R&D, INNOVATION AND THE TOTAL FACTOR PRODUCTIVITY SLOWDOWN

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INTRODUCTION

This paper presents an industry-level analysis of the links between technological change and total factor productivity growth. Over the past few decades, numerous studies have documented the links between technological change and productivity growth, generally using research and development (R&D) expenditures as an indicator of the intensity of technological change[1]. There are many steps, however, in the path leading from R&D expenditures to productivity. The R&D has to lead to successful innovation, which in turn has to be commercialised and adopted widely. Nevertheless, these studies have generally found high rates of return to R&D as compared with other forms of investment, and argue by implication that a disproportionate share of growth can be attributed to new technologies.

Given this long-run role of technological change, it is important to consider the possibility that a slowing of the generation or diffusion of new technology may have contributed to the slowdown in the growth of total factor productivity (TFP) which was documented and discussed in Englander and Mittelstadt **(1988).** Because technology does not have well-defined units, empirical analysis of this conjecture is difficult. Studies which use R&D as a proxy for the flow of new technology over time implicitly assume that the efficacy or potency of R&D is essentially constant; hence, a given increment to the R&D capital stock yields a given improvement in technology and productivity[2]. This is a restrictive assumption, as there is no reason ex ante that R&D cannot be in a period of "dry holes", in which its potency is temporarily reduced.

The hypothesis is a controversial one, and the relatively few previous studies which have investigated it differ in their conclusions. Kendrick and Grossman **(1980)**, Terleckyj **(1980)**, Baily and Chakrabarti **(1985)**, Ravenscroft **(1983)**, and Ravenscroft and Scherer **(1982)** find some evidence in favour, while Griliches **(1987)**, Griliches and Lichtenberg **(1984)** and Scherer **(1982)** find negative or mixed results. In some cases support for the hypothesis disappears with disaggregation or with a change in functional form. In others it seems to be supported for certain types of R&D but not for others.

The uncertainty in the timing of many of the steps between R&D and TFP makes studies of the relationship very data-intensive in many cases. As a result analysts often employ large data sets, cross-section data or, alternatively, undertake careful case studies. One of the contributions of this study is to apply an international dimension to the analysis of the hypothesis, using industry-level data across countries for the years **1970** to **1983**[3]. In contrast to the pure cross-section analysis which often combines data from many industries, the cross-country dimension allows a focus on the potency of research within an industry. While it imposes somewhat restrictive assumptions on production functions within an industry across countries, the evidence in Englander and Mittelstadt (**1988**) and in Meyer-zu-Schlochtern (**1988**) suggests that this assumption may be less restrictive than the assumption that different industries within the same country employ the same production function. Moreover, because the output and input data are derived from national income accounts, the relevance of the results to the TFP slowdown at the aggregate level is closer than it would be in a case study or in a firm-level study employing a sample of firms.

One methodological innovation is introduced below in conducting the statistical analysis. Most previous studies have been limited to studying the relationship of productivity and R&D in the industry ***conducting*** the research, rather than in the industry using the products of the research. As there is abundant evidence that the benefits often emerge substantially in the industry ***using*** the new technology, this study utilizes a concordance which maps the flow of technology from industry of origin to industry of use. Few studies have made this distinction, but the results suggest that it represents a promising direction for research[4]. A by-product of this concordance is a measure of the flow of technology into non-manufacturing sectors which do not conduct much of their own research.

As the potency hypothesis is controversial, two other independent approaches are also used to obtain a qualitative sense of its validity. First, patenting trends are used as an indicator of the output of research. Patents have the advantage of being a quantitative indicator of research output, as opposed to R&D expenditures, which reflect inputs to research. Secondly, stock-market data are used to provide a measure of how equity investors view the prospects for technology generation. Although none of these approaches is without problems, taken together they may present a reasonable picture of the potency of research.

This article presents five arguments:

- First, there is some evidence that the effectiveness or productivity of R&D may have declined during the mid to late **1970s.**
- Second, the decline seems to have been industry-specific, with basic metals, non-electrical machinery and motor vehicles industries showing the most decline; by contrast, the so-called high-tech industries show no evidence of decline in recent years.
- Third, in terms of assessing the impact of R&D on technology and hence TFP, it is important to analyse the industry ***using*** the new technology as well as the industry ***creating*** **it.**
- Fourth, there are wide discrepancies in the flow of new technology into industries, with non-manufacturing benefiting less than manufacturing.

- Fifth, stock-market data can be interpreted as pointing towards an increased flow of new technology applications in the future, after some slowing in the early and mid-1970s.

These results are of interest because they suggest that part of the TFP slowdown may have been caused by a slowing of new technology generation, a development whose sources and remedies are poorly understood. In addition, they highlight the uneven distribution of innovation across sectors, which may partially account for the divergent trends in TFP growth and price inflation in manufacturing and service industries observed in many economies. It is unlikely that macroeconomic policies can influence these developments, although microeconomic policies to correct market failures may be appropriate.

I. RECENT TRENDS IN R&D SPENDING BY INDUSTRY

As this paper focuses on TFP growth at the industry level, it is useful first to review the general characteristics of the industry level R&D data. The R&D conducted by the business sector is very concentrated in the chemical and machinery industries as a proportion of overall R&D (Table 1). The food, textiles, wood, paper, and stone clay and glass industries together account for less than 6 per cent of total R&D spending in the seven largest OECD economies, and most are well below this level. Moreover, the concentration in machinery and chemicals has been growing, particularly in the machinery component. Non-manufacturing industries generally account for a very small proportion except in Canada. While detailed data are not available for most countries, the retail and wholesale trade, transportation and service industries apparently undertake very little R&D.

The concentration is even more evident when R&D expenditures are presented as a share of industry output (Table 2). The R&D intensities of the chemical and machinery industries are much higher than that of any other sector and there is little sign in the data that there is any tendency towards intensities being equalised. R&D activity outside of manufacturing is very small as compared to its output, being less in most cases than that of the least R&D-intensive manufacturing sector.

II. R&D POTENCY: CONCEPTUAL FRAMEWORK

It is important to clarify what is meant by potency, because R&D productivity can change for other reasons too. With some modifications, invention production or

Table 1. Industry shares in total R&D

Per cent

	United States		Japan		Germany		France		United Kingdom		Italy		Canada	
	1970	1983	1970	1984	11970	1983	11970	1983	1970	1983	1970	1984	1971	1984
Manufacturing	63.3	69.9	56.1	60.5	38.2	65.7	32.1	52.6	60.0	59.3	46.5	49.7	12.5	36.7
Food	0.8	0.9	1.6	1.7	0.3	0.8	0.7	0.6	2.0	1.2	0.5	0.4	1.2	1.3
Textiles	0.2	0.2	1.1	0.8	0.2	0.4	0.9	0.3	1.5	0.2	1.6	0.4	0.3	0.2
Wood	0.1	0.2	0.2	0.2	0.2	0.3	0.0	0.0	0.2	0.1	0.0	0.0	0.3	0.3
Paper	0.6	0.7	0.7	0.5	0.1	0.3	0.1	0.2	0.5	0.3	0.1	0.1	1.7	1.1
Chemicals	8.3	8.6	13.6	11.5	16.4	15.8	10.0	10.6	10.0	11.6	13.0	13.1	5.2	6.0
Machinery	49.3	53.3	30.5	37.3	17.4	42.5	15.6	36.3	41.4	43.1	27.1	32.2	18.0	24.5
Electrical group	15.4	15.7	15.1	17.2	16.2	16.7	11.8	14.3	13.2	20.3	8.7	10.2	10.7	14.0
Aerospace	19.0	15.8	0.0	0.0	5.6	3.7	11.4	10.0	15.3	10.9	..	7.6	2.8	4.7
Other transport	5.8	7.1	7.0	10.2	9.0	10.8	5.5	6.6	5.1	3.8	14.2	8.3	0.7	1.4
Machinery group	9.0	14.7	8.5	9.9	6.6	11.3	6.9	5.3	7.8	8.2	4.2	6.1	3.9	4.4
Basic metals	1.8	2.0	5.1	4.6	2.5	3.6	1.6	1.9	2.5	1.4	1.1	2.4	3.6	2.5
Stone, clay, glass	0.6	0.6	1.3	1.7	0.4	0.8	1.2	0.8	1.1	0.5	0.2	0.2	0.2	0.3
Other manufacturing	1.6	3.4	2.1	2.2	0.7	1.2	2.0	1.8	0.8	0.8	3.0	0.9	1.8	0.5
Non-manufacturing	2.6	2.4	4.6	4.6	5.8	5.0	3.5	4.2	4.5	3.9	8.0	6.5	7.8	11.2
Mining	..	..	0.4	0.2	1.5	1.6	0.6	0.4	1.6	1.1	..	..	1.7	1.9
Construction	..	..	1.5	1.5	0.4	0.3	0.4	0.4	0.4	0.3	0.8	0.6	..	..
Other non-manufacturing	..	..	2.7	2.9	3.9	3.1	2.5	3.4	2.5	2.5	..	..	..	..
Total business sector	65.9	72.3	30.7	65.1	44.0	70.7	35.6	56.8	64.5	63.2	54.5	56.2	10.3	47.9

.. Not available.
Source: OECD, DSTI database.

discovery can be modelled as a production activity similar to other production activities. It has a "technology" and it uses "germplasm". In this context germplasm may be regarded as the set of knowledge and techniques available for the conduct of research. For a given technology and a fixed germplasm base, R&D designed to produce inventions (also broadly defined) is taken to be subject to diminishing returns, and hence to rising marginal costs. An increase in R&D in this case will result in a lower marginal (and probably, average) product of R&D.

This concept of R&D potency or germplasm can be regarded as an extension of the economic analysis of inventions and technological progress. In the early models of Solow (1957) and others, technological progress was modelled as proceeding at a constant rate. Subsequent discussions, such as Minasian (1969) and Terleckyj

Table 2. R&D expenditure by industry as share of output
Per cent of value added

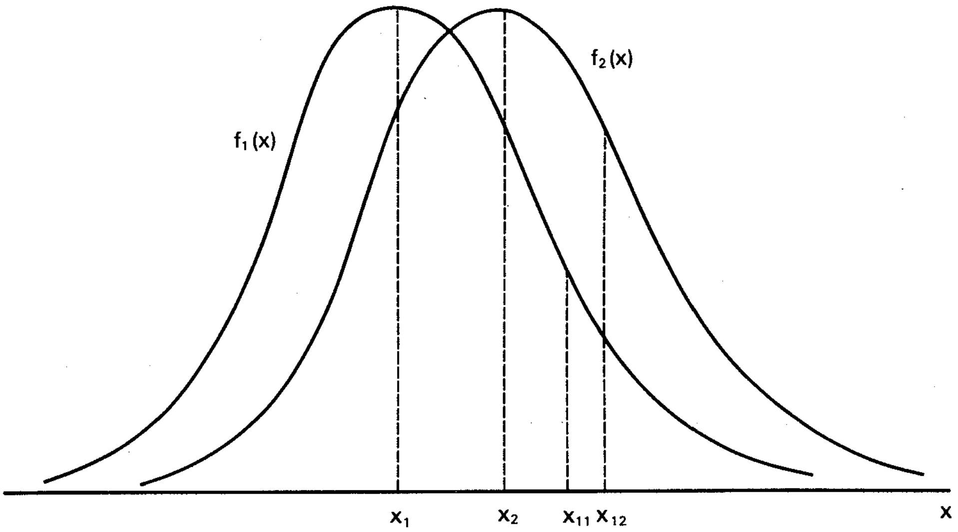
	United States		Japan		Germany		France		United Kingdom		Italy		Canada	
	1970	1983	1970	1984	1970	1983	1970	1983	1970	1983	1970	1984	1971	1984
Manufacturing	7.79	8.25	4.00	4.76	3.45	5.31	4.01	4.61	5.36	5.78	1.46	2.02	2.32	2.97
Food	0.97	0.94	0.87	1.69	0.13	0.53	0.34	0.33	0.84	0.56	0.11	0.13	..	..
Textiles	0.41	0.31	1.42	1.70	0.13	0.59	0.61	0.40	1.33	0.35	0.25	0.09	..	..
Wood	0.46	0.54	..	..	0.65	0.77	..	..	..		..	..	..	..
Paper	0.82	0.85	1.47	1.50	0.13	0.53	0.19	0.30	0.41	0.38	0.07	0.04	..	..
Chemicals	7.85	10.24	9.06	7.93	6.12	6.97	6.60	7.01	7.59	8.78	4.39	4.57	..	..
Machinery	15.04	14.31	7.35	6.07	5.35	7.58	10.06	9.60	8.72	12.11	2.68	4.42	..	..
Basic metals	2.13	5.60	2.96	3.61	1.61	4.09	0.60	1.07	1.09	1.13	0.62	1.80	..	..
Stone, clay, glass	2.07	2.22	1.48	4.18	0.53	1.64	1.69	1.38	1.45	1.00	0.07	0.10	..	..
Other manufacturing	2.03	2.46	0.83	3.22	1.12	4.79	1.17	1.15	1.75	2.09	1.29	1.34	..	
Non-manufacturing	0.11	0.09	0.17	0.25	0.28	0.29	0.12	0.15	0.17	0.17	0.12	0.13	0.06	0.25
Total business sector .	2.15	2.12	1.35	2.09	1.70	2.29	1.44	1.61	1.91	1.88	0.62	0.85	0.63	0.83

.. Not available.
Source: OECD, DSTI database.

(1974) allowed the rate of productivity growth to vary, but modelled the relationship of R&D and productivity as essentially fixed whether over time or across industries. The examination of potency can be regarded as weakening the restriction that this relationship be taken as fixed. In a sense this represents a return to an earlier Schumpeterian analysis in which technology was one of the driving forces behind economic growth, but in which the opportunities to innovate were not constant over time[5].

A plant-breeding example may be instructive in clarifying and illustrating the concept of germplasm. Plant breeders systematically search for genetic recombinations of existing plant germplasm stocks using certain technologies. They make crosses between varieties to obtain new genetic combinations. They subject the progeny of these crosses to selection pressures to facilitate their search for new cultivars with more desirable, i.e. more valuable, traits. The frequency distribution $f_1(x)$ (Figure 1) characterises the possible new cultivars of value x for a given technology of breeding and selection. This distribution describes the invention potential, and is fixed for a given set of varieties under standard breeding techniques.

Figure 1

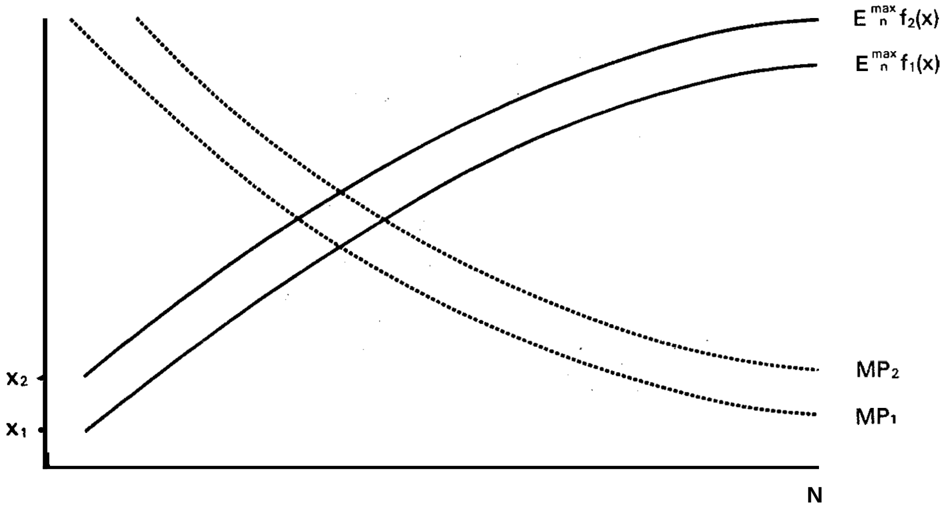


R&D potency is related both to the growth in the technology of invention and to growth of the germplasm stocks of invention. If the technology and the germplasm stock are fixed, cumulated **R&D** over a number of periods will result in a falling marginal product of invention. This can be seen as "exhausting" the invention potential available to the inventor. If new technologies of invention are developed and/or new germplasm is developed, new invention potential is developed, i.e. invention potential is replenished. Potency is defined as the relative rate of exhaustion and replenishment of invention potential. When the rate of exhaustion exceeds the rate of replenishment, potency is said to decline.

The production function of plant breeding (R&D) search activity can be specified as follows: Suppose a single random cross is made. The expected value of the progeny is x. However, if repeated crosses are made and evaluated after selection, the expected value of the maximum of the progeny values is greater than x. The "order statistic" expression for this expected maximum for a sample of size *n* is :

$$E \max_{n} f(x) = n \int_{0}^{\infty} F^{n-1}(x) f(x)\, dx$$

Figure 2



This expression may be regarded to be a stochastic invention production function. Figure 2 shows its presumed general shape, and hence illustrates its diminishing marginal and average product nature.

Note that the basic reason for diminishing marginal product is that only the maximum x has value. A cross producing progeny of value x_{12} is valuable only to the extent that x_{12} is greater than x_{11}. Figure 1 reflects the probability of discovering a given increment to x becoming smaller as the already discovered varietal values get higher. The researcher is searching in the small "tail" of the distribution and ultimately will exhaust the full potential available.

New breeding technology such as more reliable screening methods, better production of progenies from particular parental traits, improved selection pressure techniques, etc. can speed up the search process and make it more efficient. It can enable the breeder to identify more valuable characteristics in existing germplasm.

The germplasm base may also be improved. In the case of a plant breeder, new cultivars may be obtained either from explorations to collect wild heretofore unexploited "landraces", or from other breeding programmes where original landraces have been recombined in varieties and advanced materials[6].

The availability of improved technology and of germplasm creates a new potential distribution of inventions, i.e. new inventions potential. This can be thought of as replenishing the potential. Distribution $f_2(x)$ in Figures 1 and 2 illustrate how this replenishment raises the marginal product of R&D.

A firm optimising the returns to its R&D investment will search until the marginal value product of search equals the marginal cost of search. If the replenishment effect is growing at a zero rate, research will become impotent, i.e. after one or more periods the marginal product of research will equal the marginal cost of research: it will not pay to undertake further research. If the replenishment effect grows at a steady rate, P, optimisation will result in a constant level of R&D investment per period, potency will be unchanged over time, and the rate of improvement in the value of technology will be P. If P rises, optimisation calls for moving to a higher level of R&D spending. Marginal products will not rise, but average products will, and *so* will the rate of technology value improvement. Conversely, if P falls, optimisation calls for a lower R&D spending level and lower marginal products of R&D[7]. Accordingly, relatively high research efficiency and more research resources will be found in industries with higher potency.

III. DID THE POTENCY OF R&D DECLINE IN THE 1970s?

Changes in the potency or productivity of R&D have important policy implications. A reduction in the potency of R&D can be regarded as reflecting a reduced "invention potential" for researchers or some structural weakening in the R&D process (Evenson, 1984). This would consequently slow the pace of R&D activity, the flow of inventive output per unit of R&D, and the growth in TFP. Such a decline in R&D potency would be consistent with the general deceleration of R&D activity observed in the 1970s and the slowing of TFP growth. It would also be consistent with results reported in Griliches (1987) which suggest that the returns to R&D were lower in 1977 than 1972, although the differences were not statistically significant.

Because R&D data measure ***inputs*** into research, they cannot indicate whether the potency of R&D has changed over time. To accomplish this, it is necessary to examine the ***output*** of research, a concept which unfortunately is neither well defined nor easily quantified. Patents are used here as a measure of research output. There are a number of potential problems, however. First, patents data are "noisy", varying from year to year and across industries, apparently independently of the pace of innovation. However, much of the noise which appears at the firm level disappears when the data are aggregated to the industry level. Noise is also less of a problem when looking at cross-country and inter-industry patenting patterns averaged over a number of years. If the same relative patenting and productivity patterns occur over time in the same industries across a number of countries, this suggests changes in invention potential.

Table 3. Total patent applications

	1965	1970	1975	1980	1983
United States	72317	76 195	64 445	62 098	59 391
Japan	60 796	100 511	135 118	165 730	227 708
Germany	38 148	32 172	30 198	30 582	32 140
France	17 509	14 106	12 110	11 086	11 288
United Kingdom	24 214	25 227	20 842	19710	20011
Italy	7 473	7 241	5 977	6 375	..
Canada	1854	1986	1853	1785	2017
Australia	4 123	3 984	4311	6 587	6 930
Austria	2 714	2 267	2 525	2 345	2 388
Belgium	1766	1339	1060	992	925
Denmark	1153	815	828	964	1167
Finland	819	861	164	356	1719
Greece	888	1411	664	308	1251
Iceland	..	19	14	19	32
Ireland	157	205	329	394	567
Netherlands	2 505	2462	966	995	2118
New Zealand	788	897	243	148	1 110
Norway	870	938	752	716	825
Portugal	128	178	72	92	91
Spain-	4 089	2 966	1903	1876	1369
Sweden	4814	4 343	4 042	4126	4331
Switzerland	5 721	5 927	5 834	4313	4212
Turkey	99	89	98	134	..

.. Not available.
Source: OECD, DSTI database.

Schankerman and Pakes (1985) argue that the average quality of patents has increased over time, and hence declining patent counts do not necessarily reflect reduced output from R&D. Nevertheless, their calculations of the quality-weighted patents per researcher still show a decline in the 1970s, which is suggestive of a decline in potency. Moreover, in contrast, Mansfield (1986) argues that firms are in fact patenting a higher proportion of their inventions in recent years, *so* that declining patent numbers would reflect an even steeper decline in inventions.

A final problem is that applications for patents may respond to the costs of patenting which include legal and search costs which can far exceed patent office fees. Declining patent counts may reflect a fall in the propensity to apply for a patent if these costs increase. There is little or no evidence, however, that the cost of patenting has generally risen in OECD countries. Moreover, to the extent that such cost changes are common to all industries within a country, inter-industry trends within a country can still be examined.

A number of recent studies have shown patents to be of value in studying the process of technological change. Griliches (1984) and Griliches et *al.* (1986) discuss the usefulness of patents as an indication of invention activity; they conclude that while there are large stochastic elements and great variance in the value of individual patents, patent counts are a reasonably good measure of real research output.

In line with developments in R&D expenditure, the pace of patenting slowed in the 1970s, although there was an absolute decline in patenting, in contrast to the mere slowing of R&D growth (Table 3). With the exception of Japan, patent applications generally peaked among the large countries in 1965 or 1970. For many countries, however, patent applications rose between 1980 and 1983. This may indicate that the decline in potency has been temporary.

Ratios of inventions per unit of R&D expenditure or per unit of R&D personnel are a starting point for an assessment of potency change. With patent applications falling and R&D inputs rising, it is clear that patents per unit of R&D input fell sharply in the 1970s. Table 4 reports three-year centred averages of ratios of patents applied for or granted to scientists and engineers engaged in R&D (panel A), and to real spending in R&D (panel B). Three ratios are reported: one for applications for patents by domestic inventors; a second for grants to domestic inventors (by year of application); and a third for external applications, i.e. patent applications by inventors in other countries.

With the exception of Japan, the ratios of patent applications to either scientists and engineers or to R&D spending usually show monotonic declines since the mid-1960s. For Germany, France and Italy the declines are very large. Even Japan shows a decline in patent applications per unit of R&D[8]. Part of these declines may reflect changes in the overall propensity to patent in different countries, rather than declining potency. The second set of ratios, based on patent grants, is probably a more reliable series on which to base an assessment of general potency. These ratios show the same strong pattern of decline, again with Japan showing relatively little decline in grants per scientist and engineer. The decline is stronger in the R&D data, reflecting the rising cost of R&D. The external applications data show the same relative patterns across countries, but with only moderate declines or even slight upward trends[9]. The ratio of external to domestic applications has risen in all countries since the mid-1960s as international markets for inventions have grown and, in general, as trade and foreign investment have expanded. Except for Japan, the declines in the ratios of patents to research inputs have been large enough to suggest that the potency of R&D has probably declined to some extent. Such a decline in the potency of R&D is consistent with the slowing in R&D intensity and TFP growth.

Further evidence on this issue would be apparent in similar ratios by industrial sector within a country. A change in the propensity to patent due to economy-wide factors should have relatively little industry-specific effect. That is, a rising cost of

Table 4. Indicators of the potency of research

	1965	1970	1975	1980	1983
A. Patents per scientist or engineer engaged in R&D					
Patent applications/scientists and engineers					
United States	0.185	0.199	0.185	0.131	0.121
Japan	0.744	0.903	0.930	0.896	1.017
Germany	0.936	0.579	0.490	0.408	0.393
France	0.875	0.542	0.411	0.330	0.295
United Kingdom	0.373	0.374	0.338	0.257	0.263
Italy	0.910	0.629	0.438	0.355	0.309
Canada	0.415	0.353	0.301	0.170	0.142
Patent grants/scientists and engineers					
United States	0.142	0.142	0.135	0.082	0.069
Japan	0.205	0.195	0.230	0.207	0.196
Germany	0.287	0.160	0.158	0.121	0.101
France	0.471	0.414	0.257	0.220	0.203
United Kingdom	0.160	0.159	0.146	0.067	0.078
Italy	0.653	0.517	0.342	0.167	0.143
Canada	0.248	0.254	0.206	0.137	0.115
External patent applications/ scientists and engineers					
United States	0.289	0.343	0.266	0.249	0.267
Japan	0.103	0.239	0.191	0.254	0.247
Germany	1.298	1.239	0.987	1.101	0.937
France	0.981	0.938	0.797	0.983	0.897
United Kingdom	0.497	0.497	0.392	0.366	0.436
Italy	0.892	0.909	0.738	0.700	0.645
Canada	0.148	0.183	0.142	0.111	0.093

patenting or a general increase in the supply of scientists should have similar effects across industries. Industry-specific factors, such as the traditions of patenting, the basic nature of the technology and industrial organisational aspects, will cause different levels in the patent ratios. To the extent that such factors are relatively stable, however, they should not account for changes in patent ratios over time. Changes in potency, on the other hand, are industry-specific and should show up in differential changes in the patent ratios across industries. Hence, if large differences are found across industries in the changes in these ratios, there is a reasonably strong case for attributing them to potency changes[10].

Table 5 reports patent ratios for U.S. industries based on the U.S. Office of Technology Assessment and Forecasting (OTAF) concordance. The data show that the declines in these ratios differ substantially, with relatively small declines in the

Table 4 *(continued)*

	1965	1970	1975	1980	1983
B. Patents per million units of local currency (1980 prices) spent on R&D					
Patent applications/R&D					
United States	1.76	2.00	1.85	1.37	1.18
Japan	64.70	58.70	63.10	52.70	52.90
Germany	3.49	2.19	1.71	1.25	1.20
France	0.96	0.68	0.48	0.36	0.33
United Kingdom	9.86	9.34	7.78	6.16	6.06
Italy	9.54	6.05	4.11	3.73	3.03
Canada	2.09	1.99	1.78	1.14	0.99
Patent grants/R&D					
United States	1.34	1.43	1.35	0.85	0.68
Japan	17.80	12.60	15.60	12.20	10.20
Germany	1.07	0.61	0.55	0.37	0.31
France	0.51	0.52	0.30	0.24	0.22
United Kingdom	4.22	3.97	3.35	1.61	1.82
Italy	6.84	4.98	3.21	1.75	1.40
Canada	1.25	1.43	1.22	0.92	0.80
External patent applications/R&D					
United States	2.74	3.46	2.66	2.61	2.62
Japan	8.96	15.51	12.92	14.47	12.85
Germany	4.84	4.69	3.44	3.37	2.86
France	1.06	1.18	0.93	1.07	0.97
United Kingdom	13.13	12.39	9.11	8.79	10.19
Italy	9.35	8.76	7.21	7.35	6.31
Canada	0.75	1.03	0.84	0.75	0.65

Note: Japanese and Italian data per billion of yen and lira. R&D data are the BERD (Business Enterprises' R&D Expenditures in deflated national currency) data. The scientist and engineer data are the BEMP [Business Enterprises' R&D Personnel) Full Time Equivalent series. Patent data are from World Intellectual Property Organization (WIPO) sources and are three-year centred averages except for 1983, which is the 1982-83 average.

aircraft and space, and food industries; and severe declines in the primary metals, non-electrical machinery, and scientific and professional instruments industries. This evidence indicates that potency has not been constant over recent years. It is unlikely that any overall decline in the propensity to patent can explain the large differential changes across industries.

Inventions and invention pools are not confined to an individual country but are, to some degree, international in character, especially across developed countries. Hence, if there is a slowing of invention possibilities in particular industries, this should be reflected in common movements across countries of patenting rates in the

Table 5. Indicators of research output in U.S. industries

	1965	1970	1975	1981	Ratio 198111965
A. Patents per scientists and engineers					
Electrical machinery	0.102	0.107	0.087	0.057	0.56
Chemical products	0.153	0.140	0.122	0.099	0.65
Petroleum, natural gas	0.083	0.072	0.070	0.050	0.60
Aircraft, space	0.005	0.006	0.007	0.004	0.82
Motor vehicles	0.009	0.008	0.007	0.004	0.45
Primary metals	0.086	0.072	0.050	0.023	0.27
Fabricated metals	0.67	0.66	0.50	0.30	0.45
Scientific, professional instruments	0.39	0.40	0.271	0.130	0.33
Non-electrical machinery	1.01	0.75	0.500	0.260	0.26
Food, kindred products	0.046	0.064	0.054	0.038	0.83
Textiles	0.129	0.144	0.135	0.101	0.78
Rubber, plastic	0.240	0.212	0.206	0.152	0.63
Stone, clay, glass	0.255	0.235	0.170	0.134	0.53
B. Patents million dollars of R&D expenditure (1980 prices)					
Electrical machinery	2.02	2.04	1.63	1.20	0.59
Chemical products	3.29	3.05	2.57	1.91	0.58
Petroleum products	1.85	1.28	1.09	0.75	0.41
Aircraft, space	0.066	0.089	0.10	0.065	0.99
Motor vehicles	0.580	0.525	0.404	0.196	0.35
Primary metals	1.97	1.89	1.290	0.650	0.33
Fabricated metals	5.73	4.60	3.50	2.50	0.44
Scientific, professional instruments	7.59	6.61	5.33	2.66	0.35
Non-electrical machinery	7.84	5.23	3.38	1.98	0.25
Food, kindred products	0.95	1.15	1.44	0.81	0.85
Textiles	4.80	5.90	4.07	3.16	0.66
Rubber, plastic	8.14	6.03	4.31	4.25	0.53
Stone, clay, glass	5.62	5.65	4.07	3.19	0.57

Source: National Science Board, *Science Indicators: the 1984 Report.*

same industries over time, even if large level differences remain between countries. Table 6 presents data for Japan by industry where the patent classification is based on the International Patent Classification (IPC) and is similar to the European Patent Office concordance. These data show a fairly high correlation with the U.S. data presented in Table 5: patents per scientist and engineer declined most for transport equipment and non-electric machinery, and least for the food and textile industries.

Finally, it can be shown that at least some of the industries perceived to be developing innovations and applications of scientific research did not have a falling

Table 6. **Patent applications per scientist and engineer and relative to R&D expenditures in Japan, 1967-1976**

	Patents per scientist and engineer				Patents relative to 1970 Million yen R&D expenditure			
	1967-68	1971.72	1975-76	1975-76 / 1967-68	1967-68	1971-72	1975.76	1975.76 / 1967.68
Chemicals	1.60	1.30	1.42	0.89	0.425	0.187	0.218	0.52
Non-electrical machinery	3.28	2.66	2.33	0.71	0.948	0.422	0.273	0.29
Electrical machinery	1.23	0.93	1.12	0.91	0.378	0.132	0.197	0.52
Transport and construction equipment	2.08	1.49	1.32	0.63	0.328	0.136	0.110	0.33
Textile and household goods	4.82	5.54	4.89	1.01	1.413	1.071	0.988	0.70
Foods	1.37	0.84	1.38	1.01	0.494	0.169	0.270	0.55
All industries	1.80	1.43	1.54	0.86	0.733	0.200	0.236	0.43

Source: **Evenson** (1984).

Table 7. **Patent activity in selected countries, for selected technologies: 1975-77 and 1980-82**

Patents granted

	All technologies	Robotics	Lasers	Micro-biology-enzymology	Drugs	Integrated circuits	Telecom-munications	Internal combustion engine	Steel and iron
World total									
1975-77	1 197 447	481	2814	1760	57987	8080	28 636	16887	18745
1980-82	1 240 822	1093	4289	9581	58176	12766	37 783	18762	18529
United States									
1975-77	320 338	134	1326	361	17291	3499	7 742	4363	3077
1980-82	284 670	148	1295	2463	16773	3433	8 461	3942	2653
Japan									
1975-77	176 278	44	312	820	9016	1460	3 278	2287	5531
1980-82	251 219	144	1568	3265	11568	6068	13 794	3416	7323
West Germany									
1975-77	736 448	72	357	231	10007	1324	6 207	4305	2438
1980.82	212 129	150	421	1172	8102	1223	5 651	5434	1842
France									
1975-77	81 292	48	282	47	4393	390	2 598	1884	944
1980-82	73 576	72	270	422	4413	549	2 373	1498	688
United Kingdom									
1975-77	83 879	15	134	145	7187	297	2 071	1581	756
1980-82	77 832	43	211	602	7055	329	1793	1451	460
Other									
1975-77	299 212	168	403	156	10093	1110	6 740	2467	5999
1980.82	341396	536	524	1657	10265	1164	5711	3021	5563

Source: National Science Board, ***Science Indicators:*** *The **1985 Report.***

off of patents; indeed, they experienced rapid growth in patents (Table 7). Moreover, the advances in these high-tech fields are not in general limited to a single country. Similarly, the "smokestack" industries shown in the final two columns of Table 7 show generally stagnant patenting patterns across most countries.

IV. TECHNOLOGY DEVELOPMENT BY INDUSTRY OF ORIGIN AND INDUSTRY OF USE

In order to complete the chain from research input to research output to technological change and TFP developments, it is important to recognise explicitly that the industry or firm originating the research may not be the industry or firm ultimately using or benefiting from the inventions or innovations which emerge. R&D originating in one industry may produce some inventions used in the same industry; these are often, but not always, process inventions. But many inventions are used in other industries; these are generally product inventions, and usually are employed in industries which purchase the product exploiting the innovation.

The distinction between industry of origin and industry of use stems from the difficulties in comparing new or improved products with established ones in real terms – that is, evaluating the quality component in price increases. Although in some cases it is possible to compare a new product's price with that of an existing good *so* as to determine its relative value, the higher profits of the innovating firm are often treated as resulting from price increases, while higher productivity is found in the product-using firm. This has been found repeatedly in studies of the construction of price indices (Gordon, 1971). Further, innovating firms have been found to capture a fairly small fraction of the rents from innovation.

To adapt an example from Griliches (1979), consider a new light-bulb which is invented and can be produced with the same quantity of inputs but which lasts twice as long as previous models. The inventing firm could in principle price the new bulb at twice the old price. If statistical authorities recognise the quality improvement, then for the same quantity of bulb production, the firm's output and productivity would be seen as doubling. TFP in the using industry, on the other hand, will be unchanged when it buys one new bulb instead of two old ones. If some of the price increase is treated as a pure price increase, then real materials inputs in the using industry will be seen as falling; but with one new bulb providing the same services as two old bulbs, and nothing else having changed, real value added and, hence, measured productivity will have risen. Alternative assumptions on pricing and competition will give similar results. Note that none of this changes nominal input, output, or profits; but it merely allocates the productivity gains across firms.

Modelling the flow of technology from one industry to another is difficult because technology does not have a well-defined unit of measurement. However, as the preceding discussion has suggested, patents can serve as a good proxy for the flow of inventions. By classifying individual patents as they emerge from an industry as primarily being useful in specific industries (which may include the originating industry), a concordance can be created which maps patents from the industry of origin to the industry of use[11]. Thus far, this has been done systematically only in the Canadian patent system, which classifies each patent both according to industry of origin and industry of use. A fuller description of the construction of the concordance is given in Annex A and Evenson and Putnam (1988).

A matrix relating inventions by industry of origin to inventions by industry of use was constructed from the Canadian data. By computing the proportion of patented inventions originating in one industry but used in other industries, it is possible to estimate the flow of technology. Table 8 reports a technology flow matrix based on the Canadian data using the same industrial breakdown for which the TFP data are available. Columns sum to unity. Taking, for example, inventions originating in the fabricated metals industry, the concordance indicates that these are used primarily in the machinery industry (42.8 per cent) and in the construction industry (28.9 per cent). This matrix can be used for other countries, provided that the degree of detail at which assignments are made is sufficiently broad. This is because the technology in use across OECD countries is broadly similar and the mapping from industry of origin to industry of use is done at a very detailed level[12]. If Canadian technology flow patterns are very different from those of other countries, however, the application of the Canadian-based concordance could provide nonsensical results. A simple test of the usefulness of the concordance is that the technology flow matrix should produce a stronger linkage between R&D and TFP than does the standard industry of origin approach.

In Table 8, non-manufacturing sectors such as transportation, services, real estate, and wholesale and retail trade are not listed as industries of origin because their patenting is minimal. However, the coefficients on the use side for these industries suggest that they do benefit from research in most of the industries listed. For example, social and personal services is the industry of use for about 10 per cent of textile patents, while transportation uses 9 per cent of non-electrical machinery and fabricated metals patents and 30 per cent of mining patents. The concordance suggests that the industry of use for the bulk of innovations is in manufacturing.

Industry flow data such as these do not capture all relevant innovative activities, however. First, the concordance does not capture the flow of innovations from academic or public sector research. Second, neither the R&D data nor the concordance capture what are termed "soft" innovation activities, such as the writing of computer software, an activity rapidly growing in importance (Soete,

Table 8. Industry of origin to industry of use concordance for Canada

Industries of use	Food	Textiles	Wood	Paper	Chemicals	Petroleum refining	Rubber and plastics	Electrical equipment	Non-electrical machinery	Trans-portation equipment	Basic metals	Fabri-cated metals	Stone, clay, glass	Other manufac-turing	Mining	Construc-tion
Food	0.684	0.002	0.008	0.055	0.028		0.061	0.002	0.042			0.014	0.009	0.006		0.015
Textiles		0.370		0.023	0.025		0.011		0.018			0.003	0.005	0.018		
Wood		0.030	0.325	0.008	0.004		0.004		0.014		0.003	0.027	0.002	0.006		
Paper		0.030	0.005	0.394	0.025	0.014	0.003	0.005	0.058		0.003	0.003	0.001	0.015		
Chemicals	0.009	0.311	0.005	0.071	0.674	0.407	0.337	0.004	0.130		0.013	0.029	0.023	0.016		0.015
Machinery		0.040	0.052	0.050	0.065	0.348	0.280	0.758	0.335	0.911	0.319	0.428	0.134	0.177		0.028
Basic metals		0.010	0.003		0.007	0.029		0.005	0.056		0.363	0.015	0.028	0.007	0.050	
Stone, clay, glass		0.010		0.005	0.005		0.006	0.002	0.026		0.003	0.007	0.430	0.004	0.050	
Other manufacturing		0.030	0.042	0.025	0.017	0.004	0.020	0.025	0.011		0.012	0.007	0.022	0.208		
Mining					0.007	0.008	0.003	0.008	0.071	0.004	0.012	0.026	0.020	0.022	0.500	0.082
Construction		0.030	0.254	0.080	0.008	0.088	0.140	0.047	0.056	0.056	0.169	0.289	0.270	0.022		0.520
Agriculture	0.280	0.020	0.014	0.025	0.027		0.025	0.003	0.060	0.003	0.002	0.014	0.014	0.027	0.100	0.205
Transportation		0.003	0.035	0.124	0.001	0.081	0.066	0.054	0.089	0.016	0.079	0.090	0.019	0.020	0.300	0.071
Wholesaling and retailing	0.025	0.002	0.104	0.033	0.004	0.011	0.025	0.025	0.013	0.001	0.003	0.010	0.007	0.023		
Financial institutions			0.009	0.014				0.003	0.001			0.004	0.001			
Business real estate			0.050	0.025	0.009		0.006	0.020	0.002	0.004		0.002	0.001	0.106		0.008
Social and personal services	0.002	0.100	0.088	0.060	0.087		0.065	0.030	0.016	0.005	0.016	0.015	0.013	0.314		0.021
Government services		0.012	0.005	0.009	0.007	0.010	0.003	0.009	0.002		0.003	0.015	0.001	0.009		0.035

Table 9. The ratio of R&D expenditure used in an industry to that originating in the industry

Data refer to 1983

	United States	Japan	Germany	France	United Kingdom	Italy	Canada
Food	1.92	1.22	2.02	1.67	1.30	2.43	0.97
Textiles	3.78	1.02	2.05	1.37	2.25	1.05	1.13
Wood	1.81	1.20	1.27	3.88	3.67	15.66	0.74
Paper	2.08	2.23	4.45	3.78	3.12	10.54	0.87
Chemicals	0.82	0.85	0.80	0.77	0.79	0.76	0.68
Machinery	0.48	0.79	0.69	0.57	0.54	0.64	0.59
Basic metals	0.70	0.44	0.44	0.52	0.74	0.33	0.51
Stone, clay, glass	1.30	0.67	1.05	0.77	1.14	2.37	1.87
Other manufacturing	0.28	0.17	0.26	0.15	0.36	0.20	0.23
Mining	..	5.76	1.27	2.11	1.27	7.93	0.81
Construction	..	3.18	10.78	7.46	8.07	4.70	..

Note: A figure of 1.0 indicates that an industry is the origin of as much R&D as it uses.

1987). Third, productivity growth in non-manufacturing may be related to the development and marketing of new products and delivery networks, rather than through formal R&D or software expenditures. Some of the new financial instruments or the large, high-volume, low-margin retail establishments are examples. Thus the concordance must be viewed as measuring only a part of innovative activity. Nevertheless, the evidence that services benefit from these alternative channels of innovation to a disproportionate degree is limited, and the wide advantage of manufacturing in the measured innovation flow points toward the possibility that non-manufacturing may be lagging behind in innovation and productivity growth.

The concordance can be used to identify sectors which import and export technology, as embodied in the patent and R&D data. If it is assumed that each patent emerging from an industry incorporates the same amount of R&D, i.e. that agriculture for example, which uses 28 per cent of the food industry's patents also benefits from 28 per cent of the food industry's R&D[13], the technology importing and exporting industries within a given country can be identified (Table 9). In general, the patterns are similar across countries, with food, textiles, wood, paper, mining and construction being big importers of technology from other industries; and chemicals, machinery and basic metals being technology exporters to other industries. Canada is an exception to some of these patterns. The ratios for the importing industries differ greatly because, as discussed above, the denominators, representing R&D originating in the industry, tend in many cases to be quite small.

Table 10. R&D stocks by industry of origin (IOO) and industry of use (IOU) as a percentage of output in 1983

	United States		Japan		Germany		France		United Kingdom		Italy		Canada	
	IOO	IOU	IOO	IOU	IOO	IOU	IOO	IOU	IOO	IOU	IOO	IOU	IOO	IOU
Manufacturing	106.20	52.72	29.03	21.46	47.63	34.63	51.97	28.96	116.03	47.84	18.07	13.39	28.17	15.44
Food	11.90	17.71	9.16	10.51	2.52	7.59	4.02	6.38	14.28	17.58	0.87	2.20	..	..
Textiles	7.23	10.48	14.41	12.05	4.76	11.01	7.59	8.82	9.31	25.47	1.77	1.96	..	..
Wood	5.01	8.46		..	3.48	6.38	..	..	..		..	..	..	..
Paper	9.05	15.44	10.48	18.00	2.78	19.77	2.56	13.15	8.36	19.21	0.53	3.80		
Chemicals	79.33	66.63	53.51	43.16	71.38	54.51	67.63	55.26	103.75	87.29	35.75	28.83	..	..
Machinery	187.57	78.49	32.31	27.12	64.74	42.97	97.30	50.83	171.02	77.47	30.27	25.56	..	..
Basic metals	54.79	33.44	28.60	12.13	36.39	20.96	9.56	6.43	29.38	21.21	5.94	4.41	..	..
Stone, clay, glass	32.19	29.30	20.53	13.55	8.71	12.02	24.06	15.71	19.52	23.39	0.82	1.31	..	..
Other manufacturing	32.55	7.26	21.57	3.70	24.60	11.08	15.67	1.77	10.55	3.08	22.96	2.21	..	..
Nonmanufacturing	..	3.83	..	3.48	..	4.54	..	2.59	..	6.22	..	1.16	..	1.96
Mining	..	8.26	11.97	34.84	37.16	47.08	..	..	2.99	5.53	..	..	4.70	3.42
Construction	..	18.46	2.94	8.59	0.72	11.24	4.56	9.25	2.94	19.22	1.42	4.01	..	4.76
Transportation	..	11.59	..	6.37	..	10.54	..	8.34	..	11.27	..	2.37	..	4.32
Wholesaling and retailing	..	1.25	..	0.68	..	1.52	..	0.87	..	1.80	..	0.27	..	0.57
Financial institutions	..	0.47	..	..	..	0.33	..	0.30	..	..	..	..	..	..
Business real estate	..	0.99	..	..	..	2.10	..	0.57	..	..	..	..	..	..
Social and personal services	..	5.46	..	3.08	..	4.65	..	5.06	..	13.85	..	1.01	..	4.85
Government services	..	0.65	..	0.61	..	0.64	..	0.42	..	0.61	..	0.20	..	0.17
Total business sector	..	14.83	..	10.45	..	15.03	..	10.03	..	20.43	..	4.89	..	5.57

Note: Output measured by value added in each sector. For construction of R&D stocks, see Annex B

Expressing these technology flows in currency terms, and cumulating them assuming a constant obsolescence rate and benchmark (see Annex B), yields an estimate of the stocks of technology accumulated by each industry (Table 10). This stock of technology relative to output gives a relatively good measure of the technology intensity of each industry, and hence should be related to the level of TFP in each industry.

Even without formal regression analysis, a number of interesting features stand out from the estimates. First, manufacturing has accumulated a large stock of technology relative to output in each country. The levels differ because, as discussed above, research intensities differ between countries, with Italy and Canada conducting far less R&D than the other large countries. Secondly, and more important for the analysis of TFP developments, relatively little technology appears to have flowed into the non-manufacturing sectors. (Mining is an exception in Japan and Germany, but that reflects the very small mining output in these countries, and a possible bias at this level of aggregation from applying the Canadian-based concordance to other countries.) This again suggests that non-manufacturing requires a very large flow of non-patentable innovations to offset the concentration of patentable innovations in manufacturing.

V. R&D AND TOTAL FACTOR PRODUCTIVITY DEVELOPMENTS

This section analyses how closely the level of TFP in specific industries is related to the stock of R&D in that industry, and looks for further evidence of a decline in the potency of R&D[14]. The estimated results for manufacturing industries presented below appear to show a strong positive effect of R&D on TFP; the estimated coefficients on industry of use R&D are positive for seven of eight manufacturing industries and, taken together, significantly positive, although the estimated effects differ greatly across industries (Table 11).

These results support those generally reported in the literature of a strong positive link between R&D spending and productivity growth and also those of Scherer (1982) and Griliches and Lichtenberg (1984), in which user R&D was found to be closely related to TFP developments. In particular, it is noteworthy that the chemicals and machinery industry groups, in which R&D use is heavily concentrated, and which contain most of the high-tech industries, as discussed above, show very strong responses to both R&D use and spending. The textile industry is an exception in that it also shows a strong response but is not very R&D-intensive.

As for non-manufacturing industries, the link between R&D and TFP is less clear than in manufacturing industries; the R&D stock coefficients for four of eight

Table 11. **Estimated coefficients on the R&D stock in TFP equations**[a]

The equations are estimated on data across six countries
over annual observations from about 1970 to **1983**[b]

	Regression 1 Industry of use A&O	Regression **2** Industry of origin R&O
Food	0.01 (0.2)	–0.02 (–0.9)
Textiles	0.50 (11.7)	0.54 (8.8)
Paper	0.09 (3.8)	0.04 (1.5)
Chemicals and rubber	0.26 (8.0)	0.25 (7.5)
Machinery, instruments and equipment	0.30 (15.1)	0.25 (15.3)
Primary metals	0.01 (1.2)	0.004 (0.4)
Stone, clay and glass	0.03 (1.3)	–0.02 (–1.0)
Miscellaneous manufacturing	–0.11 (–4.1)	–0.14 (–5.8)
Mining	–0.05 (–2.3)	–
Construction	–0.07 (–3.9)	–
Transportation	0.02 (0.8)	–
Wholesaling and retailing	0.17 (8.0)	–
Financial institutions	0.16 (2.8)	–
Business real estate	–0.16 (–1.4)	–
Social and personal services	–0.16 (–5.8)	–
Government services	0.04 (1.6)	–
Adjusted R^2	0.50	0.64
SEE	12.9	10.7

a) For each of the two reported regressions, the dependent variable is the level of TFP indexed to 1970–100; the independent variables are country-specific dummies, industry-specific dummies, a time trend (common), country-specific capacity utilization, and a three-year lag of the stock of R&D for each industry, indexed to 1970–100. The addition of country and industry dummies interacted with time, or running separate industry regressions, did not qualitatively alter the results. *t*-statistics are reported in parentheses.

b) The OLS regressions are based on annual data from 1969-83 for the United States, Germany and the United Kingdom; 1970.84 for Japan and Italy; and 1972-83 for France. For Canada, only data on non-manufacturing industries for 1970433 were used. A detailed listing of the industries by country is available from the authors.

industries are negative, in some cases significantly *so.* Although negative coefficients are difficult to explain, the overall fits for non-manufacturing industries are much poorer than for manufacturing. The small amount of innovation directed at non-manufacturing does not appear to explain much of the change in TFP in these sectors. When the equations are run separately for manufacturing and non-manufacturing industries about 75 per cent of the variance in TFP for manufacturing is explained in a statistical sense, as opposed to 20 per cent in non-manufacturing. However, it is noteworthy that coefficients for industries such as wholesaling and retailing and financial institutions which are perceived to be benefiting from the introduction of automated equipment, are significantly positive.

In a variety of alternative specifications, the stock of **R&D** in the industry of use was more closely related to the evolution of TFP than was the stock in the industry of origin. This was true even when individual equations were run for each industry, allowing for industry-specific time trends. The higher explanatory power of the industry of use variables is the more striking because, as seen above, many innovations are used in the industry of origin, *so* that the two **R&D** measures show broadly similar movements'[5].

A second question of interest is whether TFP and **R&D** links are primarily industry-specific or country-specific. That is, are the productivity effects of **R&D** more common to all industries within a country than to the same industry across countries? The data give a clear answer: more than a third of the explanatory power of the **R&D** stock was lost when the industry-specific **R&D** variables were replaced by country-specific **R&D** variables. This is consistent with the similar industry patenting patterns discussed above and also with the notion that the possibilities for innovation have a strong industry component to them.

Finally, it is interesting to recall that chemicals and machinery account for the great majority of industrial **R&D** in the seven largest **OECD** countries, and have very high **R&D** intensities measured both by industry of use and origin. The high significance of the estimated coefficients in the regressions for chemicals and machinery can thus be regarded as indicating that **R&D** resources have shifted into industries in which they are highly productive. (As noted above, the textiles industry is an exception in having a relatively low R&D intensity, but a high apparent productivity of **R&D.)**

To test for **R&D** potency changes, additional regressions were run in which the **R&D** effect was allowed to change after 1973. Changes in potency could be more clearly tested for if the comparison was made with data from the 1960s, when the indicators suggested that potency was at a peak. Nevertheless, the results suggest that there was some potency shift around the mid-1970s (Table 12, left panel). The estimated shifts in the **R&D** coefficients are often significantly different from zero. In eleven of the sixteen industries **R&D** appears to have become less productive in the 1974-79 period compared with the 1970-73 period, and this pattern is maintained

Table 12. R&D potency: sub-period comparisons Coefficients on R&D

	Regression 1			Regression 2		
	1970-73 (1)	1973.79 *shift*• (2)	1980.83 *shift*• (3)	1970-73 (1)	1974.79 *shift*• (2)	1980-83 *shift*• 131
Food	0.185 (0.9)	-0.122 (-0.5)	-0.308 (-1.4)	0.027 (0.1)	-0.030 (-0.11	-0.094 (-0.4)
Textiles	0.259 (0.8)	0.429 (0.4)	0.163 (0.5)	0.060 (0.2)	0.233 (0.6)	0.441 (1.3)
Paper	0.431 (2.11	-0.337 (-1.6)	-0.384 (-1.91	0.245 (1.1)	0.220 (-1.01	-0.148 (-0.71
Chemicals and rubber	0.566 (2.3)	-0.204 (-0.8)	-0.443 (-1.81	0.209 (0.8)	0.014 (0.11	-0.017 (-0.11
Machinery, instruments and equipment	0.231 (1.21	-0.023 (-0.11	0.055 (0.3)	0.070 (0.3)	0.086 (0.4)	0.263 (1.31
Primary metals	0.176 (1.31	-0.149 (-1.11	-0.172 (-1.3)	0.113 (0.8)	-0.099 (-0.7)	-0.086 (-0.6)
Stone, clay and glass	0.718 (3.71	-0.650 (-3.31	-0.764 (-3.9)	0.589 (2.8)	0.580 (-2.7)	-0.592 (-2.9)
Miscellaneous manufacturing	-0.505 (-2.21	0.325 (1.41	0.342 (1.5)	-0.817 (-3.4)	0.543 (2.2)	0.705 (2.9)
Mining	0.299 (1.51	-0.258 (-1.2)	-0.522 (-2.51	-0.013 (-0.11	-0.047 (-0.21	-0.168 (-0.81
Construction	0.017 (0.1)	-0.026 (-0.11	-0.127 (-0.7)	0.013 (0.1)	-0.071 (-0.21	-0.113 (-0.6)
Transportation	0.084 (0.5)	-0.064 (-0.4)	-0.160 (-0.9)	-0.097 (-0.51	-0.024 (-0.3)	-0.070 (-0.41
Wholesaling and retailing	0.370 (2.1]	-0.137 (-0.81	-0.206 (-1.21	0.389 (2.0)	-0.181 (-0.91	-0.159 (-0.81
Financial institutions	0.239 (0.5)	0.142 (0.3)	0.087 (0.2)	0.633 (1.3)	-0.192 (-0.4)	-0.247 (-0.5)
Business real estate	-0.474 (-0.31	0.196 (0.11	0.009 (0.0)	-1.212 (-0.7)	0.522 (0.3)	0.823 (0.4)
Social and personal serwices	-0.026 (-0.11	-0.199 -0.81	-0.282 (-1.21	-0.313 (-1.21	-0.010 (-0.01	-0.082 (-0.3)
Government services	0.020 (0.1)	0.067 (0.3)	-0.028 (-0.11	0.049 (0.2)	-0.094 (-0.41	-0.108 (-0.51
Adjusted R^2	0.56			0.56		
SEE	12.1			12.1		

Notes:

Dependent variable: TFP indexed to 1970–100.

Independent variables:

Regression 1: Same as Table 11, other than the omission of the common time trend. All variables are interacted with dummies for the post-1973 and post-1979 period.

Regression 2: Same as regression 1, with the addition of time trend and time trend interacted with post-1973 and post-1979 dummy variables, and separate time trends for each country.

• In both cases, the shift is defined relative to 1970.73.

in eleven of the industries after 1980. The implied shifts are also large: in seven of the eleven industries R&D seems less than half as productive in 1974-79 compared with 1970-73.

It is also noteworthy that the results correspond to those reported in Baily and Chakrabarti (1985) with respect to the two industries which they have examined in detail. The chemicals industry shows a marked decline in potency, which corresponds to the assessment of experts in the industry. In contrast, both these results and the expert assessment reported by Baily and Chakrabarti suggest little decline in innovation in textiles.

Because the R&D and TFP variables are the only variables with strong time trends, it is possible that the lower R&D coefficients are spuriously reflecting the general slowing of TFP growth. In order to test this, time trend and country dummies were interacted with the shift terms (Table 12, right panel). As might be expected from the introduction of other time-trending variables and the consequent increase in multicollinearity, the overall significance levels of the R&D variables fall, but the shift factors remain quite similar. In both periods, more than ten industries show lower returns to R&D, and in most cases the decline is quite large. These results support the hypothesis that there has been a decline in R&D potency.

VI. THE STOCK MARKET AS AN INDICATOR OF FUTURE TOTAL FACTOR PRODUCTIVITY GROWTH

There are few available predictors of the future course of technology and future TFP, but stock-market data may provide an indication of market expectations for future productivity. To the extent that new technology translates into higher profits for innovating firms, market analysts have an incentive to identify these firms, and the expected future profits will be discounted into the current price of the firms' shares, even though current sales and earnings are low. Hence, the price/earnings (p/e) ratios of high-tech firms may serve as an indicator of how much new technology the market expects these high-tech firms to produce in the future. The classification of high-tech industries is adapted from the National Science Board (1985).

In order to abstract as much as possible from macroeconomic events and other factors which move the stock market as a whole, these high-tech p/e ratios should be compared with the average p/e ratio. Changes over time in the p/e ratios of high-tech firms relative to the market average may provide information on how much technology is in the pipeline. Indeed, this is one way of defining a research-oriented firm. A firm with a p/e ratio close to the market average can be regarded as a "mature" firm whose products have achieved their potential and are earning the

Table 13. **Price-earnings ratios of high-tech firms compared to market averages"[b]**

	All firms (1)	High tech-1 (2)	Ratio (2)/(1) (3)	High tech-2 (4)	Ratio (4)/(1) (5)
1970	18.2	40.6	2.2	24.5	1.3
1971	18.6	39.5	2.1	27.8	1.5
1972	18.9	28.1	1.5	28.9	1.5
1973	11.7	15.0	1.3	17.1	1.5
1974	7.4	9.6	1.3	11.0	1.5
1975	11.0	14.8	1.3	14.6	1.3
1976	10.6	13.0	1.2	13.4	1.3
1977	8.8	12.9	1.5	11.1	1.3
1978	8.1	12.0	1.5	10.6	1.3
1979	7.5	15.2	2.0	9.8	1.3
1980	9.7	24.7	2.5	12.3	1.3
1981	8.6	22.5	2.6	11.0	1.3
1982	12.3	36.4	3.0	15.0	1.2
1983	13.5	47.3	3.5	16.8	1.2
1984	10.7	37.2	3.5	13.3	1.2
1985	15.9	176.6[c]	11.1	22.3	1.4
1986	20.5	152.5[c]	7.4	22.2	1.1

Note: High tech-1 includes only non-New York stock exchange firms.
High tech-2 includes all firms in designated SIC codes.

a) The industries labelled as high-tech are: SIC 281 (industrial inorganic chemicals), 282 (plastic materials and synthetic resin), 283 (drugs), 2870 (agricultural chemicals), 351 (engines and turbines), 357 (office computing and accounting machinery), 3651 (radio and TV receiving sets), 366 (telephone and telegraph apparatus, radio-TV transmitting equipment), 3674 (semiconductors and related devices), 3681 (computers mini and micro), 369 (X-ray electromedical apparatus and other electrical machinery), 372 (aircraft and parts), 3811 (engineering, laboratory and research equipment), 3841 (surgical and medical instruments), 489 (communications services NEC), 7391 (research and development laboratories). This classification is adapted from NSB (1985).

b) The sample included all firms on the COMPUSTAT annual tape for which *p/e* ratios could be calculated. Limiting the analysis to a constant sample of firms provided similar results.

c) These values seem too high and reflect large losses in particular industries. However, even keeping profits fixed at 1984 levels yields *p/e* ratios of between 40 and 50, which are still well above mid-1970 levels.

Source: COMPUSTAT.

average return on capital. Comparing p/e ratios for high-tech firms as a group with the market average is likely to remove much of the firm-specific noise in the data[16]. This is so even though firms may realise only a fraction of the returns to their R&D, because competition and free dissemination allows other firms to "free ride", there being no reason to expect that the extent of free ridership has changed over time.

The relative p/e data are presented in Table 13 for all firms in high-tech industries and for all high-tech firms excluding those listed on the New York Stock Exchange. The latter have been excluded from the second set of calculations because they are much more established firms which are not only creating new technology but also have established product lines. Hence, these firms are likely to be larger, both in terms of earnings and in terms of assets, and may therefore dominate the index, confounding the prospects for creating new technology with the success of these large firms in marketing their current product line.

The results provide some grounds for optimism on future TFP developments. When the p/e ratios of *all* firms in high-tech industries are compared with the overall market index, it is hard to identify any significant advance in recent years. The p/e ratios vary between 1.1 and 1.5 times the overall market index and there may even have been a slight decline in recent years (Table 13, column 5). To the extent that these firms are selling products which embody new technology, this suggests either that the pace of diffusion has not increased or that competition is driving down profit margins.

The p/e ratios for the non-New York Stock Exchange high-tech firms, however, have increased markedly in recent years. The p/e ratios of these firms declined in the early and mid-1970s relative to the market average, suggesting a possible decline in potency in that period. Recently, these firms' p/e ratios have been about seven to ten times the average market index, up from 1.2-1.5 times in the mid-1970s and just under twice the average in the early 1970s[7]. This suggests strongly that the market is currently discounting a larger future stream of products and earnings than in the past. The value of the outstanding shares of the firms has increased relative to the overall market, representing 3.2 per cent in 1986 as compared to 1.0 per cent in 1978. In addition, there are numerous privately-held high-tech firms (National Science Board, 1985), so that these data probably understate the growing importance of high-tech firms. Such growth is consistent with the hypothesised correlation of inputs to research and the potency of research.

One possible caveat to this analysis is the observation that non-high-tech non-NYSE firms also showed a marked advance in their p/e ratios relative to the overall market. Thus, it is possible that there is a common factor pushing up the p/e ratios for all non-NYSE firms. However, to the extent that the stock market can be regarded as rationally interpreting future prospects, it is not clear why the prospects of high-tech firms should seem so bright, if they were not expected to produce new technology, as that is the only "product" they are producing.

THE OUTLOOK FOR TOTAL FACTOR PRODUCTIVITY GROWTH

Taken together, this paper and the macroeconomic analysis in Englander and Mittelstadt (1988) suggest more optimism with respect to future TFP growth than would have been appropriate in the 1970s and early 1980s. With respect to macroeconomic conditions, the period of sharply accelerating inflationary pressures, and the consequent need for highly restrictive policies, seems past. Provided that steady, non-inflationary growth can be maintained, the structural adjustments and tax reforms undertaken in many countries may produce both faster growth of capital and a more efficient use of both old and new capital. While the papers did not find evidence that energy prices or demographics were major factors contributing directly to the slowdown, it is nonetheless comforting that they do not appear likely to inhibit TFP growth over the near term. Moreover, this paper has found some support in both the acceleration of R&D spending at the beginning of the 1980s and in the stock market evaluation of high-tech firms for the proposition that there may be some pick up in the pace of technology generation and commercialisation over the next few years. Such assessments are, of course, tentative, but they represent a turnaround from the conditions of ten or so years ago. To the extent that such optimism is well founded, the years ahead may hold both increases in the rate of per capita income growth and downward pressure on inflation; and, consequently, more room to ease macroeconomic policies and reduce unemployment.

While the basic outlook seems positive, there are also factors acting in the opposite direction. The persistence of trade imbalances and various tariff and non-tariff barriers raises the possibility of increased protectionism and potentially slower growth in the future. To the extent that these reduce growth and, perhaps as importantly, the dissemination and trade in new technology, TFP growth may remain close to the stagnant rates of recent years. In the absence of such outcomes, however, the general assessment for future TFP gains remains optimistic.

NOTES

1 For a clear definition of R&D, see "Frascati Manual" (OECD, 1981). which provides the internationally standardized definition of R&D. See Kendrick and Vaccara (1980) for papers and additional references on the return to R&D.

2. Griliches (1987) is an exception. In general, one can analyse the returns to R&D on a cross-sectional basis at different points in time. However, there are risks in translating cross-section results into time series.

3. The countries are the United States, Japan, Germany, France, Italy, the United Kingdom and Canada. The industries are listed in Table 10.

4. Among others, Scherer (1982). Bernstein (1987). Jaffe (1986) and Terleckyj (1980) have tried to analyse technology on the basis of industry of use as well as origin.

5. See, **for** example, Schumpeter (1934).

6. See Evenson and Kislev (1975) for an application of this model to organised varietal breeding programmes.

7. See Evenson and Kislev *(op. cit.)*.

8. An important issue here is the relative timing of R&D and inventions: how much R&D precedes an invention, and how much takes place after an invention has been made and patented? Hall, Griliches and Hausmann (1986) investigate this question with U.S. firm data and conclude that, in terms of yearly data, a contemporaneous relationship is generally most likely.

9. This increasing tendency to patent abroad argues against the notion that patenting propensities have diminished greatly over time because they offer so little protection that no-one bothers to patent new inventions.

10. Scherer (1983), Soete (1979) and Pavitt (1982) suggest that changes in industrial structure can also change the propensity to patent within industries. To the extent that these happen across countries simultaneously, it may be impossible to separate potency and market structure effects simply by looking at patenting ratios. To differentiate between the hypotheses, reference has to be made to actual productivity performance, since there is no presumption on how market structure affects productivity growth.

11. A current limitation of the concordance is that only one industry is selected as benefiting from the new technology, but data are also becoming available on second and tertiary industries of use. An alternative which has been suggested is the use of standard input-output matrices to map the flow of technology.

12. The actual assignment of inventions underlying Table 8 was made from the IPC "group" level to 4-digit Standard Industrial Classification (SIC) and then aggregated up to the level of industries in Table 8. This aggregation applies Canadian weights to other countries, a problem which could be avoided by applying the concordance to, say, French patents at the

detailed level and then aggregating up to the industry levels using French weights. At this stage it is not possible to do this because there is not a full set of French patent data by IPC group easily available.

13. Implicitly, this weights the patent flows by the patenting propensities of each industry and enables the calculation of technology flows in currency units.

14. The specification of the estimated equations is very simple. To make different industries comparable and eliminate heteroskedasticity, all R&D stock and TFP measures were indexed to 1970 = 100. Regressing levels rather than growth rates allows more of the variation to come from the cross-sections whereas a growth rate specification would produce estimates reflecting primarily short-term relationships. The industry TFP data are based on Meyer-zu-Schlochtern (1988) and are also discussed in Englander and Mittelstadt (1988).

15. Including both R&D stock measures in the same regression for manufacturing raised the adjusted R^2 very marginally. However, the coefficients become very hard to interpret, so subsequent regressions used only the stock of R&D by industry of use.

16. In a study which did not specifically distinguish between high-tech and other firms, Pakes (1984) found that stock prices were related to R&D and patents in a very noisy and variable way in a sample limited to 129 firms.

17. With regard to timing, the high-tech p/e ratios declined a year in advance of the market ratio in the early 1970s and rose two or three years in advance of the market in the late 1970s. Also note that the market p/e ratio in 1986 was at about its 1970-72 level while the high-tech ratio was a good deal higher. This argues against these relative p/e ratios just picking up a higher amplitude on the part of high-tech firms.

Annex A

THE YALE-CANADA CONCORDANCE

For analytic and empirical work relating inventions or other measures of research output to research inputs, i.e. R&D spending or research personnel, it is important to "match" inventions for an industry to the industry of origin of the R&D. The industry of origin is the industry, firm or group of firms actually conducting the R&D. For purposes of analysis of industry TFP a different relationship between the industry undertaking the R&D and producing inventions is required. R&D originating in one industry may produce some inventions that are "used" in the same industry. These are generally, but not always, process inventions. Many inventions, however, are used in other industries. These are generally product inventions and generally they are used in "upstream" industries in an input-output sense.

In this note the problems of assigning or concording patented invention to an industry of origin (to match them with R&D data) and to an industry of use (to match them with TFP data) are discussed. We also report and discuss a matrix of technology flows from industries of origin and industries of use based on Canadian Patent Office data (The Yale-Canada Concordance).

Data on R&D and Sience and Engineering personnel by industrial sector have been collected for a number of years. Similar data are not collected on patented inventions. However, patents are classified according to engineering, and to some extent industrial, features. Most national patent offices have their own system but an International Patent Classifications system has been in widespread use for more than twenty years. The use of this system has helped to standardize patents.

At present only two very crude "concordances" between industry classes and patent classes have been made. The first is the U.S. Patent Office concordance between U.S. patent class and industries and the second is the concordance of the European Patent Office. Neither concordance is ideal.

The first attempt at a patent concordance (in this case, between the U.S. Patent Classification (USPC) system and the U.S. Standard Industrial Classification (SIC) system) was undertaken by the U.S. Patent and Trademark Office (PTO). Their method was to examine the description of patent sub-classes and, based on that description, to assign all patents in that sub-class to an industry. If the patents pertained to more than one industry, the entire sub-class was assigned to each relevant industry. Obviously, this resulted in multiple counting of patents and in distorted totals for many industries. Subsequently, the PTO modified this approach, *so* that sub-classes with multiple industry assignments were "fractionalised" according to the number of industries to which they were assigned. For example, if a sub-class was assigned to five industries, one-fifth of the total patents in the sub-class was assigned to each industry. This eliminated the multiple counting of patents, but serious distortions persisted.

This approach has other practical, as well as conceptual, drawbacks. In the first place, it could only be used for U.S. patents. More seriously, it made no distinction between the industry in which the invention originated and the industry in which it was used. The European Patent Office and other offices have used a similar approach with broad International Patent Classification (IPC) assignments.

A new concordance based on the Canadian Patent Office assignment of patents to industry of origin and industry of use has recently been developed. The Yale-Canada concordance is a means of assigning patents that have been classified by IPC system to an industry. The IPC system is primarily "function-oriented", meaning that it groups together inventions that employ similar engineering concepts or ideas (e.g. similar pumps or similar chemical structures). Economic data, on the other hand, are "industry-oriented". Because any given industry will typically use inventions that have many different types of function and because inventions that have a similar function are spread across many industries, there is no simple means of translating one classification system into the other. A minimum competence in a technology field is required for such classification.

Evenson and Putnam **(1988)** have developed a more precise concordance using Canadian data. The concordance constructed from the Canadian PATDAT database mitigates a number of the deficiencies of prior efforts. Since **1972,** Canadian examiners have assigned both an industry of origin (IOO) code and an industry of use (IOU) code to Canadian patents. This began on a trial basis with Canadian-origin patents and patents granted to large firms. In **1978** this system was extended to all Canadian patents. Also in **1978,** Canada began to classify its patents according to the IPC system. Between **1978** and **1984,** approximately **125 000** patents have received codes for IPC, IOO and IOU. Thus, it is possible to generate two concordances, IPC-IOO and IPC-IOU, based on the fraction of each IPC sub-class that was assigned to each industry (of origin and use, respectively). When these fractions are multiplied by the patent counts in each IPC sub-class and summed over all the sub-classes, they generate an estimate of the total number of patents assignable to each industry. Furthermore, since this concordance is based on the IPC system, one can generate industry estimates for all countries that classify their patents by the IPC.

To illustrate this, consider a matrix like the one below.

$$
\begin{array}{c|ccccc}
 & C_1 & C_2 & C_3 & \ldots\ldots & C_N \\
\hline
I_1 & a_{17} & a_{12} & a73 & \ldots\ldots & a_{1N} \\
I_2 & a_{21} & a_{22} & a23 & \ldots\ldots & a_{2N} \\
I_l3 & a_{31} & a32 & a_{33} & \ldots\ldots & a_{3N} \\
 & & & & & \\
I_M & a_{M1} & a_{M2} & a_{M3} & \ldots\ldots & a_{MN}
\end{array}
$$

a_{ij} is the fraction of the *j*th sub-class assigned to the *i*th industry (I_i), where the fraction is calculated by dividing the number of patents in sub-class C_j assigned to industry I_i by the total number of patents in C_j. The columns of this coefficient matrix must then sum to unity. This matrix can be post-multiplied by a $Nx1$ vector of patent counts by IPC sub-class to generate an $Mx1$ vector of estimate patent counts for the M industries. Two such concordance matrices have been developed, one for IOO and one for IOU.

There are several types of variability introduced by this method. First, the a_{ij} may not be stable over time. Second, they may not be stable across countries. Third, even if the conditional expectation of patent counts for each (I,C) pair (conditioning on Canada as the source and the given time period) were the same as the unconditional expectation, we still have to regard the coefficient matrix as the result of a random draw.

Evenson and Putnam **(1988)** discuss methods by which to assess statistically the variability of the estimates provided by this method and to produce a standard error for each estimate. Initial tests have also been conducted on the concordances' reliability. For example, the patent counts for each year for each industry in Canada was predicted using the matrix generated over the entire sample and a vector of patent counts by IPC by year. Since the actual assignment is known, the predicted and actual totals for each year can be compared. At the 2-digit SIC level, most industries (27 out of 32 IOU; 18 out of 26 1OO) show a coefficient of variation (standard deviation divided by the mean) of less than 0.2.

Annex B

CONSTRUCTION OF R&D STOCK VARIABLES

The estimated initial value of R&D stocks, RS_0 is determined by:

$$RS_0 = RF_0/g + d$$

where RF_0 is R&D expenditure in the initial period of data availability, g is the estimated rate of growth of R&D, and d is the rate of obsolescence of R&D stocks, as in Griliches (1980). R&D flows were cumulated to a stock using the assumed initial value of the stock and the standard perpetual inventory method. The R&D stock by industry of use was calculated by feeding the annual real R&D flows by industry of origin through the concordance and cumulating the resultant industry of use flows to a stock. For regression purposes the R&D stock in each industry in each country (except France), was indexed to 100 in 1970. (For France the R&D stock was indexed to 100 in 1972 because of data limitations.)

The rate of obsolescence of R&D was set at 5 per cent, in order to reflect the possible reduction of the impact of older R&D as product mixes and relative input prices shift over time. This social rate of depreciation is higher than Griliches' assumption of zero depreciation, but much lower than the private rates of depreciation estimated in the literature. A three-year lag was assumed between changes in the R&D stock and their effects on TFP.

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