TECHNICAL CHANGE, PRODUCTIVITY AND ECONOMIC GROWTH

Abstract:
This paper investigates the relationship between productivity and technological change. The question that we shall address in this paper, is whether the recent slow down in productivity can be explained by the slow-down of innovation activities. This paper attempts to measure technical change, in order to measure the effects of economic growth for European member states. It introduces the reader, first, to some basic elements and concepts that are central to understanding the approach. The characteristics of the innovation process are examined: its nature, sources and some of the factors shaping its development. Particular emphasis is laid on the role of technical change and dissemination based on the fundamental distinction between codified and tacit forms. These concepts recur throughout the paper and particularly in discussions on the nature and specifications of the systems approach. The paper concludes by summarizing some of the major findings of the discussion and pointing to some directions for future research activities.

Keywords: Technical change, productivity, catching-up, economic growth.

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1. Introduction

Many studies have suggested that there is a close correlation between technological development and productivity (see for example Abramovitz, 1986; Fagerberg, 1987, 1988, 1994), and economists have analysed different possible views of why productivity growth has declined. These alternative explanations can be grouped into the following categories:

- the capital factor, for instance investment may have been insufficient to sustain the level of productivity growth;
- the technology factor, for instance a decline in innovation might have affected productivity growth;
- the increased price of raw materials and energy;
- government regulations and demand policies that affect the productivity level;
- the skills and experience of the labour force may have deteriorated or workers may not work as hard as they used to;
- the products and services produced by the economy have become more diverse; and
- productivity levels differ greatly across industries.

This paper attempts to measure the relationship between technology and productivity, or more precisely, to investigate the correlation between technological development and the decline in productivity growth. We shall empirically test the technological and catching-up models using data for the EU member states.

2. Looking for the Growth Issues: Recent Trends on Innovation Activities and Productivity

Schmookler (1966), Kendrick (1991), and Abramovitz (1986) have studied the interaction between technological change and productivity. In these studies, factor prices were used to weight the various inputs in order to obtain a measure of total input growth. The approach developed by Abramovitz (1986), Solow (1957) and Denison (1962) involves the decomposition of output growth into its various sources, which can be defined as the growth accounting and residual method.

Growth accounting tries to explain changes in real product and total factor productivity based mainly on a comparison between the growth of inputs (capital and labour) and the growth of output. One part of actual growth cannot be explained and has been classified as 'unexplained total factor productivity growth' (or the so called residual).

In particular, following the decomposition analysis by Solow (1957), many alternative factors can explain the path of economic growth. According to Solow's findings, technology has been responsible for 90 per cent of the increase in labour productivity in the United States in the twentieth century. The unexplained decline in productivity growth can thus be regarded as resulting from a collapse in technological activities. This may have happened because the availability of technological opportunities has been temporarily or permanently reduced.

Furthermore, technological gap theories (Abramovitz, 1986; Fagerberg, 1987, 1988, 1994) relate the technological level and innovation activities to the level of economic growth. According to these theories, countries where more innovation activities take place tend to have a higher level of value added per worker (or a higher per capita GDP). Following the technological-gap argument, it would be expected that the more technologically advanced countries would also be the most economically advanced (in terms of innovation activities and per capita GDP). Technology-intensive industries play an increasingly important role in the international manufacturing trade of OECD countries. In the 1990s, OECD exports of high- and medium-high-technology industries grew at an annual rate of around 7%, and their shares in manufacturing exports reached 25% and 40%, respectively, in 1999.

Table 1: Recent trends in productivity growth, 1980-99

	Trend growth in GDP per hour worked				Trend growth in multi-factor productivity			
	Total economy, percentage change at annual rate				**Business sector, percentage change at annual rate[4]**			
	1980-90[1]	1990-99[2,3]	1990-95[2]	1995-99[3]	1980-90[5]	1990-99[6,7]	1990-95[6]	**1995-99[7]**
Canada	1,1	1,3	1,3	1,4	0,5	1,2	1,1	**1,3**
Mexico	..	-0,6	-1,0	-0,1	..	..	..	**..**
United States	1,3	1,6	1,3	2,0	0,9	1,1	1,0	**1,2**
Australia	1,2	2,0	1,8	2,2	0,5	1,4	1,4	**1,5**
Japan	3,2	2,5	2,6	2,2	2,1	1,2	1,3	**0,9**
Korea	6,3	5,1	5,3	4,7	..	..	..	**..**
New Zealand	..	0,7	0,5	0,9	0,7	0,9	1,0	**0,7**
Austria	..	..	..	2,9	..	..	..	**..**
Belgium	2,4	2,3	2,3	2,4	1,7	1,4	1,3	**1,6**
Czech Republic	..	..	..	1,7	..	..	..	**..**
Denmark	1,7	1,8	1,9	1,6	0,9	1,5	1,5	**1,5**
Finland	2,8	2,9	3,0	2,8	2,3	3,3	3,0	**3,6**
France	2,7	1,8	1,8	1,6	1,8	1,0	0,9	**1,1**
Germany	2,3	2,0	2,2	1,8	1,5	1,1	1,1	**1,1**
Greece	1,3	1,4	0,9	2,0	..	..	..	**..**
Hungary	..	2,7	2,7	2,7	..	..	..	**..**
Iceland	..	1,5	1,3	1,6	..	1,3	1,2	**1,4**
Ireland	3,6	4,3	4,0	4,6	3,6	4,5	4,4	**4,6**
Italy	2,6	2,0	2,3	1,6	1,5	1,1	1,2	**0,8**
Luxembourg	..	5,1	5,5	4,6	..	..	..	**..**
Netherlands	2,9	1,8	1,9	1,7	2,3	1,7	1,9	**1,5**
Norway	2,6	2,6	3,1	2,0	1,2	1,7	2,1	**1,2**
Portugal	..	2,3	2,4	2,2	..	..	..	**..**
Spain	3,2	1,4	2,0	0,7	2,3	0,7	0,9	**0,5**
Sweden	1,2	1,7	1,8	1,6	0,7	1,3	1,3	**1,3**
Switzerland	..	0,8	0,6	1,2	..	..	..	**..**
United Kingdom	**2,3**	**1,9**	**1,9**	**1,9**	**2,2**	**0,9**	**0,8**	**1,0**

1. Data for Belgium, Denmark, Greece and Ireland refer to 1983-90.
2. Data for Germany, Hungary, Iceland, Mexico and Switzerland start in 1991.
3. Data for France, Japan, Korea, Portugal and Switzerland end in 1998.
4. Adjusted for hours worked, based on trend series and time-varying factor shares.
5. Data for Belgium, Denmark, Ireland refer to 1983-90, for New Zealand to 1987-90.
6. Data for Germany and Iceland start in 1991.
7. Data for Austria, Belgium, Italy and New Zealand end in 1997. Data for Australia, Denmark, France, Ireland, Japan, Netherlands and United Kingdom end in 1998.
Source: OECD calculations, based on data from the *OECD Economic Outlook No. 68*. See Economics Department Working Paper No. 248, 2000 for details; May 2001.

Substantial differences in the shares of high- and medium-high-technology industries in manufacturing exports are found across the OECD area, ranging from over

75% in Japan, Ireland, and the United States to less than 20% in Greece, New Zealand and Iceland.

Between 1990 and 1999, the annual growth rate of exports in technology-intensive industries was highest in Mexico (29%), followed by Ireland (18%). A catch-up effect can also be seen in Iceland and Turkey which still have a relatively low share of high- and medium-high-technology industries in manufacturing exports; they experienced annual growth of trade in technology-intensive industries of 17% and 15%, respectively.

High-technology industries represent around 50% of manufacturing exports in Ireland and 27% in Mexico, compared with 38% in the United States, 35% in Switzerland and 32% in Japan. The relatively high export share of technology-intensive goods in Ireland and Mexico does not appear to be the result of domestic R&D efforts; rather, it points to the role of foreign affiliates and technological transfers. Both countries import many intermediate goods for assembly, mainly from the United States, and then export finished goods. Table 1 indicates the recent trends in productivity growth, for the period 1980-1999. The level of technology in a country cannot be measured directly, but an approximation measure can be used to obtain an overall picture of the set of techniques invented or diffused by that country. We shall use real per capita GDP as an approximate productivity measure. The most representative measures for technological inputs and outputs are patent activities and research expenditure. Catching-up theory (Abramovitz, 1986; Fagerberg, 1987) starts with the investigation of growth performance. The main idea is that large differences in productivity among countries tend to be due to unexpected events (for instance wars).

Table 2: R&D intensity[1] & export specialisation[2] in high-technology industries 1999

	Export specialisation	R&D intensity
Canada	13,0	**1,2**
United States	38,3	**3,0**
Japan (3)	30,7	**3,2**
Korea	34,2	**1,3**
Denmark (3)	18,8	**1,8**
Finland	24,1	**2,6**
France (3)	23,1	**2,2**
Germany	18,5	**2,7**
Ireland (4)	46,0	**1,1**
Italy	10,6	**0,8**
Netherlands (4)	25,1	**1,6**
Norway (4)	10,7	**1,2**
Spain (3)	9,3	**0,6**
Sweden (3)	27,0	**3,9**
United Kingdom (3)	**32,4**	**2,1**

1. Manufacturing R&D expenditures/manufacturing production.
2. High-technology exports/manufacturing exports.
3. 1998.
4. 1997.

Source: OECD, STAN and ANBERD databases, May 2001.

According to these studies, the only possible way for technologically weak countries to converge or catch up with the advanced countries is to copy their more productive technologies.

The outcome of the international innovation and diffusion process is uncertain; the process may generate a pattern where some countries follow diverging trends or one where countries converge towards a common trend. In this literature, economic development is analysed as a disequilibrium process characterised by two conflicting forces:

- innovation, which tends to increase economic and technological differences between countries, and
- diffusion (or imitation), which tends to reduce them. Technological gap theories are an application of Schumpeter' s dynamic theory.

Table 3: Annual average growth rate of exports in high- and medium-high-technology industries, 1990-99

	High- and medium-high-technology	**Total manufacturing**
Mexico	29,4	**26,4**
Ireland	17,6	**13,3**
Iceland	17,2	**3,7**
Turkey	15,1	**9,7**
Greece	10,6	**2,4**
New Zealand	10,1	**3,2**
Portugal	9,8	**4,7**
Spain	9,5	**8,2**
Australia	9,1	**5,4**
Canada	9,1	**8,0**
Finland	8,6	**5,0**
United States	8,5	**7,9**
Sweden	6,9	**4,7**
OECD	6,5	**5,4**
Belgium-Luxembourg	6,2	**4,4**
United Kingdom	6,0	**4,9**
France	5,9	**4,5**
Netherlands	5,9	**3,4**
Austria	5,8	**4,6**
EU	5,7	**4,4**
Norway	5,4	**2,6**
Denmark	4,8	**3,2**
Italy	4,7	**4,0**
Japan	4,2	**4,0**
Germany	4,0	**3,1**
Switzerland	**3,8**	**3,2**

Source: OECD, STAN database, May 2001.

Table 2 illustrates R&D intensity that is Manufacturing R&D expenditures/manufacturing production and export specialisation that is the High-technology exports/manufacturing exports in high-technology industries 1999. Whereas, Table 3 indicates the annual average growth rate of exports in high- and medium-high-technology industries for the period 1990-1999. Furthermore, Table 4 presents the annual average growth rate for the labor productivity growth by industry, for the period 1995-1998. Finally, Table 5 illustrates the Labor productivity levels relative to total non-agricultural business sector, for the period 1998 European Union.

Table 4: Labor productivity growth by industry, 1995-98 annual average growth rate.

	United States				Japan			European Union[1]		
	ISIC Rev. 3	Employment	Real value added	Labour productivity	Employment	Real value added	Labour productivity	Employment	Real value added	**Labour productivity**
All industries	01-95	2,1	4,6	2,4	0,3	1,5	1,2	1,0	2,4	**1,4**
Total non-agriculture business sector[2]	10-67,71-74	2,5	5,9	3,3	-0,3	1,4	1,7	1,2	2,6	**1,4**
Mining and quarrying	10-14	0,7	3,7	3,1	-3,9	-0,9	3,1	-3,5	-1,5	**2,1**
Food, drink, tobacco	15-16	0,2	-5,4	-5,6	-1,3	-2,1	-0,8	0,3	0,0	**-0,4**
Textiles, clothing	17-19	-5,3	-3,9	1,6	-4,8	-3,8	1,0	-1,7	-1,4	**0,4**
Paper, printing	21-22	0,0	-0,4	-0,4	-1,7	-2,1	-0,4	0,1	1,5	**1,3**
Petroleum refining	23	-1,4	-0,4	1,1	-0,7	3,9	4,6	-1,9	0,9	**2,8**
Chemicals	24	0,1	2,6	2,5	-0,5	0,7	1,1	-0,9	1,3	**2,3**
Rubber, plastics	25	1,3	4,6	3,2	-2,1[3]	-3,4[3]	-1,4[3]	1,6	3,3	**1,7**
Non-metallic minerals	26	1,1	3,1	1,9	-1,9	-2,1	-0,2	-0,5	-0,1	**0,4**
Basic metals and metal products	27-28	1,2	2,5	1,4	-1,6	-2,7	-1,1	0,4	1,0	**0,6**
Machinery and equipment	29-33	1,8	14,5	12,4	-0,7	4,7	5,5	0,1	3,0	**2,9**
Transport equipment	34-35	2,2	2,5	0,4	-0,4	-1,9	-1,5	2,0	4,3	**2,3**
Wood and other manufacturing	20,36-37	1,3	0,5	-0,8	-2,1[3]	0,1[3]	2,2[3]	-0,1	1,0	**1,1**
Electricity, gas and water supply	40-41	-2,0	-1,6	0,4	0,8	4,3	3,5	-2,6	2,1	**4,8**
Construction	45	4,5	4,9	0,4	-0,1	-2,0	-1,9	-0,6	-0,4	**0,3**
Services : Wholesale and retail trade, hotels, restaurants	50-55	1,6	8,5	6,8	0,3[4]	1,1[4]	0,8[4]	1,4	2,4	**1,0**
Transport and storage	60-63	3,2	4,5	1,3	0,4	-3,4	-3,8	0,8	3,0	**2,2**
Post and telecommunications	64	2,4	4,5	2,1	0,4	17,7	17,3	-1,1	7,6	**8,7**
Finance and Insurance	65-67	2,6	7,5	4,8	-1,4	0,6	2,0	0,5	3,1	**2,6**
Business services	**71-74**	**6,3**	**7,0**	**0,6**	**2,2**	**6,4**	**4,1**	**5,8**	**5,6**	**-0,2**

Source: OECD, STAN and National Accounts databases, May 2001.

One of the main measures is the *research and development intensity index* (RDI) that is defined as: (BERD/GDP)*100, where BERD is business expenditure on R&D. We can also usue some other alternative measures, as GERD/GDP that is the ratio of gross expenditures on research and development to gross domestic product, or furthermore, GERD/GFCF that is the ratio of gross expenditures on research and development to gross fixed capital formation.

Table 5: Labor productivity levels relative to total non-agricultural business sector, 1998 European Union

	EU	Labor productivity annual average growth, 1995-98
Textiles, clothing	0,7	**0,4**
Wholesale/retail trade, hotels, restaurants	0,7	**1,0**
Wood and other manufacturing	0,8	**1,1**
Construction	0,8	**0,3**
Basic metals and metal products	1,0	**0,6**
Food, drink, tobacco	1,0	**-0,4**
Rubber, plastics	1,0	**1,7**
Business services	1,1	**-0,2**
Non-metallic minerals	1,1	**0,4**
Transport and storage	1,1	**2,2**
Machinery and equipment	1,1	**2,9**
Paper, printing	1,1	**1,3**
Transport equipment	1,2	**2,3**
Finance and Insurance	1,6	**2,6**
Post and telecommunications	1,7	**8,7**
Chemicals	1,7	**2,3**
Mining and quarrying	2,5	**2,1**
Electricity, gas and water supply	3,1	**4,8**
Petroleum refining	**3,8**	**2,8**

Source: OECD, STAN and National Accounts databases, May 2001.

Low starting point, low rates of catch-up In the OECD area, cross-country differences in GDP per capita and labour productivity have eroded considerably since the 1950s. Over the 1950s and 1960s, income levels of OECD countries except Australia, New Zealand and the United Kingdom were catching up with those of the United States.

In the 1970s, this phenomenon was less widespread and the rate of catch-up had fallen, Korea being the main exception. In the 1980s, there was even less catch-up, as GDP per capita grew more slowly than in the United States in 19 OECD countries. Table 6 illustrates the share in total gross value added for medium and high-technology manufactures for the period of 1998.

A final group of countries started with low income levels in the 1950s and have caught up little or not at all. It includes Eastern European countries, Mexico and Turkey. Changes in levels of GDP per hour worked show a slightly different pattern. Out of 21 OECD countries for which data are available, only Mexico and Switzerland have not been catching up with US productivity levels almost continuously over the post-war period. Several European countries now stand even with the United States in terms of average labour productivity and some have even surpassed it.

Labour productivity levels relative to the total non-agriculture business sector, 1998, European Union. The ratio of value added to employment provides an indication of which industries yield relatively high value added per unit of labour input. Although total employment is not the best measure of labour input for this purpose (see box), a reasonably clear pattern emerges.

Table 6: Share in total gross value added, 1998. High- and medium-high-technology manufactures

	High-technology manufactures	Medium-high-technology manufactures	High- and medium-high-technology manufactures
Iceland (1997)	#N/A	1,6	**1,6**
Greece	0,6	1,2	**1,8**
Norway (1997)	0,9	2,6	**3,5**
New Zealand (1996)	#N/A	3,7	**3,7**
Portugal (1997)	1,2	3,2	**4,5**
Australia	#N/A	5,7	**5,7**
Netherlands	#N/A	6,2	**6,2**
Spain	1,3	5,1	**6,4**
Denmark	2,0	4,4	**6,5**
Italy	1,6	5,6	**7,2**
Canada (1997)	2,0	5,3	**7,3**
Austria	2,1	5,2	**7,3**
France	2,5	4,9	**7,4**
Slovak Republic	#N/A	7,9	**7,9**
United Kingdom	3,0	5,1	**8,1**
Mexico	2,4	5,9	**8,3**
Belgium	#N/A	8,3	**8,3**
EU	2,2	6,2	**8,4**
United States	3,7	4,8	**8,5**
OECD	3,1	5,7	**8,8**
Czech Republic (1997)	1,4	8,3	**9,8**
Finland	4,5	5,5	**10,0**
Sweden	3,5	6,5	**10,0**
Hungary	3,5	6,8	**10,3**
Japan	3,6	7,1	**10,7**
Switzerland	#N/A	11,5	**11,5**
Germany	2,1	9,6	**11,7**
Korea	5,6	7,0	**12,6**
Ireland (1997)	**7,6**	**8,8**	**16,3**

Source: OECD, STAN and National Accounts databases, May 2001.

The same was true for 20 OECD countries in the 1990s. Japan and Korea had the highest rates of catch-up over the 1950-99 period, with GDP per capita growing more rapidly, by 2.7% and 3.2%, respectively, than in the United States.

Most of Western Europe had much lower rates of catch-up, typically below 1% a year. Countries such as Australia, New Zealand, the United Kingdom and Canada were already at relatively high income levels in 1950 and have since done little catching up with the United States. Switzerland had a marked decline in relative income levels. Table 7 showing the trends of growth in GDP per hour worked for the total economy and for the percentage change at annual rate.

Table 7: Trend growth in GDP per hour worked. Total economy, percentage change at annual rate

	1990-95 (1)	1995-99 (2)
Korea	5,3	**4,7**
Ireland	4,0	**4,6**
Luxembourg	5,5	**4,6**
Austria	..	**2,9**
Finland	3,0	**2,8**
Hungary	2,7	**2,7**
Belgium	2,3	**2,4**
Japan	2,6	**2,2**
Australia	1,8	**2,2**
Portugal	2,4	**2,2**
Norway	3,1	**2,0**
United States	1,3	**2,0**
Greece	0,9	**2,0**
United Kingdom	1,9	**1,9**
Germany	2,2	**1,8**
Netherlands	1,9	**1,7**
Czech Republic	..	**1,7**
France	1,8	**1,6**
Denmark	1,9	**1,6**
Sweden	1,8	**1,6**
Italy	2,3	**1,6**
Iceland	1,3	**1,6**
Canada	1,3	**1,4**
Switzerland	0,6	**1,2**
New Zealand	0,5	**0,9**
Spain	2,0	**0,7**
Mexico	**-1,0**	**-0,1**

1. Data for Germany, Hungary, Iceland, Mexico and Switzerland refer to 1991-95.
2. Data for Austria refer to 1996-99; data for France, Japan, Korea, Portugal and Switzerland refer to 1995-98.

Source: OECD calculations, based on data from the OECD *Economic Outlook No. 68*. See S. Scarpetta et al., Economics Department Working Paper No. 248, 2000 for details; May 2001.

By the end of the 1990s, industries predominantly involved in the extraction, processing and supply of fuel and energy goods produced the highest value added per labour unit. These industries were more than twice as productive as the average industry. They account for about 5% of total OECD value added and are typically highly capital-intensive.

Besides the energy-producing industries, those that yield the most value added per labour unit are those considered technology and/or knowledge intensive. In manufacturing, the chemical industry has the highest relative labour productivity level, while in services, finance, insurance and telecommunications lead the way.

Construction, wholesale and retail trade, hotels and restaurants and textiles show relatively low levels of labour productivity in all three major OECD regions. These industries are typically highly labour-intensive, have a high proportion of low-skilled jobs and are not considered high-technology sectors. OECD economies are also characterised by considerable differences in labour productivity growth. In the second half of the 1990s, labour productivity growth in the three major OECD regions was typically highest in manufacturing of machinery and equipment, in telecommunications and in finance and insurance. Labour productivity growth in some sectors of the economy was negative over the most recent period. This may reflect cyclical or structural patterns, but may also be due to measurement difficulties.

Labour productivity by industry can be measured in several ways. For the measurement of output, total production or value added are the typical yardsticks. If production (gross output) is used, productivity measures need to cover a combination of inputs, including intermediate inputs (such as materials and energy), labour and capital. If value added is used as the output measure, labour and capital suffice as indicators of factor inputs. The indicators shown here are determined by data availability and simply measure value added per person employed. Further adjustments to labour input, including adjustment for part-time work and hours worked per worker, can be made for certain OECD countries but international comparisons are not yet feasible.

For the labour productivity levels, 1998 value added at current prices was used. For the European Union, member countries' value added data were aggregated after applying 1998 US dollar GDP PPPs – industry-specific PPPs are preferable, but are not available for all sectors and countries.

For value-added volumes (used to estimate labour productivity growth), the European Union series were derived by aggregating member countries' value-added volumes after applying 1995 US dollar GDP PPPs, the reference year for the volume series being 1995. This is not an ideal practice since some countries, such as France and Sweden, now use annually reweighted chained (rather than fixed-weight) Laspeyres aggregation methods to derive their value-added volumes by industry. Volumes calculated in this manner are generally non-additive.

The labour productivity levels by industry are relative to the total non-agriculture business sector. This consists of all industries except agriculture, hunting, forestry and fishing (ISIC 01-05), real estate activities (ISIC 70) and community, social and personal services (ISIC 75-99; includes mainly non-market activities such as public administration, education and health).

Productivity growth in some services sectors may be low because estimates of real output are based on input measures (such as employment). Much effort is currently being undertaken in Member countries to improve the measurement of real output in the services sectors. Sectors that are considered technology- and/or knowledge-intensive are highlighted in the graphs.

3. The Relationship Between Productivity, Technical Change and Growth

According to the OECD Productivity Manual: There are many different approaches to the measurement of productivity. The calculation and interpretation of the different measures are not straightforward, particularly for international comparisons. The OECD Productivity Manual is the first comprehensive guide to various productivity measures and focuses on the industry level.

OECD estimates of productivity adjusted for the business cycle: For its recent work on economic growth, the OECD developed estimates of productivity growth adjusted for the business cycle. Most productivity measures are procyclical; they tend to accelerate during periods of economic expansion and decelerate during periods of recession. This is partly due to measurement: variations in volume output tend to be relatively accurately reflected in economic statistics, but variations in the rate of utilisation of inputs are at best only partially picked up. Even if capacity utilisation is accurately measured, the standard model of productivity fits the realities of the business cycle somewhat awkwardly. Much economic and index number theory relies on long-term, equilibrium relationships involving few unforeseen events for economic actors. Table 8 illustrates the income and the productivity levels for the period of 1999. The percentage point of differences for PPP, (Purchase Power Parity) it's based on Gross Domestic Product per capita respecting the United States.

The economic model of productivity measurement is therefore easier to implement and interpret during periods of continued and moderate expansion than during a rapidly changing business cycle. It is therefore appropriate to examine productivity growth over longer periods of time or to adjust productivity estimates for cyclical fluctuations. Usually, TFP is the total factor productivity that is a weighted average of the growth in labour and capital productivity. Whereas, the capital productivity is the ratio of output to capital and the labour productivity is the output per employed person.

As expected, the best results are obtained for the logarithmic models, which imply a steeper curve. Patenting data reflect the innovation process, while both the research indexes reflect the imitation and the innovation process. The research and development data reflect imitation, innovation and diffusion activities. The relation between productivity (as measured by per capita GDP) and innovation activities should be expected to be log linear, rather than linear and steeper for the patent data than for the index based on research data.

For structural change we use as an approximation changes in the share of exports and agriculture in GDP. Technological gap models, as developed here, can say little about how to boost the level of innovation activities or improve diffusion and innovation. We test the following versions of the models:

GDP (or PROD) = f [GDPPC, EXPA (or GERD), INV] (the basic model) (1)

GDP (or PROD) = f [GDPPC, EXPA (or GERD), INV, EXP] (2)

GDP = f [GDPPC, EXPA (or GERD), INV, TRD] (3)

Since annual observations are strongly affected by short-term fluctuations, average values of the variables for the period 1973~1997 are calculated. The first model may be regarded as a pure supply model, where economic growth is a function of the level of economic development GDPPC (GDP per capita with a negative expected sign), the growth of patenting activity (EXPA with a positive sign) and investment share (INV with a positive sign). However it can be argued that this model overlooks differences in overall growth rates between periods due to other factors, and especially differences in economic policies.

Table 8: Income and productivity levels, 1999. Percentage point differences in PPP-based GDP per capita with respect to the United States

	Gap	Productivity	Labour use (1)
Switzerland	-15	-9	**-6**
Norway	-17	8	**-25**
Canada	-21	-14	**-6**
Denmark	-21	-7	**-14**
Iceland	-22	-28	**6**
Netherlands	-22	9	**-32**
Australia	-24	-16	**-8**
Japan	-25	-26	**1**
Ireland	-25	-4	**-21**
Belgium	-27	10	**-36**
Austria	-27	-5	**-22**
Germany	-30	-6	**-23**
Italy	-32	6	**-38**
Sweden	-32	-16	**-15**
United Kingdom	-32	-13	**-19**
Finland	-33	-18	**-15**
France	-35	-3	**-32**
New Zealand	-45	-38	**-7**
Spain	-46	-24	**-23**
Portugal	-51	-47	**-5**
Korea	-53	-60	**7**
Greece	-55	-44	**-12**
Czech Republic	-60	-61	**1**
Hungary	-67	-55	**-12**
Mexico	**-75**	**-69**	**-6**

1. This reflects the joint effect of differences in the demographic structure of countries (the ratio of the working-age population to the total population), in employment rates and in average hours worked per person

Source: OECD, GDP and population from National Accounts database; working-age population, labor force and employment from Labor Force database; hours worked from OECD calculations, see S. Scarpetta, et al., Economics Department Working Paper No. 248, 2000; May 2001.

We can easily investigate the relationship between these two approximate measures using cross-section data on average growth rates in the period 1973~97 for the EU member states. The results are presented in Table 9. Whatever the form of the independent variable, a positive relationship between productivity and gross expenditure on R&D; this can be interpreted as due to the poor reliability of gross research expenditure data as an explanatory variable of innovation activities.

Table 4: Relationship between productivity and innovation for the EU member states, 1973~1997

Relation between productivity and patents: **GDPPC = 5547.23 + 529.695EXPA** **t = (7.455) (4.544)** **R^2 = 0.28 (adj.df 0.22). DW = 2.05** **Rho (autocorrelation coefficient) = -0.0962, t = -0.344. SEs and variance shown are heteroskedastic consistent estimates.**
The logarithm models: **LGDPPC = 8.068 + 0.564LEXPA** **t = (21.099) (2.336)** **R^2 = 0.23 (adj.df 0.16). DW = 1.69** **Rho (autocorrelation coefficient) = 0.705, t = 0.223. SE's and variance shown are heteroskedastic consistent estimates.** **LLGDPPC = 2.160 + 0.783LLEXPA** **t = (128.747) (2.868)** **R^2 = 0.31 (adj. df 0.24). DW = 1.81** **Rho (autocorrelation coefficient) = -0.032, t = -0.101. SEs and variance shown are heteroskedastic consistent estimates.**
The relation between productivity and gross expenditures on research and development: **GDPPC = 9584.54 - 366.10GERD** **t = (5.738) (-1.324)** **R^2 = 0.76 (adj. df 0.52). DW = 1.644** **Rho (autocorrelation coefficient) = 0.131, t = 0.475. SEs and variance shown are heteroskedastic consistent estimates.**
The logarithm models: **LGDPPC = 9.424 - 0.384LGERD** **t = (25.721) (-1.529)** **R^2 = 0.091 (adj.df 0.02) DW = 1.24** **Rho (autocorrelation coefficient) = 0.347, t = 1.352. SEs and variance shown are heteroskedastic consistent estimates.** **LLGDPPC = 2.200 - 0.0647LLGERD** **t = (141.439) (-1.586)** **R^2 = 0.087 (adj.df 0.017) DW = 1.177** **Rho (autocorrelation coefficient) = 0.385, t = 1.525. SEs and variance shown are heteroskedastic consistent estimates.**

Notes: GDPPC = GDP per capita average for the period 1973~1997, absolute values in constant (1985) prices (US$ 000) for per capita GDP. EXPA = average annual growth rates for the period 1973~1997 for external patent applications. GERD = average annual growth rates for the period for gross expenditure on research and development. LGDP, LPROD, LEXPA, LGERD, LEXP, LINV, LTRD, LLGERD, LLGDPCP are the above variables in logarithmic and in loglogarithm form.

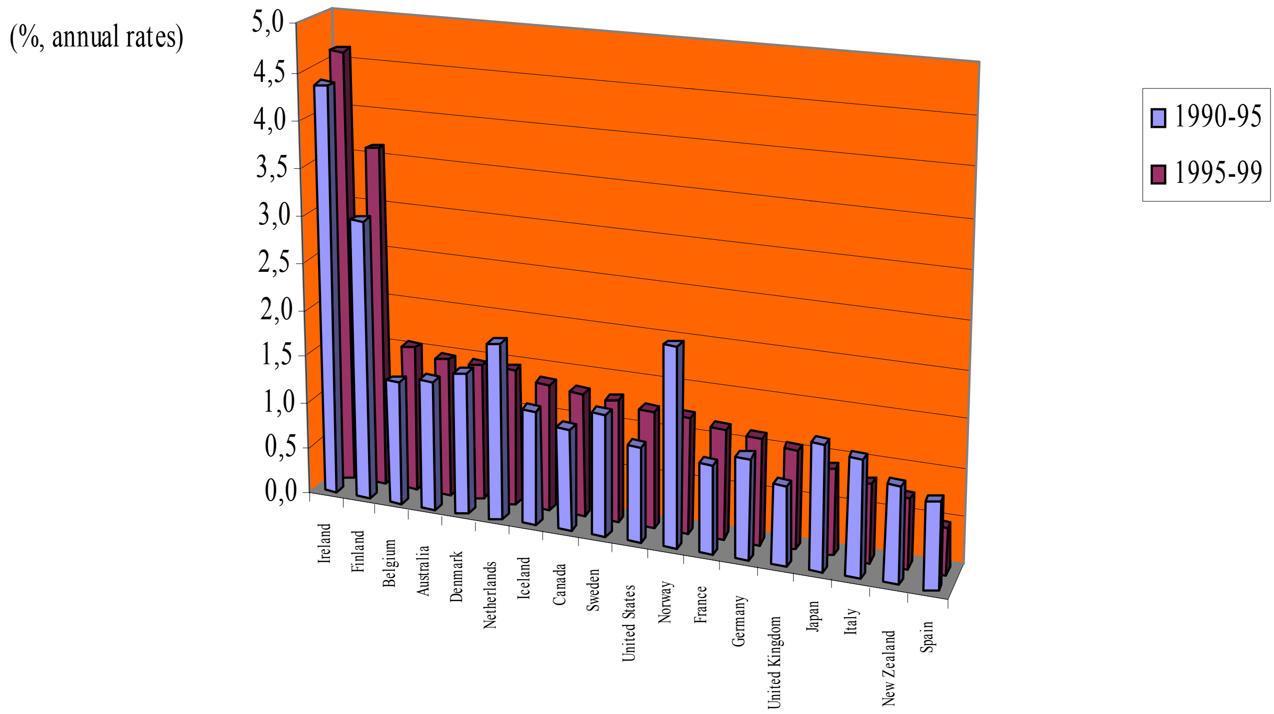
The correlation between productivity and patenting is much closer than between productivity and research expenditure. When conducting an econometric analysis of the technological gap models, it is important to include the most relevant variables. For the level of productivity, as a proxy we can use real GDP per capita (GDPPC). For the national technological level we can use some approximate measures, for instance we can again use the traditional variables of technological input and technological output (GERD and EXPA).

Following the model of Fagerberg (1987, 1988, 1994) we can test the basic technological gap model (with and without these variables), reflecting structural change, in order to determine the degree to which these variables have added something to the other explanatory variable of the model. We shall use external patent applications

(EXPA) and gross expenditure on research and development (GERD) as proxies for the growth of national technological activities, and GDP per capita (GDPPC) (in absolute values at constant prices) as a proxy for the total level of knowledge appropriated in the country (or productivity).

Investment share (INV) has been chosen as an indicator of an improvement in the capacity for economic exploitation of innovation and diffusion; the share of investment may also be seen as the outcome of a process in which institutional factors take part (since differences in the size of investment share may reflect differences in the institutional system). Figure 1 shows the multifactor productivity growth for the Business Sector, for the period 1990-1999.

Figure 1: Multifactor Productivity Growth, Business Sector, (1990-1999)



In addition, Table 10 shows the model for EU member states, including as additional variables exports (as a share of GDP) and the terms of trade; this indicates that growth has been influenced by changes in the terms of trade (terms of trade shock). The export variable also has the expected sign and the results support the hypothesis of structural change as a source of economic growth. The second model takes account of structural changes using as a proxy the share of exports in GDP. The third model uses an additional variable that reflects changes in the macroeconomic conditions and suggests that growth rates are seriously affected by changes in the terms of trade. The models are tested for EU member states. The basic model is tested for the variables of GDP, GDP per capita, external patent applications and investment as a share of GDP. The explanatory power (or the overall goodness of fit of the estimated regression models) is not very high, but this is not surprising for cross-sectional data. However there is a problem with interdependence between the variables. For this reason we shall focus on the relationship between productivity and innovation. Most of the variables have the expected signs.

Table 10: The basic model tested for the EU member states, 1973~1997

The basic model including patents:
GDP = 2.824 - 0.002GDPPC + 0.10EXPA + 0.027INV
t = (1.53) (-3.30) (2.30) (0.32) R^2 = 0.52 (adj. df 0.39). DW = 1.52
Rho (autocorrelation coefficient) = 0.385, t = 1.475. SEs and variance shown are heteroskedastic consistent estimates.
The logarithm model:
LGDP = 1.499 - 0.384LGDPPC + 0.155LEXPA + 0.806LINV
t = (0.593) (-2.569) (0.930) (1.340) R^2 = 0.56 (adj. df 0.42). DW = 1.36
Rho (autocorrelation coefficient) = 0.297, t = 0.985. SEs and variance shown are heteroskedastic consistent estimates.

The basic model including patents:
PROD = 0.453 - 0.00015GDPPC - 0.0198EXPA + 0.174INV
t = (-0.386) (-3.979) (-0.245) (3.012) R^2 = 0.64 (adj. df 0.54). DW = 1.49
Rho (autocorrelation coefficient) = 0.301. SEs and variance shown are heteroskedastic consistent estimates.
The logarithmic model:
LPROD = -0.566 - 0.384LGDPPC - 0.131LEXPA + 1.558LINV
t = (-0.220) (-2.519) (-0.770) (2.541) R^2 = 0.75 (adj. df 0.66). DW = 1.38
Rho (autocorrelation coefficient) = 0.241, t = 0.786. SEs and variance shown are heteroskedastic consistent estimates.

The basic model including the gross expenditures on research and development:
GDP = 1.775 - 0.00129GDPPC + 0.0142GERD + 0.0646INV
t = (0.92) (-1.86) (0.21) (0.75) R^2 = 0.40 (adj. df 0.24). DW = 2.30
Rho (autocorrelation coefficient) = -0.153, t=-0.539. SEs and variance shown are heteroskedastic consistent estimates.
The logarithm model:
LGDP = 0.619 - 0.275LGDPPC + 0.00625LGERD + 0.837LINV
t = (0.246) (-2.098) (0.0396) (1.408) R^2 = 0.47 (adj. df 0.33). DW = 2.38
Rho (autocor.coefficient) = -0.228, t = -0.815. SEs and variance shown are heteroskedastic consistent estimates.

The basic model including the gross expenditures on research and development:
PROD = 0.349 - 0.00018GDPPC - 0.0716GERD + 0.168INV
t = (0.231) (-3.413) (0.933) (2.677) R^2 = 0.66 (adj. df 0.57). DW= 1.43
Rho (autocorrelation coefficient)=0.301. SEs and variance shown are heteroskedastic consistent estimates.
The logarithmic model:
LPROD = -0.404 - 0.421LGDPPC - 0.0345LGERD + 1.568LINV
t = (-0.130) (-2.585) (-0.176) (2.126) R^2 = 0.61 (adj. df 0.50) DW=1.79
Rho (autocorrelation coefficient) = -0.0131, t = -0.0402. SEs and variance shown are heteroskedastic consistent estimates.

Notes: GDP = annual average growth rates for real gross domestic product. PROD = annual average growth rates for product (defined as labour product GDP per person employed). GDPPC = average absolute values in constant (1985) prices (US$ 000) for GDP per capita. EXPA = annual average growth rates for external patent applications. GERD = annual average growth rates for gross expenditures on research and development. EXP = annual average growth rates for exports as a share of GDP. INV = annual average growth rates for investment as a share of GDP. TRD = annual average growth rates for the terms of trade. LGDP, LPROD, LEXPA, LGERD, LEXP, LINV and LTRD are the above variables in a logarithmic form.

The introduction of the terms of trade variable into the basic model led to a negative sign for the innovation variables (GERD and EXPA); this indicates that the economic slowdown after 1973 can be better explained by a terms of trade shock. However, some of the results are not statistically significant and the explanatory power is not very high.

In both cases we used the same approach, first testing the basic model and then introducing the terms of trade and export variables. It is worth noting that for the technologically advanced member states the estimated coefficients display the expected signs except for exports (EXPA) and gross expenditure on R&D (GERD). The results do not support the hypothesis of structural changes as independent causal factors of economic growth. These results can be seen as supporting the view that the influence of a change in outward orientation on growth depends on the international macroeconomic conditions (since random shocks and crises and slow growth in world demand in the 1970s restrained the growth of outward-oriented countries).

Table 11: Trends in multi-factor productivity growth,[1,2] 1990-95 and 1995-99

	1990-95	1995-99
Ireland	4,4	4,6
Finland	3,0	3,6
Belgium	1,3	1,6
Australia	1,4	1,5
Denmark	1,5	1,5
Netherlands	1,9	1,5
Iceland	1,2	1,4
Canada	1,1	1,3
Sweden	1,3	1,3
United States	1,0	1,2
Norway	2,1	1,2
France	0,9	1,1
Germany	1,1	1,1
United Kingdom	0,8	1,0
Japan	1,3	0,9
Italy	1,2	0,8
New Zealand	1,0	0,7
Spain	0,9	0,5

1. Adjusted for hours worked, based on trend series and time-varying factor shares.
2. 2. Series end in 1997 for Austria, Belgium, Italy and New Zealand; 1998 for Australia, Denmark, France, Ireland, Japan, Netherlands and United Kingdom. Data for Germany start in 1991.
3. *Source:* OECD calculations, based on data from the OECD *Economic Outlook No. 68*. See S. Scarpetta et al., Economics Department Working Paper No. 248, 2000 for details; May 2001.

Productivity ratios relate a measure of output to one or several inputs to production. The most common productivity measure is labour productivity, which links output to labour input. It is a key economic indicator as it is closely associated with standards of living. Ideally, estimates of labour productivity growth should incorporate changes in hours worked.

Estimates of the increase in GDP per hour worked for OECD countries–adjusted for the business cycle – show that Korea, Ireland and Luxembourg had the highest rates of productivity growth in the 1990s. Switzerland, New Zealand, Spain and Mexico had the lowest. In countries such as Ireland, Australia, the United States, Greece and Germany, labour productivity growth in the second half of the 1990s was substantially higher than in the first half. Table 11 indicates the trends in multi-factor productivity growth, for the period 1990-1995 and also for 1995-1999.

Labour productivity is a partial measure of productivity; it relates output to only one input in the production process, albeit an important one. More complete measures of productivity at the economy-wide level relate output growth to the combined use of labour and capital inputs.

This measure is called multi-factor productivity (MFP). Growth in MFP is key to long-term economic growth, as it indicates rising efficiency in the use of all available resources. It is also a better reflection of technological progress than the increase in labour productivity, since the latter can also be achieved through greater use of capital in the production process and the dismissal of low-productivity workers.

Estimates of MFP growth are available for fewer countries than estimates of labour productivity growth, primarily because of the limited availability of data on capital stock. The estimates show that Ireland and Finland experienced the most rapid MFP growth over the 1990s. In countries such as Ireland, Finland, Belgium, Australia, Canada, the United States, France and the United Kingdom, MFP growth accelerated during the 1990s. In other countries, such as the Netherlands, Norway, Spain and Japan, MFP growth declined.

3. Conclusions

Technological progress has become virtually synonymous with long-term economic growth. This raises a basic question about the capacity of both industrial and newly industrialised countries to translate their seemingly greater technological capacity into productivity and economic growth. Usually, there are difficulties in estimating the relation between technology change and productivity. Technological change may have accelerated, but in some cases there is a failure to capture the effects of recent technological advances in productivity growth or a failure to account for quality changes in previously introduced technologies.

The countries of Europe have a long cultural and scientific tradition and the major scientific discoveries and developments in technology are products of European civilisation. There is a close relationship between innovation and productivity levels. However there are large technological disparities between the member states, which affects productivity performance, increases economic disparities and hinders economic integration.

There are various explanations in the literature for the slow-down in productivity growth in the OECD countries. One source of the slow-down may be substantial changes in the industrial composition of output, employment, capital accumulation and resource utilisation. Another may be that technological opportunities have declined; or else new technologies have been developed but their application to production has been less successful. Technological factors act in a long-term way and should not be expected to explain medium-term variations in the growth of GDP and productivity.

The technological gap models represent two conflicting forces: innovation, which tends to increase productivity differences between countries; and diffusion, which tends to reduce them. In Schumpeterian theory, growth differences are seen as the combined result of these forces. We have applied an economic growth model based on Schumpeterian logic. This technological gap model provides a good explanation of the differences among various countries. The empirical estimates suggest that the convergence hypothesis applies for industrialised countries. Research on why growth rates differ has a long history that goes well beyond growth accounting exercises. The idea that poorer countries eventually catch up with richer ones was advanced as early as in the nineteenth century, to explain continental Europe's convergence with Britain. In the 1960s one of the most basic model was the Marx~Lewis model of abundant labour supplies, which explained the divergent growth experience of the Western European countries.

To achieve safe results it is necessary to conduct a cross-country, multi sectoral analysis of how technological activities affect the different sectors. According to our estimates there is a relationship between the level of economic growth and the growth of technological activities. Technological activities (best measured by patents) appear to contribute considerably to economic growth, unless this is a negative demand effect. Specifically, our results confirm that there is a close relationship between the level of economic growth (as measured by per capita GDP) and the level of technological development (as measured by the number of external patents). Our results indicate that both imitation and innovation activities have a significant effect on the growth of GDP and productivity. Countries that are technologically backward might be able to generate more rapid growth than even the advanced countries if they were given the opportunity to exploit the new technologies employed by the technological leaders.

The pace of the catching up depends on the diffusion of knowledge, the rate of structural change, the accumulation of capital and the expansion of demand. Those member states whose growth rates are lagging behind could catch up if they reduced the technological gap. An important aspect of this is that they should not rely only on technology imports and investment, but should also increase their innovation activities and improve their locally produced technologies (as happened in Korea and Singapore).

However our results confirm that some of the small and medium-sized EU member states have attained high levels of per capita GDP without a large innovation capacity. To explain the differences in growth between these countries in the postwar period a much more detailed analysis of economic, social and institutional structures should be conducted. When we compare the technologically advanced and less advanced member states, it is not difficult to see that the less advanced countries lacked experience of large-scale production, technical education and resources.

The catching-up hypothesis is related to economic and technological relations among countries. There are different opportunities for countries to pursue a development strategy that depends on resource and scale factors. In summary, we can say that the introduction of new technologies has influenced industrialisation and economic growth. Of course, for countries with poor technological apparatus the impact of new technologies is much smaller. Finally, it seems that the technological gap between the less and more advanced countries is still widening.

4. References

Abramovitz, M. (1986) 'Catching-up, foreign ahead and falling behind', Journal of Economic History, vol. 46.

Baily, M. N. and A. K. Chakrabarti (1988) *Innovation and the productivity crisis* (Washington, DC: Brooking Institution).

Berndt, E. R. and J. Triplett (1990) ‘Productivity and economic growth’, in D. Jorgenson (ed) *Fifty years of economic measurement studies in income and wealth*, (Cambridge, Mass.: NBER), pp. 19~119.

Berndt, E. R. (1991) *The practice of Econometrics: classic and contemporary* (Reading, Mass.: Addison-Wesley).

Bhalla, A. and A. Fluitman (1985) ‘Science and technology indicators and socio-economic development’, World Development, vol.13, no. 2.

Boskin, M. J. and L. J. Lau (1992) ‘Capital, technology and Economic growth’, in Rosenberg, Landau and Mowery (eds) *Technology and the wealth of nations* (Stanford, CA: Stanford University press).

CEC (1987) *Research and technological development for Europe*, (Brussels: CEC).

CEC (1991) ‘*Government financing of R&D 1980~1990’* (Brussels, Eurostat).

Davidson, R and G. J. Mackinnon (1993) *Estimation and inference in Econometrics* (Oxford: Oxford University Press).

Denison, E. F. (1962) *The sources of economic growth in the United States* (Washington: Committee for Economic Development).

Diewert, W. E. and T. J. Wales (1987) ‘Flexible functional forms and global curvature conditions’, Econometrica, vol. 55, no. 1, (January), pp. 43~68.

Fabricant, S. (1954) *Economic progress and economic change* (Princeton, NJ: Princeton University Press).

Fageberg, J. (1987) ‘A technology gap approach to why growth rates differ’, Research Policy, vol.16, pp. 87~99.

Fageberg, J. (1988) ‘Why growth rates differ’ in G. Dosi, C. Freeman, R. Nelson and L. Soete (ed) *Technical change and Economic Theory*.

Fageberg, J. (1991) ‘Innovation, catching-up and growth’ in *Technology and productivity - the Challenge for Economic Policy*, (Paris: OECD).

Fageberg, J. (1994) ‘Technology and international differences in growth rates’, Journal of Economic Literature, vol. XXXII, no. 3.

Fageberg, J. (1995) ‘User-producer interaction, learning and comparative advantage’, Cambridge Journal of Economics, vol.19, pp. 243~56.

Gittleman M. and E. N. Wolf (1995) ‘R&D activity and cross-country growth comparisons’, Cambridge Journal of Economics, vol. 19, pp. 189~207.

Griliches, Zvi (1973) ‘Research expenditures and growth accounting’ in B. R. Williams (ed.), *Science and technology in economic growth*, London.
Griliches, Zvi (1988) *Technology, education and productivity* (Oxford: Basil Blackwell).

Griliches, Zvi (1979) ‘Issues in assessing the contribution of R&D to productivity growth’, *Bell* Journal of Economics, vol. 10.

Griliches, Zvi (1980) ‘R&D and the productivity slow down’, American Economic Review, vol. 70, no. 2.

Griliches, Zvi and F. Lichtenberg (1984) ‘R&D and productivity growth at the industry level: Is there still a relationship?’, in Zvi Griliches (ed), *R&D, patents and productivity* (Cambridge, Mass.: Harvard University Press).

Jorgenson, D. W., F. M. Gollop and B. M. Fraumeni (1987) ‘Productivity and U.S. economic growth’, *Growth in Aggregate Output* (Cambridge, Mass.: Harvard University Press).

Keller, A. (1990) ‘Econometrics of technical change: techniques and problems’, in P. Hackl (ed) *Statistical analysis and forecasting of economic structural change* (International Institute for Applied Systems Analysis).

Kendrick, J. W. (1984) *International comparisons of productivity and causes of the slowdown* (Cambridge, Mass.: Ballinger).

Kendrick, J. W. (1991) ‘Total factor productivity - what it does not measure: an overview’, in OECD, *Technology and productivity: the challenge for economic growth* pp. 149~57, (Paris: OECD).

Korres G. (1996) “Technical Change and Economic Growth: An Empirical Study for the European Member States”, Avebury Press, London.

Landau, R. (1989) ‘Technology and capital formation’, in D. Jorgenson and R. Landau (eds) *Technology and capital formation* (Cambridge, Mass.: MIT Press).

OECD (1991) *Industrial policy in OECD countries: annual review 1990* (Paris: OECD).

OECD (1991) *Technology and productivity - the challenge for economic growth* (Paris: OECD).

OECD (1991) *Economic-Outlook: Historical Statistics, 1960~1990* (Paris: OECD).

OECD (1991) *Basic Science and Technology Statistics* (Paris: OECD).

OECD (1992) *TEP - technology in a changing world* (Paris: OECD).

OECD (1992) *TEP-technology and economy: the key relationships* (Paris: OECD).

OECD: (2000): *Economic Outlook,* France.

OECD: (2001): Economics Department Working Paper No. 248, (Scarpetta et al) May 2001.

OECD, STAN and National Accounts databases, May 2001.

Quinn, A. (1990) *Trends in scientific R&TD in the EEC* (Brussels: CEC).

Sato, R. and G. Suzawa (1983) *Research and Productivity* (Boston, Mass.: Auburn House).

Schmookler, J. (1966) *Invention and economic growth* (Cambridge, Mass.: Harvard University Press).

Schumpeter, J. A. (1934) *The theory of economic development* (Cambridge, Mass.: Harvard Economic Studies).

Schumpeter, J. A. (1942) *Capitalism, socialism and democracy* (New York: Harper).

Solow, R. M. (1957) 'Technical change and the aggregate production function' Review of Economics and Statistics, vol. 39, pp. 312~20.

UNESCO (1969) *The measurement of scientific and technological activities* (Paris: UNESCO).

UNESCO (1992) *Scientific and technology in developing countries: strategies for the 1990s* (Paris: UNESCO).

Varian R. Hall, Theodore C. Bergstrom, and R. Hal (1993) *Workouts in intermediate microeconomics* 3rd ed., (New York: W. W. Norton).

Vernon, R. (1966) 'International investment and international trade in the product cycle', Quarterly Journal of Economics vol. 80, no. 2, pp. 190~207.

Zander, U. (1991) *Exploiting a technological edge-voluntary and involuntary dissemination of technology*, (Stockholm: Institute of International Business (IIB), Stockholm School of Economics).