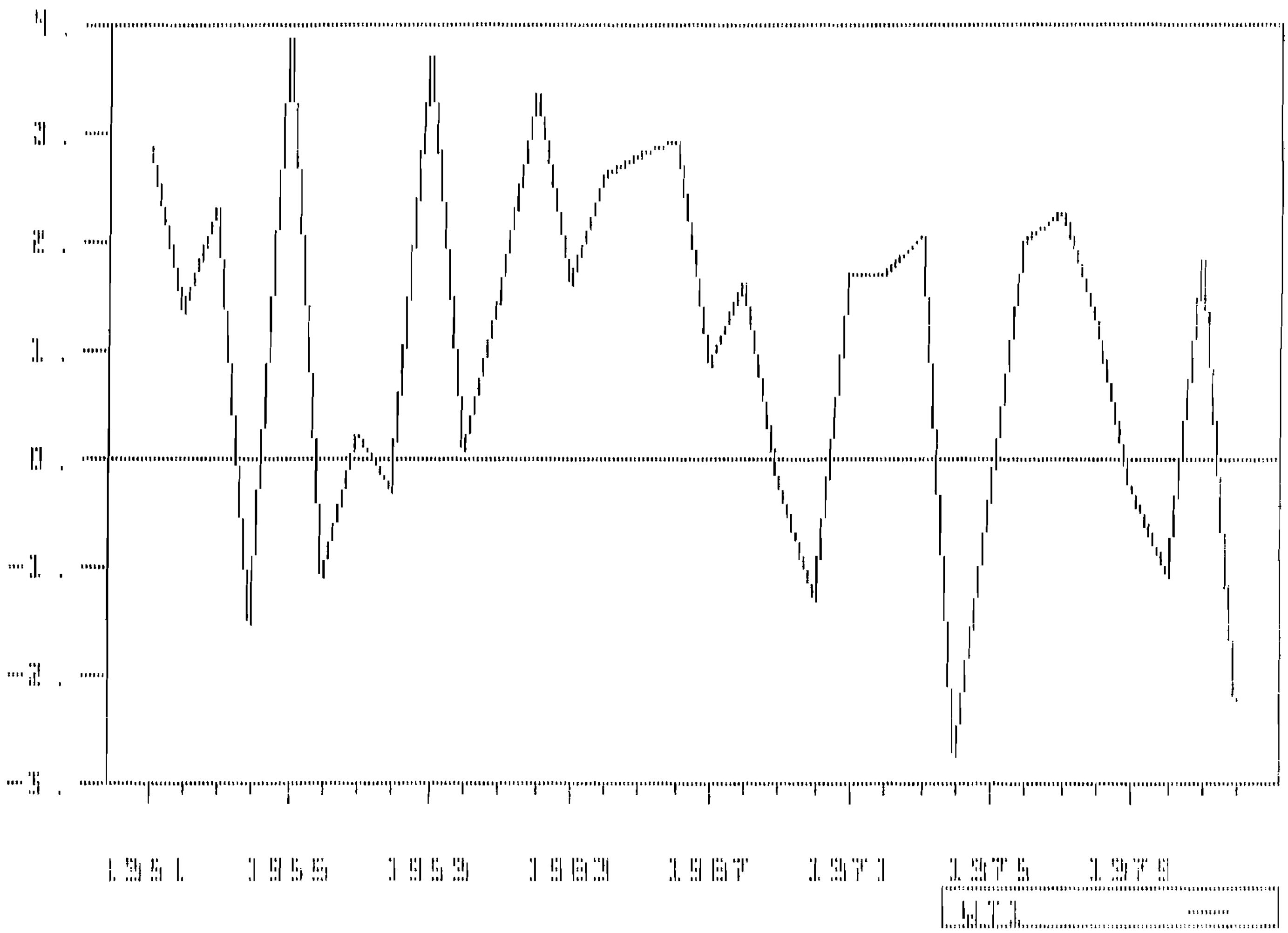

Figure 1: The rate of technical progress (WT1) calculated according to equation (11) and using the estimates $v_K = 0.75$, $v_L = 0.25$.

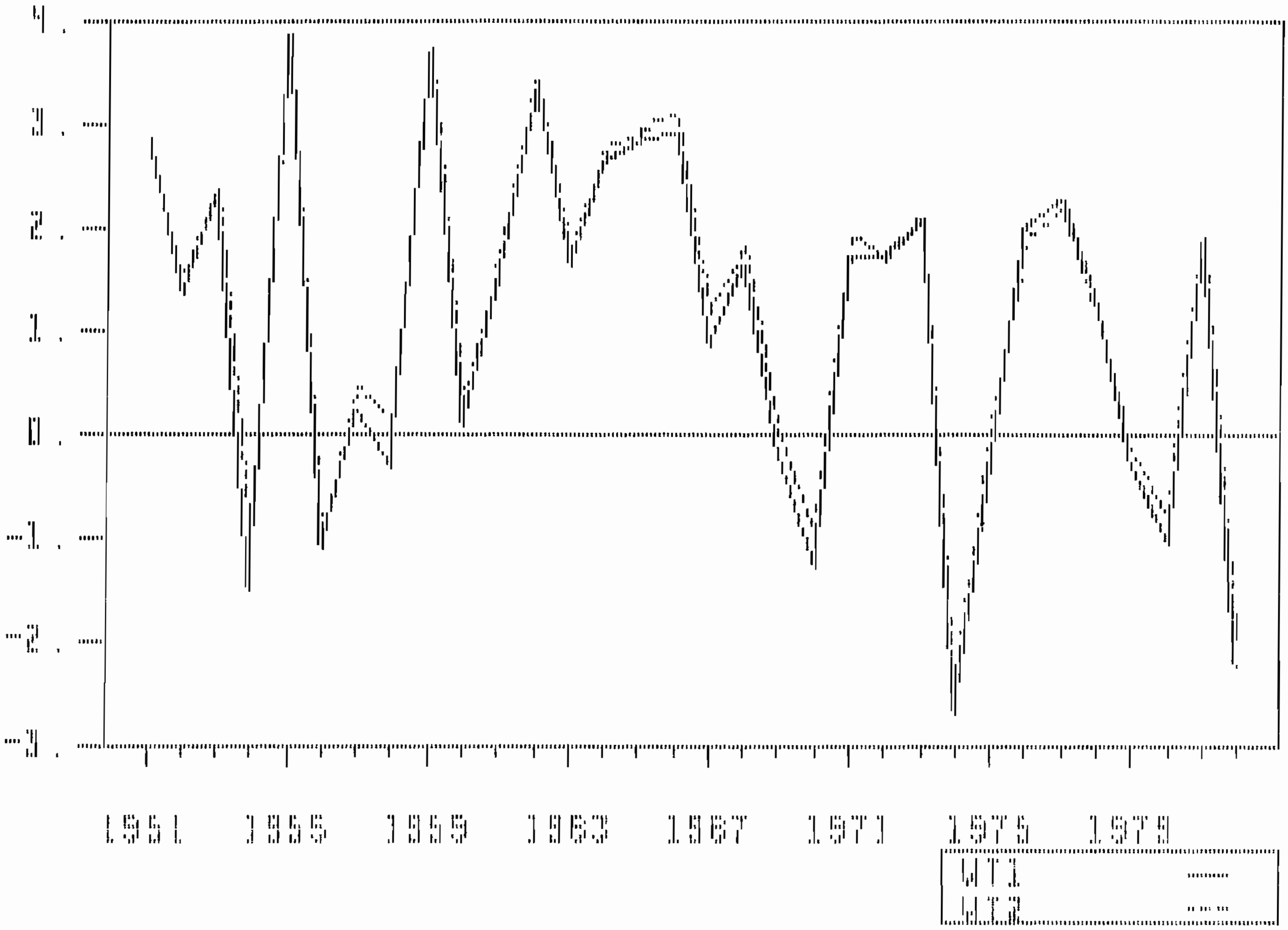

Figure 2: The rate of technical progress using different estimates of value shares (in case of WT1 $v_K = 0.75$, $v_L = 0.25$; in case of WT2 $v_K = 0.65$, $v_L = 0.35$).

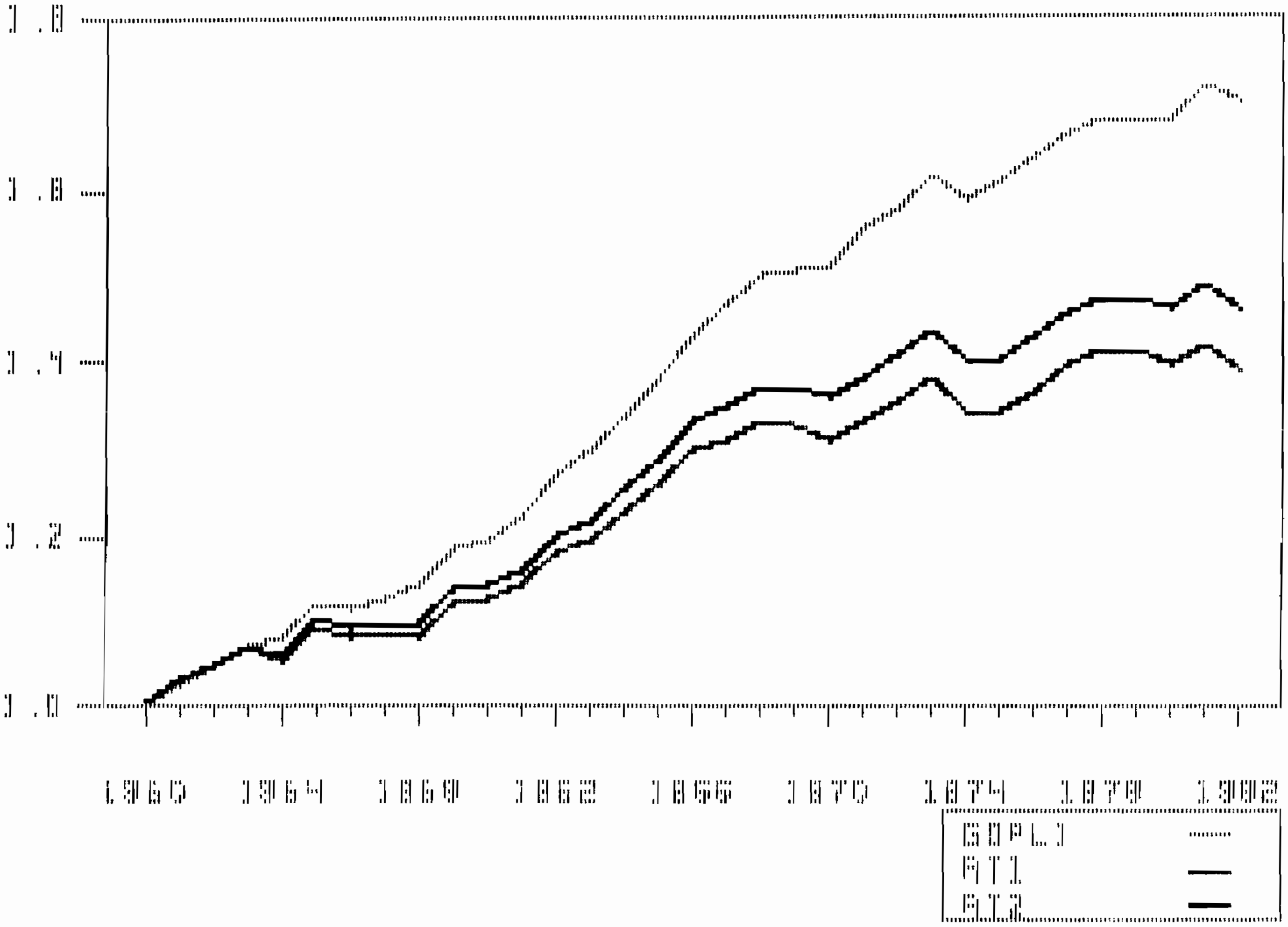

Figure 3: Cumulated rate of productivity growth and the cumulated rate of technical progress ($AT1$ and $AT2$ calculated according to the estimates of $WT1$ and $WT2$, respectively).

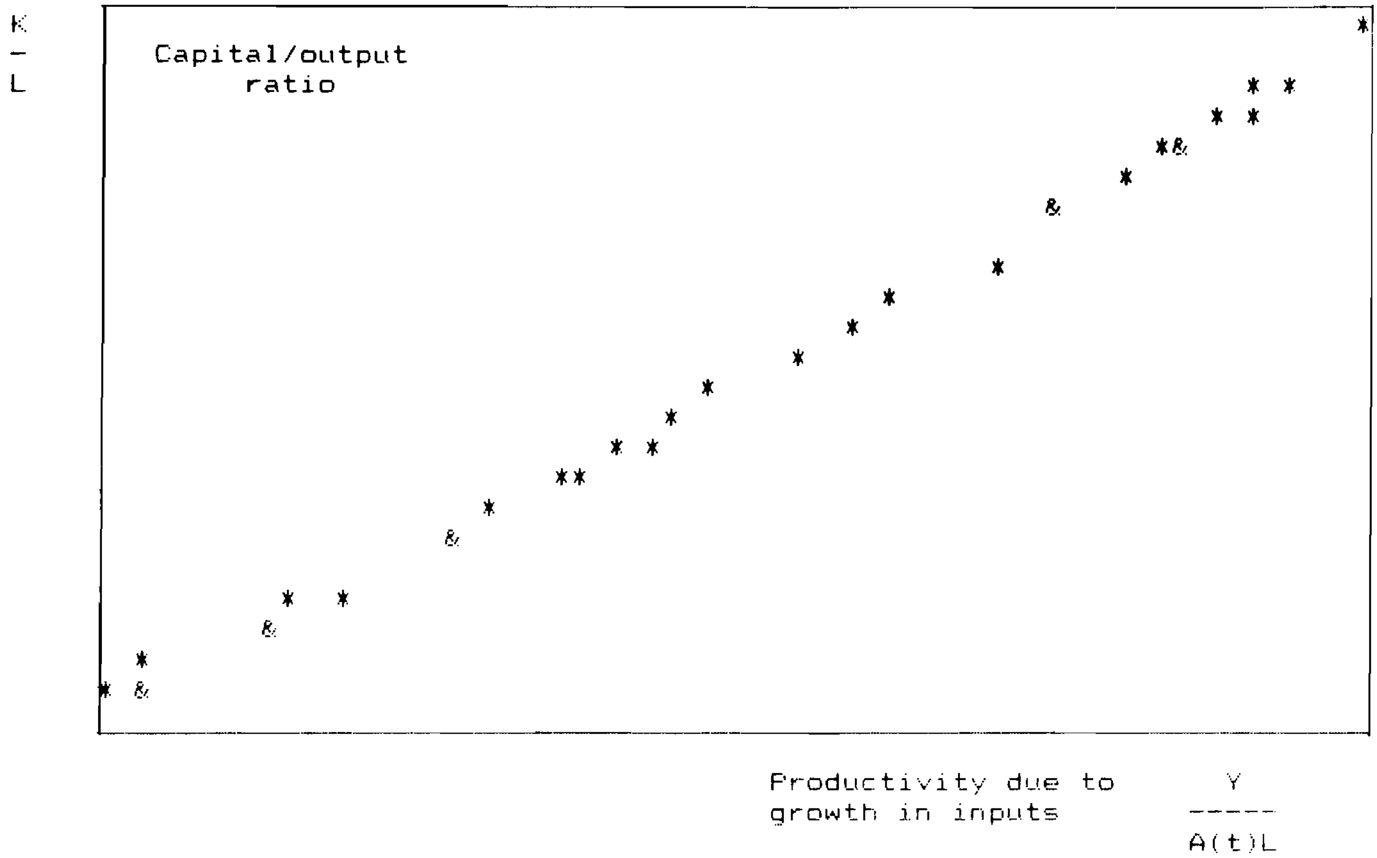

Figure 4: Scatter of the relationship between capital/labor ratio and the growth of productivity attributable to growth in inputs (the production function without shifts).

ANNEX I

STATISTICAL DATA FOR THE UNITED STATES

Table 1

Basic data for calculation of the production function

Gross domestic product (GDP), capital (K) and labor(L) inputs (USA, 1950-1982)

	GDP	Capital (K)	Labor (L)
	(billions of 1975 us$)		(*)
1950	678.21	1500.00	114.359
1951	730.95	1560.04	120.531
1952	758.06	1615.46	122.559
1953	795.44	1664.90	125.473
1954	778.28	1719.32	122.044
1955	831.83	1774.93	125.604
1956	849.89	1841.95	129.355
1957	865.87	1907.63	130.174
1958	861.68	1969.60	127.556
1959	913.35	2021.84	130.253
1960	932.55	2086.64	132.030
1961	956.47	2154.62	131.965
1962	1009.49	2221.72	134.231
1963	1050.35	2299.44	136.717
1964	1105.73	2387.56	139.469
1965	1172.90	2484.74	143.427
1966	1241.27	2599.36	146.315
1967	1275.57	2719.88	146.959
1968	1327.19	2830.44	149.228
1969	1364.76	2949.29	152.719
1970	1360.90	3068.30	151.786
1971	1402.54	3170.38	152.289
1972	1478.33	3280.73	158.062
1973	1559.79	3406.26	163.221
1974	1549.55	3547.63	164.735
1975	1538.80	3658.48	161.150
1976	1613.99	3729.68	166.605
1977	1698.58	3810.41	172.256
1978	1778.09	3914.86	178.803
1979	1819.87	4039.90	182.943
1980	1815.82	4164.34	182.280
1981	1870.39	4255.79	183.468
1982	1826.31	4343.15	181.063

Source: H. Ross (1985)

Note: (*) Labor is calculated as follows:
L=employed persons (millions) * (hours of work per week * 52 * .oo1)

Table 2

The share of motor vehicles (SMOTO) and railroads (SRAIL)
in total intercity freight traffic
(USA, 1950-1982, in percent)

	SMOTO	SRAIL
1950	15.8	57.4
1951	15.6	56.8
1952	16.6	55.6
1953	17.6	52.1
1954	18.6	50.5
1955	17.2	50.4
1956	18.1	49.2
1957	18.8	47.6
1958	20.8	46.7
1959	21.4	46.0
1960	21.5	44.7
1961	22.4	44.2
1962	22.3	44.4
1963	22.9	43.8
1964	22.9	43.7
1965	21.8	43.7
1966	21.7	43.3
1967	21.9	41.8
1968	21.6	41.2
1969	21.3	40.8
1970	21.3	39.8
1971	22.0	39.7
1972	22.1	39.0
1973	22.6	38.4
1974	22.4	37.5
1975	21.9	36.7
1976	23.2	36.3
1977	24.1	36.1
1978	24.3	35.2
1979	23.6	36.0
1980	22.3	37.5
1981	21.7	38.0
1982	23.1	36.0

Source: For period 1950-1970: Historical Statistics of the United States, U. S. Department of Commerce, Washington, D. C., 1975, p. 707.

For period 1971-1982: Statistical Abstract of the U. S., 1987, Department of Commerce, p. 579.

Table 3

Estimated annual change of railroad productivity

Rate of change in railroad productivity (WRAIL), growth rate of aggregate input (WINP) and output (WOUTP) under assumptions of input-output separability and Hicks neutral technical change

	WRAIL	WINP	WOUTP
1952	.1	-4.4	-4.3
1953	-.6	-1.9	-2.6
1954	.1	-9.4	-9.3
1955	6.7	2.3	9.0
1956	3.1	-.6	2.5
1957	-1.0	-4.3	-5.3
1958	-2.0	-9.2	-11.0
1959	2.6	-.6	2.0
1960	1.3	-2.6	-1.3
1961	2.3	-4.6	-2.3
1962	4.6	-1.2	3.4
1963	2.9	-.6	2.3
1964	3.4	.8	4.3
1965	4.4	-1.2	3.2
1966	3.4	.6	4.0
1967	-2.3	-1.6	-3.9
1968	.1	.1	.2
1969	.9	.4	1.3
1970	-3.5	1.2	-2.3
1971	-4.4	-2.2	-6.6
1972	7.0	-3.1	3.9
1973	4.6	3.6	8.3
1974	1.3	.0	1.3

Source: D. W. Caves, L. R. Christensen and J. A. Swanson (1980)
WRAIL: p. 177, WINP and WOUTP: p. 178.

Note: The estimation of productivity growth is based on computation of the log-differences of the five input and four output indexes. The five inputs are the followings: a) labor, b) way and structures, c) equipment, d) fuel, e) materials. The four outputs are: a) freight ton-mile, b) average lenghth of freight haul, c) passanger mile, d) average length of passenger trip. When multiplied by one hundred , the log-differences of input and output indexes can be interpreted as percentage growth rates of productivity, as shown in the first column of this table.

Table 4

Investment in transport equipment

The share (SITR) of transport equipment investments (ITRANS) in gross capital formation (IS) by type of good

	IS	ITRAN	SITR
	(1)	(2)	((2/1)*100)
1960	1193	97	8.13
1961	1193	92	7.71
1962	1334	112	8.39
1963	1420	109	7.67
1964	1500	123	8.20
1965	1688	153	9.06
1966	1795	167	9.30
1967	1735	163	9.39
1968	1829	195	10.66
1969	1877	206	10.97
1970	1727	169	9.78
1971	1844	185	10.03
1972	2947	283	9.60
1973	3161	343	10.85
1974	2945	314	10.66
1975	2616	269	10.28
1976	2781	302	10.85
1977	3074	360	11.71
1978	3366	402	11.94
1979	3469	405	11.67
1980	3258	322	9.88
1981	3293	315	9.56
1982	3076	282	9.16

Source: OECD, National Accounts, Vol.II, Detailed Tables, various issues.

Note: Data in column 1 and 2 are in billions of 1970 US$ for period 1960-1971, and of 1975 US$ for period 1972-1982.

Table 5

Estimates of R&D expenditures and R&D capital
in Electrical Equipment and Communication Industries
(USA, 1948-1980, in million of 1972 US$)

	Company R&D Excpenditures (RDEXC)	Government R&D Excpenditures (RDEXG)	Stock of Private R&D Capital (RDCAP)
1948	450	274	3200
1949	487	298	3440
1950	527	310	3690
1951	570	325	3960
1952	617	454	4240
1953	667	787	4550
1954	736	875	4870
1955	804	963	5230
1956	870	1050	5610
1957	936	1842	6030
1958	957	2025	6480
1959	1018	2429	6960
1960	1233	2438	7490
1961	1279	2302	8060
1962	1344	2395	8680
1963	1419	2580	9350
1964	1502	2553	10080
1965	1622	2640	10860
1966	1842	2831	11710
1967	1963	2841	12630
1968	2119	2826	13630
1969	2255	2754	14700
1970	2196	2418	15850
1971	2219	2351	17090
1972	2313	2367	18420
1973	2357	2280	19860
1974	2353	2007	21400
1975	2228	1837	23070
1976	2332	1934	24850
1977	2316	1930	26750
1978	2484	1909	28750
1979	2771	2095	30850
1980	3039	2103	33020

Source: N. E. Terleckyj (1984)
RDEXC: p. 122, RDEXG: p. 123, RDCAP: p. 133.

Note: Series of RDEXC is based on the company-funded expenditure for R&D in electrical equipment and communication industries compiled by the National Science Foundation (NSF) for the years 1953-1980. The corresponding data for government-funded R&D (RDEXG) were obtained from selected issues of the NSF Research and Development in Industy report. The data for RDCAP are compounded from RDEXC and RDEXG in accordance with the estimation procedures discussed by Terleckyj (1984) pp.123-127.

Table 6

Estimated total factor productivity of rail (TRAIL), and nonrail (TFPNR) transport, and of communication (TFPC) (USA, 1948-1976)

	TFPNR	TFPC	TFPR
1948	75.9	42.2	48.1
1949	70.0	45.1	45.8
1950	74.9	48.3	51.8
1951	78.3	51.8	55.7
1952	76.1	53.1	55.2
1953	77.5	55.8	54.3
1954	77.8	56.8	54.0
1955	80.7	61.7	58.6
1956	83.3	62.8	60.5
1957	84.2	66.5	60.0
1958	83.3	71.4	61.2
1959	84.6	76.7	65.8
1960	87.1	78.9	67.8
1961	88.0	82.5	72.1
1962	89.3	85.7	75.2
1963	92.8	90.0	81.0
1964	93.6	91.8	85.1
1965	97.8	94.4	94.0
1966	101.4	97.0	101.5
1967	100.0	100.0	100.0
1968	106.9	101.5	98.8
1969	107.2	107.3	105.6
1970	106.4	107.3	99.9
1971	108.8	109.8	94.2
1972	114.0	113.7	96.8
1973	119.9	118.4	106.5
1974	121.7	119.5	101.2
1975	120.3	127.8	93.4
1976	124.2	134.4	95.3

Source: J. W. Kendrick and E. S. Grossman (1980)
TFPNR: p. 134, TFPC: p. 135, TFPR: p. 133.

Note: Total factor productivity is the ratio of real output to total factor inputs. Kendrick and Grossman use a value added measure of real output (gross output less purchased materials and other intermediate products). Labor and capital factor inputs are based on official estimates published by Department of Labor and by Conference Board, respectively.

Table 7

Aggregate cost structure

Nominal GDP (GDPN), capital consumption (CN), labor compensation (WGN), property income (QN), indirect taxes minus subsidies (TMSN)

(USA, 1950-1982, in billions of US$)

	GDPN	CN	WGN	QN	TMSN
1950	288.74	30.28			
1951	333.28	35.06			
1952	350.22	37.31			
1953	369.04	39.61			
1954	368.27	41.01			
1955	401.12	43.17			
1956	422.62	47.52			
1957	444.69	51.09			
1958	450.68	53.16			
1959	487.71	55.36			
1960	505.27	54.76	295.83	112.91	44.15
1961	523.31	56.31	304.56	116.66	45.89
1962	563.47	58.17	326.14	127.87	49.16
1963	594.72	60.24	344.05	136.40	52.32
1964	635.55	63.07	369.32	147.07	55.94
1965	688.61	66.90	398.02	165.40	59.49
1966	753.61	72.40	440.96	177.57	61.29
1967	797.16	78.56	473.33	179.19	66.34
1968	870.27	85.95	522.14	189.74	74.55
1969	940.53	95.34	575.46	191.72	81.90
1970	988.70	105.19	615.06	180.61	89.33
1971	1073.21	115.53	655.82	199.05	98.72
1972	1179.99	127.08	722.11	222.99	104.49
1973	1315.29	139.16	805.95	254.11	115.29
1974	1420.87	163.33	883.13	245.37	125.31
1975	1538.80	190.38	938.21	269.77	134.97
1976	1705.91	207.67	1044.04	303.17	145.93
1977	1903.07	230.58	1160.60	352.51	158.02
1978	2140.44	262.95	1310.58	400.88	168.64
1979	2382.22	302.91	1468.82	431.94	180.04
1980	2598.59	346.45	1612.18	435.01	202.66
1981	2923.77	386.90	1783.30	520.71	237.76
1982	3041.36	419.02	1881.11	497.84	242.93

Source: H. Ross (1985), p. 11, 12, 21.
(OECD, National Accounts, Vol. I.,Main Aggregates, Tape 1984)

Annex II

1. Statistical tools

In what follows, the estimations are OLS estimations. The estimated equations are tested by using the following test procedures:

Tests for first-order autocorrelation in the residuals

DW Durbin-Watson d test. The null-hypothesis is that there is no first order autocorrelation ($\rho = 0$, where $u_t = \rho u_{t-1} + e_t$) For reference see J. Durbin and G. S. Watson (1950-51).

M Durbin's m test. The null-hypothesis is the same as in the case of the DW test. Under the null-hypothesis the test statistics is asymptotically N(0,1) distributed. For reference see J. Durbin (1970)

LM1 Godfrey's LM test. The null hypothesis is the same as is in the case of the DW test. Under the null-hypothesis the test statistics is asymptotically $\chi^2_{(1)}$ distributed. For reference see L. Godfrey (1978 a,b)

Test for second order autocorrelation in the residuals.

LM2 Godfrey's LM test for first and second-order autocorrelation. The null hypothesis is that there is no first and second order autocorrelation ($\varrho_1 = \varrho_2 = 0$, where $u_t = \varrho_1 u_{t-1} + \varrho_2 u_{t-2} + e_t$) Under the null-hypothesis the test statistics is asymptotically $\chi^2_{(2)}$ distributed. For reference see L. Godfrey (1978 a,b)

Test for the normality of the residuals.

JB Jargue-Bera LM test. The null hypothesis is that the distribution of the residuals is normal. Under the null-hypothesis the test statistics is asymptotically $\chi^2_{(2)}$ distributed. For reference see C. M. Jarque and A. K. Bera (1980)

Test for structural change in the parameters.

CH The null-hypothesis is that in the given year (indicated in the table) there is no structural change in the parameters. Under the null-hypothesis the test statistics is asymptotically $F(k, T-2k)$ distributed, where T is the number of observation and k is the number of the explanatory variables. For reference see G. C. Chow (1960).

The time of structural change is detected by using the Quandt ratios For reference see R. Quandt (1960)

Test for heteroscedasticity and random coefficient variation

BP Breusch-Pagan LM test. The null-hypothesis is that the residuals are homoscedastic. Under the null-hypothesis the test statistics is asymptotically $\chi^2_{(k)}$ distributed, where k denotes the number of explaining variables in the investigated equation. For reference see T. S. Breusch and A. R. Pagan (1979)

Test for functional misspecification

RESET Ramsey's RESET test. The null-hypothesis is that the functional specification is correct. Under the null-hypothesis the test statistics is asymptotically $F(p, T-k)$ distributed, where p is the number of the variables added to the equation.

X^2 The form suggested by J. G. Thursby and P. Schmidt (1977) is used by adding the

X^3 second and third powers of the explanatory variables.

GW Godfrey-Wickens LM test. The null-hypothesis is the same as in the case of the RESET test. Under the null-hypothesis the test statistics is asymptotically $\chi^2_{(1)}$ distributed. For reference see L. Godfrey and M. R. Wickens (1981)

To indicate the goodness of fit the following statistics are given in the tables.

SE Standard error of the estimation

MAPE Mean absolute percentage error

$\bar{R}^2$ Corrected R-square.

The calculation were performed by using the Bonn-IAS software package.

2. Testing the type of technical progress

Since in the procedure we used to calculate the rate of technical progress (or shift in the production function) the type of technical progress is of particular importance. According to M. J. Beckman and R. Sato (1969) technical progress is defined to be

Hicks-neutral (product augmenting) if the relationship between the marginal rate of substitution and the factor proportion is *unchanged*. To test for Hicks-neutrality the following two specifications were estimated and tested

$$r/w = a + b\frac{L}{K} + u \tag{A1}$$

$$\log(r/w) = a + b\log(L/K) + u\,, \tag{A2}$$

where $r = \frac{Q}{Y'N} \cdot \frac{Y}{K}$, $w = \frac{W}{Y'N} \cdot \frac{Y}{L}$, Y is real GDP, $Y'N$ is nominal GDP, W is labor income, Q is capital income, K is capital stock and L is labor input.

Technical progress is called *Harrod-neutral (labor augmenting)* ,when the relationship between the capital-output ratio and the return to capital, r (as defined above) is unchanged. In terms of the production function it means

$$Y = F(K, A(t)L)\,.$$

The tested specifications were the following

$$r = a + b\frac{Y}{K} + u \qquad 0 < b < 1 \tag{A3}$$

$$\log(r) = a + b\log(Y/K) + u\,, \tag{A4}$$

By contrast to the Harrod-neutral case, technical progress is *Solow-neutral (capital augmenting)*, when the relationship between output per worker and the wage rate, w (as defined above) does not change, that is the production function can be formulated in the following way

$$Y = F(A(t)K, L)\,.$$

The corresponding specifications for the statistical tests are

$$w = a + b\frac{L}{K} + u \qquad 0 < b < 1 \tag{A5}$$

$$\log(w) = a + b\log(L/K) + u\,. \tag{A6}$$

Following Beckman and Sato's suggestions, two other forms were also tested. These are different forms of capital and labor augmenting technical progress.

The technical progress is *capital combining* if the relationship between the output-labor ratio (Y/L) and the return to capital (r) is unchanged. In this case, the production function takes the following form

$$Y = F(K + A(t)L, L)\,.$$

In order to perform the statistical tests the following specifications were investigated

$$r = a + b\frac{Y}{L} + u \tag{A7}$$

$$\log(r) = a + b\log(Y/L) + u. \tag{A8}$$

Finally, the technical progress is *labor combining* if there is a stable relation between the output-capital ratio (Y/K) and the wage rate (w). The production function is of the form

$$Y = F(K, A(t)K + L)$$

and the corresponding relations to be tested are

$$w = a + b\frac{Y}{K} + u \tag{A9}$$

$$\log(w) = a + b\log(Y/K) + u. \tag{A10}$$

It should be noted that the tested relationship: ((A 1)-(A 10)) are clearly confined to certain forms of the production function that is our analysis and the conclusions drown from it also depend on the specification of the production function. (The implied production functions see in Beckmann and Sato (1969) p.94)

The concept of *unchanged (or stable)* relation is also a controversial point of these types of statistical analyses. Differently from *Beckman and Sato*, we consider a relation unchanged (or stable) if it survives the usual specification and misspecification tests. (Described in Section 1 of this Annex). The estimation results and the results of the specification analysis are summarized in Table A1. The results in this table show clearly that none of the investigated relations were free from specification error. The very low Durbin-Watson d values (and the other tests of first order autocorrelation) clearly indicate the presence of first order autocorrelation and the values of the Chow test the presence of structural change in the parameters (with two exceptions, the Quandt ratio indicated 1966 as the time of structural change). Having these results, it makes no sense to rank the relations according the values of the corrected R squares. The only conclusion we can draw from this analysis that none of the types of technical progress are particularly supported by the empirical evidence.

3. Statistical test of exogenous technical progress

The assumption of exogenous technical progress means that technical progress depends only on time or put differently, the time trend is enough to explain the state of technical knowledge ($A(t)$) appearing in the production function. In order to test this assumption we tested two different relations. In the first on, constant rate of technical progress is assumed that is the following relation is tested

$$\log A(t) = a + bt + u\,,$$

where $A(t)$ is the state of technical knowledge (as defined in Section 1) and t is the time variable. The estimation results and the results of the specification analysis are the following

$$\log A(t) = \underset{(0.80)}{0.0186} + \underset{(12.33)}{0.0121t} + u$$

$$\bar{R}^2 = 0.883 \qquad SE = 0.0271 \qquad DW = 1.33$$

$$DW = 0.31^* \qquad M = 4.96^* \qquad LM1 = 12.13^*$$

$$JB = 0.92 \qquad CH = 59.83^*(\text{year=1966}) \quad BP = 1.63^*$$

$$\text{RESET} \quad X^2 = 49.15^* \quad X^3 = 39.69^* \quad GW = 0.002$$

(For the description of the specification and misspecification tests see Section 1 of this Annex ; t values in brackets; * significant at 5 % level.)
From these results, it is clear that this relation suffers from rather serious specification errors. The test statistics indicate the presence of first order autocorrelation, structural break (in 1966) and the misspecification of the functional form.

Assuming linearly changing rate of technical progress the following equation is to be tested

$$\log A(t) = a + bt + ct^2 + u\,.$$

The corresponding results are

$$\log A(t) = \underset{(6.41)}{-0.314} + \underset{(9.66)}{0.0431t} - \underset{(7.01)}{0.000675t^2}$$

$$\bar{R}^2 = 0.967 \qquad SE = 0.0144 \qquad MAPE = 3.85$$

$$DW = 0.85^* \qquad M = 2.88^* \qquad LM1 = 6.88^*$$

$$JB = 0.79 \qquad CH = 6.06^*(\text{year=1966}) \quad BP = 1.88^*$$

$$\text{RESET} \quad X^2 = 4.22^* \quad X^3 = 4.74^* \quad GW = 0.007$$

As in the previous case, the test statistics clearly indicate the presence of different types of specification errors. Consequently, the specification cannot be accepted as a stable one. It is so in spite of the fact that the different measures of goodness of fit ($\bar{R}^2$, SE, MAPE) improved quite substantially.

4. Statistical test of endogenous technical progress

The final form of the specification of endogenous technical progress investigated in our analysis is

$$
\begin{aligned}
\ln AT = {} & \underset{(4.25)}{-0.629} + \underset{(8.31)}{0.108} RDEXC + \underset{(3.53)}{0.0507} RDEXG_{-3} + \\
& + \underset{(3.11)}{0.0165} SITR + \underset{(3.08)}{0.0188} SMOTO
\end{aligned} \tag{17}
$$

$$\bar{R}^2 = 0.959 \qquad SE = 0.0160 \qquad MAPE = 4.42$$

$$DW = 1.11 \qquad M = 2.34^* \qquad LM1 = 5.62^*$$

$$JB = 0.58 \qquad CH = 8.21^* (\text{year}=1966) \quad BP = 3.17$$

$$\text{RESET} \quad X^2 = 14.29^* \quad X^3 = n.c \quad GW = 0.043\,,$$

where ($RDEXC$) and ($RDEXG$) are private and government R & D expenditures in U.S. electrical equipment and communication industries (given in Table 5), $SITR$ is the share of transport equipment investments in gross capital formation (given in Table 4) and $SMOTO$ is the share of motor vehicles in total intercity freight traffic (given in Table 2). In the case of $RDEXG$ the subscript indicates a time lag of 3 years.

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