MEASUREMENT OF THE RATE OF TECHNICAL PROGRESS

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PREFACE

In the beginning of 1985 IIASA started jointly with the University of Bonn a study on the World Economic Model under the leadership of Prof. Wilhelm Krelle. The structure of the model was developed by Prof. Krelle and discussed at the IIASA Conference on the Analysis and Forecasting of Economic Structural Change in May 1984. Since then a team of scholars from both East and West has been collecting the necessary data and estimating the parameters of submodels to be linked, at a later date, within the framework of the global model. The first quantitative results of this effort were discussed in the Workshop on Economic Growth and Structural Change, held in Lodz, Poland, December 9-10, 1985.

This paper presents the results of the estimations of production functions for OECD countries and was written in summer 1985, during the visit of Dr. O. Eismont, USSR, to the University of Bonn.

Anatoli Smyshlyaev
Acting Leader
"Economic Structural Change"

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In the joint Bonn–IIASA Research Project on Economic Growth and Structural Change the rate of technical progress in each country is taken an exogenous to the central model (Krelle, 1985) and should be explained within the framework of the country models. The first problem comprises measuring the rate of technical progress of each country in the reference period. There is an extensive literature on the identification and measurement of technical progress (see, for example, Abramovitz, 1956; Brown, 1966; Fabricant, 1954; Kendrick, 1956; Kennedy and Thirlwall, 1972, Schmookler, 1952; Solow, 1957; Tinbergen, 1942; Valavanis-Veil, 1955). The approaches differ considerably. This is largely due to different concepts associated with the notion of technical progress. Thus, prior to the measurement of the rate of technical progress we must define what we mean by this notion.[1]

Let τ be a latent variable that describes the amount of productive knowledge embodied in labor and used on the average. This knowledge can only change slowly and continuously (we do not consider catastrophes of any kind). Thus $\tau(t)$ should be a continuous function of time. The rate of technical progress is

$$w_\tau = \frac{\dot{\tau}}{\tau}$$

[1]The following ideas are based on some unpublished notes of Professor W. Krelle.

and is also a continuous function of time.[2] For simplicity, we assume a linear function

$$w_\tau = a_0 + a_1 t \quad . \tag{1}$$

Of course, this type of function can only be used for a limited time span.

By definition, τ should be linked with labor, i.e., we assume a Harrod-neutral technical progress. For simplicity we consider only two factors of production, labor and capital. We use the gross domestic product Y (minus indirect taxes plus subsidies) at constant prices as a measure of production. We assume the existence of a neoclassical production function of the form

$$Y = F(\tau L, K) \quad , \tag{2}$$

where L is labor (measured in man hours) and K is capital (measured in machine hours).

Assuming perfect competition and cost minimization, we obtain

$$\frac{\dot{Y}}{Y} = \alpha \frac{\dot{L}}{L} + (1-\alpha)\frac{\dot{K}}{K} + \alpha w_\tau \quad , \tag{3}$$

where α is labor income as a proportion of total income and $(1-\alpha)$ is capital income as a proportion of total income. Total income is defined as the GDP minus indirect taxes plus subsidies at current prices.

Unfortunately, existing statistics provide data only for total capital, K^s, and for the employed labor force, L^s, and do not account for their utilization ratios. So, labor, L, in the production function, being the amount of productive services rendered by the employed labor force, is a latent variable. The same applies to capital, K, which is also a latent variable. If we introduce labor and capital utilization ratios δ_L and δ_K, respectively, we obtain from equation (3)

$$w_\tau = \frac{1}{\alpha} w_Y - w_{L^s} - \frac{1-\alpha}{\alpha} w_{K^s} - (w_{\delta_L} + \frac{1-\alpha}{\alpha} w_{\delta_K}) \quad . \tag{4}$$

We defined w_τ as the rate of change of productive knowledge that is actually used on the average (or that is normally used in society), not of productive knowledge that is offered at exceptional times. In this case we can assume that w_{δ_L} and w_{δ_K}

[2] Generally, in this paper $w_x := \dot{x}/x$ defines the growth rate of the variable x.

have zero means

$$E[w_{\delta_L}] = E[w_{\delta_K}] = 0 \quad . \tag{5}$$

Next we turn to the problem of estimating the labor share α. Labor in the production function means the total labor, i.e., the labor of employed and self-employed persons. The statistical data for the compensation of employees do not include labor income of the self-employed, but we have to use labor income shares that include this. We estimate it by assuming that the average labor incomes of wage earners and of the self-employed are the same. The number of self-employed can be calculated from the available statistics, see OECD *Labor Force Statistics* (various years). With these corrections we obtain the values of α given in the second column of Table 1.

Table 1. Average share of labor income, 1960–1982.[a]

Country	Not including self-employed		Including self-employed	
US	0.659	(0.016)	0.746	(0.014)
FRG	0.603	(0.030)	0.728	(0.012)
Japan	0.503	(0.060)	0.770	(0.043)
France	0.579	(0.038)	0.742	(0.016)
UK	0.681	(0.012)	0.737	(0.015)
Italy	0.552	(0.043)	0.821	(0.022)
The Netherlands	0.604	(0.039)	0.719	(0.023)
Belgium–Luxembourg	0.587	(0.052)	0.730	(0.038)
Canada	0.617	(0.019)	0.709	(0.011)

Source: OECD *Labour Force Statistics* (various years); OECD *Main Economic Indicators* (various years); OECD *National Accounts* (various years).
[a] Own calculations; the values in parentheses are the standard deviations.

It is worth noting that after corrections the labor shares are similar for all OECD countries.

We now define the notional area of technical progress, $\hat{w}_{\tau,t}$, in year t by:

$$\hat{w}_{\tau,t} = \frac{1}{\alpha_\tau} w_{Y,t} - w_{L^s,t} - \frac{(1-\alpha_t)}{\alpha_t} w_{K^s,t} \quad . \tag{6}$$

This national rate includes the effects of changing the degrees of utilization of labor and capital and is not what we want to measure. But considering equation (5) we see from equation (4) that the rate of technical progress, w_τ, is determined by the trend of $\hat{w}_{\tau,t}$. Thus, w_τ is determined by

$$E[w_\tau - \hat{w}_\tau] = 0 \quad . \tag{7}$$

Following equation (1), we assume a linear trend. Because of equation (7), the unknown parameters α_0 and α_1 in equation (1) are estimated by ordinary least squares, the regression being:

$$\hat{w}_{\tau,t} = \alpha_0 + \alpha_1 t + \varepsilon_t \quad , \tag{8}$$

where ε is a stochastic variable with zero mean.

The results of the estimations for OECD countries are presented in Table 2 and plotted in Figure 1 (see Appendix). The high standard errors and the sometimes small R^2_{corr} should not irritate the reader since we have estimated the growth rates and are interested in explaining the trend and not the business cycle.

Table 2 Trend function for technical progress: $\hat{w}_\tau = \alpha_0 + \alpha_1 t$.

Country	α_0	α_1	DW	SEE	R^2_{corr}
US	3.01	−0.12	1.71	1.81	0.120
	(4.02)	(1.97)			
FRG	5.71	−0.15	1.47	1.81	0.198
	(7.67)	(2.49)			
Japan	10.65	−0.46	2.22	3.19	0.459
	(8.10)	(4.34)			
France	6.09	−0.19	1.26	1.19	0.500
	(12.47)	(4.69)			
UK	3.07	−0.10	2.70	2.00	0.061
	(3.72)	(1.53)			
Italy	8.78	−0.35	1.77	3.07	0.334
	(6.94)	(3.40)			
The Netherlands	7.21	−0.31	1.67	2.69	0.338
	(6.48)	(3.42)			
Belgium–Luxembourg	6.01	−0.14	2.12	3.13	0.033
	(4.65)	(1.30)			
Canada	3.61	−0.18	1.74	1.97	0.223
	(4.42)	(2.65)			

DW, Durbin–Watson statistics; SEE, standard error of estimations; values in parentheses are t-statistics; the estimation period was 1961–1982; t is a time trend with $t_{1960} = 0$.

The results are quite remarkable: all rates of technical progress have declined during the last 20 years, in three ways. The first consists of the countries Japan, Italy, and The Netherlands, who started with very high rates, but these declined more than those of the other countries. The second group comprises France, Belgium, and the Federal Republic of Germany, with smaller, but less declining rates. The third group consists of the US, Canada, and the UK with small rates of technical progress that do not decline so much (with the exception of Canada).

To test the plausibility of these results we compared them with the rate of technical progress that would be observed if the economy moved according to the long-term equilibrium growth path. Because of the linear homogeneity of F in equation (2) we may write equation (1) as

$$\frac{Y}{L} = \tau G(k) \quad , \tag{9}$$

where $k = \dfrac{K}{\tau L}$ is the capital–labor ratio, with labor measured in efficiency units; k is constant on the equilibrium growth path. Thus, if the economy stayed on the equilibrium growth path, we obtain from equation (8):

$$w_{Y/L} = w_Y - w_L = w_\tau \tag{10}$$

Of course, the economy does not follow the equilibrium path exactly, but may fluctuate around it. In that case the function $w_\tau = \alpha_0 + \alpha_1 t$ should follow the trend of the growth rate $w_{Y/L}$ of labor productivity.

In Figures 2–10 (see the Appendix) the growth rates of labor productivity and the estimated rates of technical progress are plotted for OECD countries (data are given in Table 3). The fit is quite satisfactory. In some cases the trend of growth rates for labor productivity is somewhat higher than the corresponding rates of technical progress as estimated using equation (7). This is easily explained since the equilibrium growth paths are not constant in time. In that case it follows from equation (8) that

$$w_{Y/L} = w_\tau + \frac{G'}{G}\dot{k} \tag{11}$$

If k is an increasing function with time, we obtain $w_{Y/L} > w_\tau$. These results can also be interpreted in the sense that the assumptions of a Harrod-neutral technical progress and of a growth trend that coincides with the equilibrium path are not far from reality.

Table 3. Growth rates of labor productivity, Y'Lab.[a]

W'YL01, Growth rate of Y'LAB01 W'YL04, Growth rate of Y'LAB04 W'YL07, Growth rate of Y'LAB07
W'YL02, Growth rate of Y'LAB02 W'YL05, Growth rate of Y'LAB05 W'YL08, Growth rate of Y'LAB08
W'YL03, Growth rate of Y'LAB03 W'YL06, Growth rate of Y'LAB06 W'YL09, Growth rate of Y'LAB09

Period	W'YL01	W'YL02	W'YL03	W'YL04	W'YL05	W'YL06	W'YL07	W'YL08	W'YL09
1960	1.360	7.884	9.119	5.665	3.938	7.068	6.996	5.759	1.930
1961	2.615	5.237	13.939	5.198	3.704	13.865	6.774	4.906	1.975
1962	3.760	5.725	7.310	5.573	0.862	7.169	2.101	4.517	2.202
1963	2.156	5.085	10.290	3.934	2.704	7.025	2.138	3.097	2.969
1964	3.194	5.610	12.231	4.800	4.244	5.022	7.354	6.220	2.647
1965	3.148	5.909	5.093	4.929	2.956	6.478	4.556	3.419	2.318
1966	3.740	4.146	8.122	3.764	3.118	5.150	2.101	−0.949	3.489
1967	2.313	5.470	8.675	5.530	4.090	5.451	7.563	6.369	1.906
1968	2.465	6.187	11.153	4.723	4.127	6.431	5.529	6.934	2.966
1969	0.481	6.916	12.929	5.162	1.000	11.311	4.846	5.602	1.778
1970	0.330	4.981	10.658	6.052	3.923	5.040	7.661	6.910	4.576
1971	2.719	4.249	5.028	5.975	5.145	5.490	4.665	2.229	4.749
1972	1.554	5.511	9.475	5.351	1.464	7.242	5.282	8.062	1.095
1973	2.176	5.480	7.059	4.329	3.971	9.881	6.357	8.027	3.000
1974	−1.569	3.956	3.062	4.052	0.097	4.718	6.007	5.686	0.104
1975	1.515	3.284	4.686	4.288	1.862	0.087	2.195	4.299	0.997
1976	1.452	4.258	2.784	4.840	3.586	1.703	4.463	3.267	3.700
1977	1.789	5.129	3.853	3.588	0.820	−0.746	1.650	2.819	1.263
1978	0.848	3.403	3.238	4.394	2.883	2.057	1.728	2.909	−0.059
1979	−0.247	3.875	3.262	3.564	0.682	3.829	1.140	0.776	−1.199
1980	0.421	1.712	1.604	1.194	0.154	5.273	−1.153	9.387	0.077
1981	2.172	1.700	3.181	1.417	3.141	−1.084	−0.400	−0.265	1.101

[a] 01, US; 02, FRG; 03, Japan; 04, France; 05, UK; 06, Italy; 07, The Netherlands; 08, Belgium–Luxembourg; 09, Canada.

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APPENDIX

The Appendix comprises Figures 1–10 on the following pages.

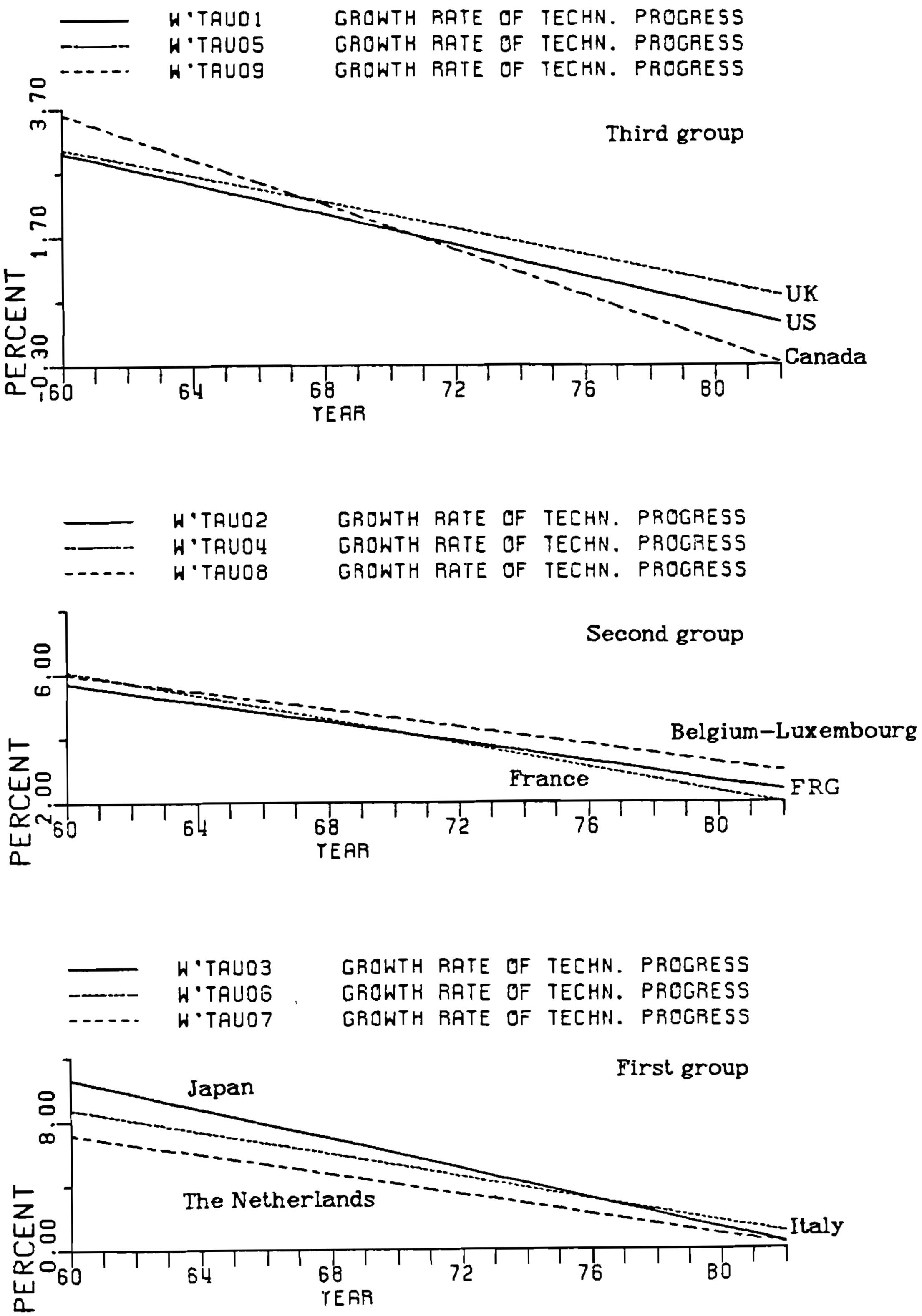

Figure 1. The results of estimated progress, clustered in three groups of similar development.

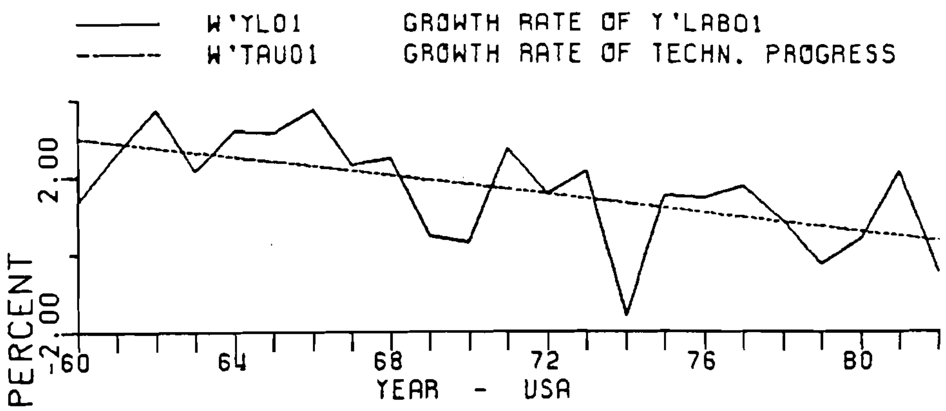

Figure 2. Comparison – US.

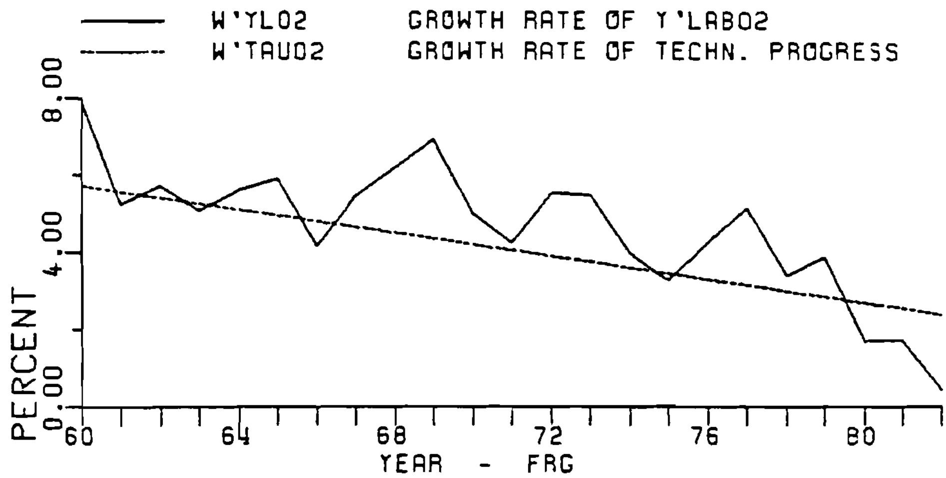

Figure 3. Comparison – Federal Republic of Germany.

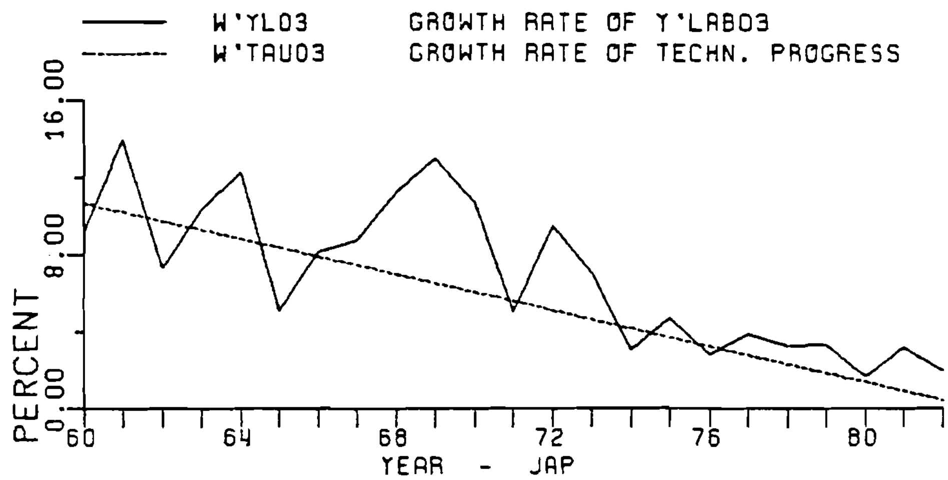

Figure 4. Comparison – Japan.

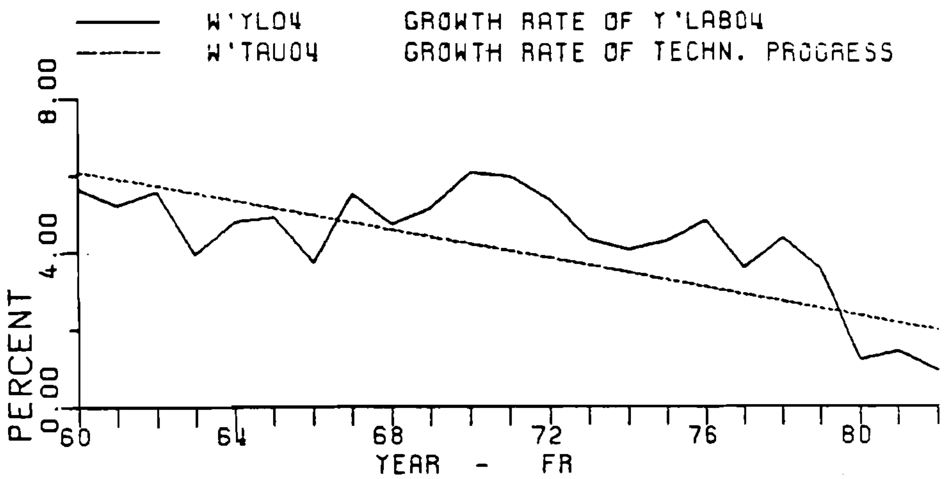

Figure 5. Comparison – France.

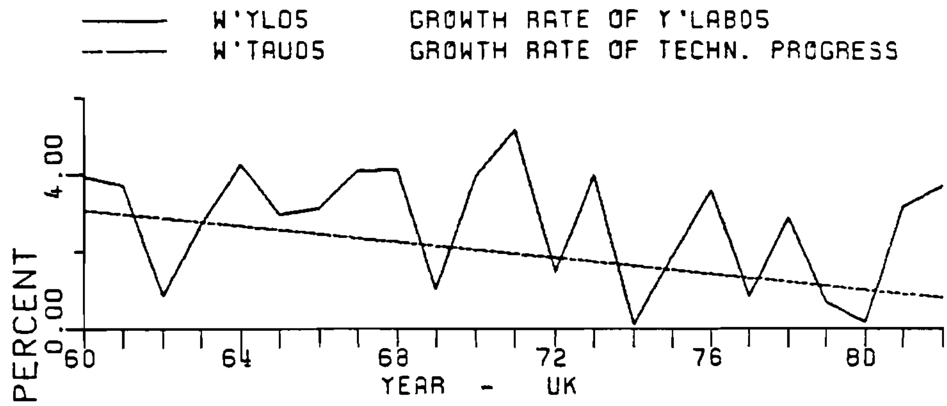

Figure 6. Comparison – UK.

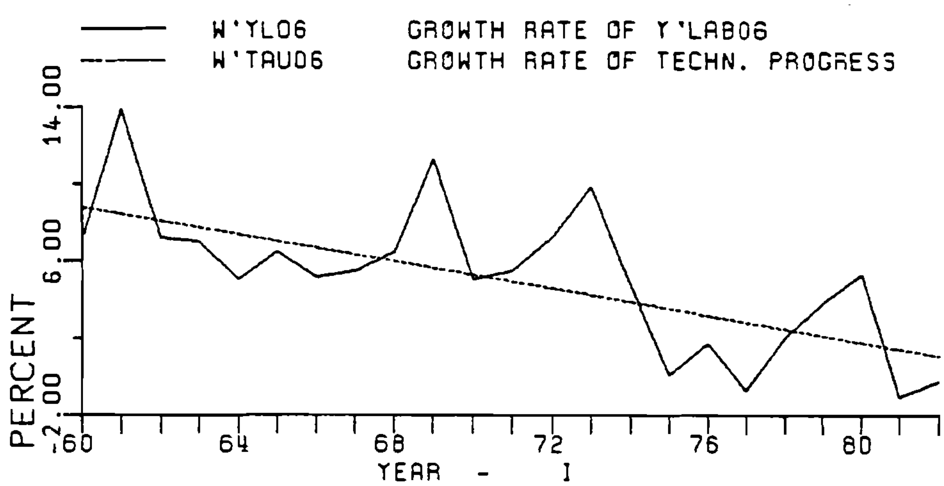

Figure 7. Comparison – Italy.

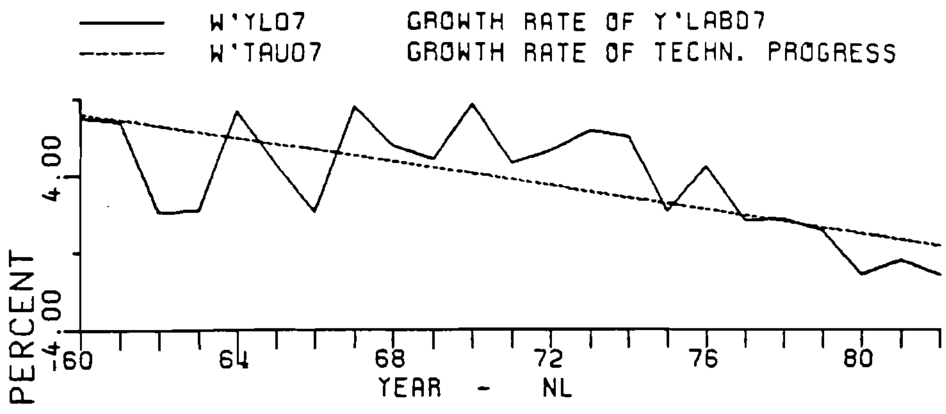

Figure 8. Comparison – The Netherlands.

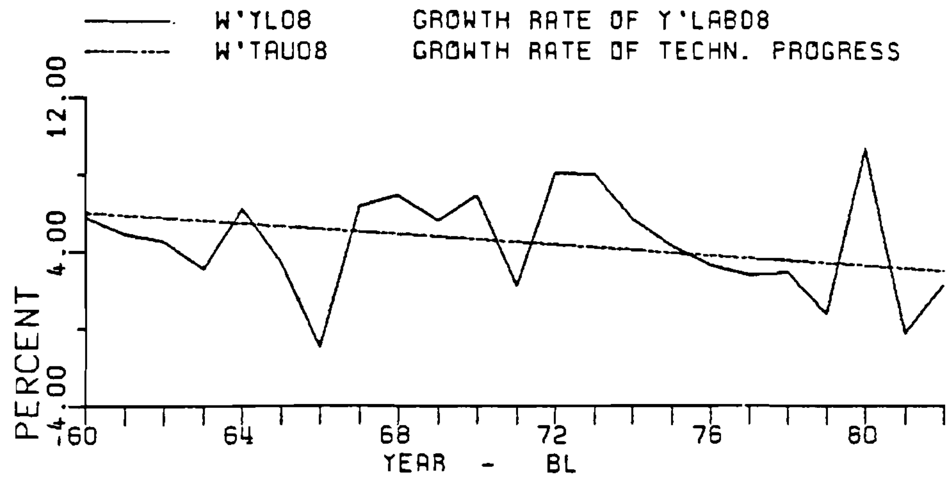

Figure 9. Comparison – Belgium– Luxembourg.

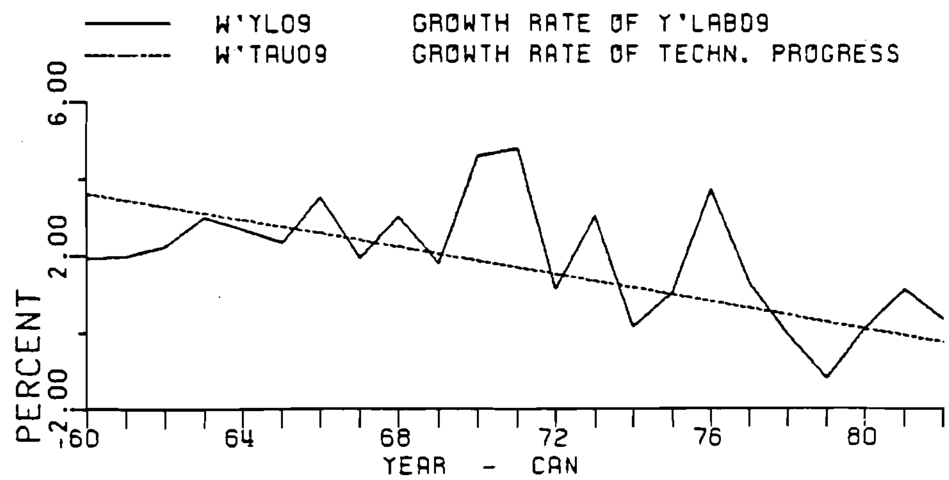

Figure 10. Comparison – Canada.