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The Impact of R&D and Technology Diffusion on Productivity Growth: Evidence for 10 OECD Countries in the 1970s and 1980s

Norihisa Sakurai*, Evangelos Ioannidis**, George Papaconstantinou**

This paper examines the empirical evidence on the impact of performed R&D and of embodied R&D on productivity performance in 10 major OECD countries (the G7 countries, Australia, Denmark and the Netherlands) over the last two decades. Industry-level performed R&D and embodied R&D variables were constructed from an input-output model developed in a previous paper on technology diffusion. The productivity variables used in this paper are Divisia growth indexes of TFP which were consistently estimated by an input-output based growth accounting procedure. The aggregate TFP estimates showed some recovery in the 1980s in most countries and notably in the United States, where most of this recovery was in manufacturing. The results from pooled regressions across countries and across industries during the 1970s and 1980s indicate that the rates of return of both R&D variables are positively significant and increasing in the 1980s. The estimated rate of return of direct R&D for manufacturing is about 15% on average across the countries and no significant difference is observed between the two decades. However, the rate of rerun of direct R&D varies across the countries: in the 1970s Japan showed the highest return (40%) but in the 1980s it was highest in Italy (50%) and Canada (30%). On the other hand, embodied R&D is an important source for productivity growth in services, pointing to very high social returns of the flows of capital-embodied technology into this sector: on average across the countries it was about 130% in the 1970s and 190% in the 1980s. The Information and Communication Technology (ICT) cluster of industries played a major role in the generation and acquisition of new technologies. In particular, the ICT services sectors in Canada and in small European economies have obtained higher gains from international R&D spillovers than from domestic ones, while domestic R&D was more important in the United States, Japan and Germany. These results are broadly consistent with the findings in other papers on this topic. By and large, we confirm the views that R&D and its diffusion through the economy as well as an open trade and investment regime are important elements in productivity performance, especially for the ICT industries.

At the time of preparation of this paper, all authors were at the Economic Analysis and Statistics Division of the Directorate for Science, Technology and Industry, OECD. Opinions expressed in the paper are personal and do not engage the OECD and its Member states, or the Central Research Institute of the Electric Power Industry in Japan.

Ce document examine l'incidence sur la productivité de la R-D directement produite et de la R-D incorporée, telle qu'elle ressort d'une étude économétrique portant sur 10 grands pays de l'OCDE (les pays du G7, plus l'Australie, le Danemark et les Pays-Bas) et sur les vingt dernières années. Les variables représentatives de la R-D produite à l'échelon d'une branche et de la R-D incorporée ont été construites à

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partir d'un modèle d'entrées-sorties développé dans un précédent document sur la diffusion de la technologie. La productivité est représentée par des indices de Divisia rendant compte de la croissance de la PTF, qui ont été estimés par une procédure de comptabilisation de la croissance basée sur les techniques d'entrées-sorties. Dans les années 80, le niveau global estimé de la PTF s'est redressé dans la plupart des pays, notamment aux Etats-Unis, où ce redressement a surtout touché le secteur manufacturier. Des régressions concernant l'ensemble des pays et des branches pour les années 70 et 80, il ressort que les taux de rendement des deux variables de R-D sont significatifs et positifs, et qu'ils ont augmenté dans les années 80. Dans le secteur manufacturier, le taux de rendement estimé de la R-D directe est d'environ 15 % en moyenne sur l'ensemble des différents pays et il ne varie guère entre les deux décennies. Il affiche, par contre, des divergences d'un pays à l'autre : dans les années 70, c'est au Japon qu'il a été le plus élevé (40 %), tandis que dans les années 80, c'est en Italie (50 %) et au Canada (30 %). De son côté, la R-D incorporée représente une source importante de croissance de la productivité dans les services où le rendement social des apports de technologie incorporée au capital dans ce secteur est très élevé, se chiffrant en moyenne sur l'ensemble des pays à 130 % environ dans les années 70 et à près de 190 % dans les années 80. Les industries des technologies de l'information et des communications (TIC) ont joué un rôle majeur dans la production et l'acquisition de nouvelles technologies. Les secteurs de services des TIC, notamment au Canada et dans les petites économies européennes, ont bénéficié davantage des retombées internationales de la R-D que des retombées nationales ; en revanche, la R-D nationale a été plus importante aux Etats-Unis, au Japon et en Allemagne. Ces résultats concordent globalement avec les conclusions d'autres études sur cette question. D'une manière générale, ils confirment que la R-D et sa diffusion à l'ensemble de l'économie, de même qu'un régime ouvert d'échanges et d'investissement, sont des éléments importants pour la croissance de la producitvité, surtout dans les industries des TIC.

Lorsque ce document a été rédigé, tous les auteurs étaient membres de la Division des analyses économiques et des statistiques de la Direction de la science, de la technologie et de l'industrie de l'OCDE. Les opinions exprimées dans ce document sont celles des auteurs et n'engagent ni l'OCDE, ni ses pays Membres, ni l'Institut central de recherche de l'industrie électrique du Japon.

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1. Introduction

The relationship between technological change and productivity has recently attracted a great deal of attention among economists and policy makers, reflecting an increasingly widespread view that technological change is a major driving force behind long-term economic growth. It is by now well recognised that R&D activity is a major source of technological progress and that the productivity benefits from successful innovations are not fully appropriated by innovating firms but instead diffuse through the rest of the economy, ultimately contributing to rising levels of productivity, standards of living and employment in the economy as a whole.

The patterns of technology diffusion

A recent OECD paper examined the nature and patterns of intersectoral and international technology flows in 10 major OECD countries (the G7 countries, Australia, Denmark, and the Netherlands).[1] Based on input-output data, it developed a methodology allowing the calculation of consistent measures of embodied technology diffusion through the purchases by industries of intermediate and capital inputs sourced domestically and from abroad. On the basis of these calculations, it examined a number of issues: the patterns of supply and demand of technology; the adequacy of existing indicators of technological level of industries for guiding policy; the role of capital equipment purchases in technology diffusion; the importance of imported technology; and the role of technology clusters, especially that of information technologies. The major conclusions drawn from that paper are summarised as follows:

While innovations are developed mainly in a cluster of high technology manufacturing industries, the main acquirers of technologically sophisticated machinery and equipment are a different cluster of industries in the services sector, with technology generation much more concentrated than technology use. The use of technology in many services industries (especially private services) is higher than what their (large) weight in the economy might suggest. The part of embodied technology acquired externally has increased over time, partly because of more extensive sourcing of high technology goods

Simple R&D intensity indicators are an inadequate measure of technological sophistication of industries; "total technology" indicators at the industry level combining both performed R&D and externally acquired technology are more appropriate. The spread between high, medium and low technology industries diminishes when accounting for the purchase of technologically sophisticated inputs. The technology intensity of small countries increases significantly with acquired technology; big increases can also be seen in the technology intensity of medium technology industries in Japan, Germany, Canada, Netherlands; the overall total technology intensity for Japan overtakes that of the United States.

Investment in R&D intensive equipment is a major carrier of technology diffusion. The estimated share of technology obtained through capital investment amounts to around 50 per cent of total acquired technology in some countries, a figure that is probably an underestimate given the use of investment flows rather than capital stocks in the analysis;); the US leads in the diffusion of technology through capital investment. The industries most depended on investment-based technology acquisition are in services (finance and insurance, social and personal, communication services); those least dependent are the high technology manufacturing industries.

Bigger countries source less technology from abroad than smaller countries which depend on imports for more than 50 per cent of their acquired technology; the share of acquired technology through imports has increased over time for all countries except Japan. In intensity terms, imported technology is more important than domestic technology for all countries except the US, Germany and Japan. The US is the most important source of technology for all countries (especially for computers and aerospace); for the US, the DAEs, China and Japan are the most important source of technology acquired through imports.

Technology emanating from the information technology cluster of industries is the bulk of technology acquired in most countries. The importance of information technology has increased over time; IT is the fastest growing acquired technology cluster, with the share of other technology clusters is steady or declining. Certain types of technology tend to gravitate to certain sectors: IT to high technology manufacturing, communications services and finance, insurance, real estate; transportation technology to transportation services; consumers goods technology to wholesale and retail trade; materials technology to agriculture, and to medium and low technology manufacturing; and fabrication technology to mining, utilities and construction.

The results of the paper thus broadly confirmed that technology acquisition through the purchase of R&D-intensive intermediate inputs and capital goods are often as important as their own research and development, in particular for the services sector whose major source of technology is through the purchase of R&D-intensive investment goods from domestic or foreign suppliers. The next step of analysis is then to introduce these measures of diffusion alongside measures of the intensity of R&D expenditures as determinants of medium-term productivity growth and employment performance in OECD countries.

Aim and scope of the paper

A number of papers have already addressed the technology and productivity nexus in various ways. Many studies have used embodied R&D in order to examine the possibility that a slowdown in the generation or diffusion of new technology has contributed to the post-1973 productivity slowdown or to disentangle the effect on an industry's productivity of direct R&D expenditures, as distinct from the effect of indirect R&D embodied in products domestically and from abroad, or for obtaining measures of the marginal productivity of R&D expenditures or of the rate of return to R&D investment.

The paper examines empirically the relationship between performed and acquired R&D and productivity gains, and attempts to address two fundamental questions on the technology-productivity relationship:

The potency of R&D and structural change in the technology and productivity nexus: has the link between R&D variables and productivity become continuously weakening during the 1970s and 1980s? If this is true, it may partly explain the so-called "productivity paradox", i.e., why productivity growth has slowed since the early 1970s against the public belief that OECD economies are in the midst of a major wave of technological change.

The relative importance of performed R&D and equipment-embodied technology: have large technology flows from manufacturing to several service sectors contributed to their productivity performance? Have international R&D spillovers accelerated in terms of other countries' productivity gains from imports of R&D-intensive products over the last two decades?

To investigate these issues across countries, the analysis is conducted for 10 OECD countries. Given the limited availability in time-series data, the regression analysis is pursued along three different dimensions, i.e., at the macroeconomic level across countries, at a country level across industries, and at a specific industry level across countries.

The remaining of the paper is as follows. Section 2 summarises productivity trends in 10 countries for the 1970s and 1980s based on the paper’s macro and sectoral TFP growth estimates. Section 3 puts forward the model relating R&D variables to productivity growth and presents regression results across countries and across industries for the two decades. Section 4 briefly compares the results with those of other studies. Conclusions are in section 5.

2. Output growth and productivity trends

Before analysing the relationship between technology and productivity, this section presents an overview of productivity performance in the 1970s and 1980s for the 10 OECD countries examined.[2] Since the measure of productivity growth used here is rather new and is estimated from detailed input-output accounts, somewhat different characteristics of productivity performance in member countries could be found compared with already available productivity data in OECD (For the mathematical presentation of the productivity measure, see Annex 2).

Despite its limitations, total factor productivity (TFP) or multifactor productivity is a better indicator for measuring the improvement in production efficiency in a given period than traditional partial factor productivity. Industries usually use a spectrum of inputs in their production activities: primary factors (labour, capital and land) as well as various intermediate inputs (raw materials, energy, distribution and other business services). In this perspective, labour productivity may increase at the same time as the productivity of other decreases so that partial productivity indicators in themselves do not provide a correct evaluation of actual changes in production efficiency. TFP allows the evaluation of an industry's overall efficiency of production by relating output to the use of numerous inputs simultaneously.

TFP is expressed as production per unit of an composite index of inputs, appropriately aggregated. Broadly, two methods can be distinguished in the literature to derive TFP: the growth accounting approach and the production function approach. Both methods produce the same results when the underlying production function is assumed to exhibit constant returns to scale and when both product and factor markets are competitive. TFP growth then corresponds to the neo-classical concept of technical change which is shown as shifts in the production function distinct from movements along the production function induced by factor substitution due to changes in relative factor prices and the bias of technological progress (Jorgenson and Griliches (1967)). The TFP growth estimates in this paper are constructed by the growth accounting approach using input-output data, so that the data are only available in terms of rate of change and not in the terms of their level.

The use of input-output accounts allows the identification of a detailed cost structure in an given industry covering a number of intermediate inputs, labour and capital. Gross output is then a suitable indicator of production at the sectoral level, whereas value added is used as the key indicator of production at the macroeconomic level because intermediate inputs can then be cancelled out at this level. In this respect, the growth accounting model in this paper is similar to the neo-classical model elaborated by Gollop and Jorgenson (1980) and Kuroda and Shimpo (1991) and is different from the previous OECD exercises which employ aggregate GDP as a production index and neglect intermediate inputs in the growth accounting (see Englander and Mittelstädt (1988), Englander *et al*. (1988) and Englander and Gurney (1994a, 1994b)). Because however of a lack of internationally comparable data to construct input-output based TFP series, the TFP growth indexes are available only at a rather aggregated sectoral level -- at most 20 sectors for each country and for the input-output years in each country which differ across countries (see also Box). These deficiencies will be remedied in the near future as more expanded data on capital, labour and input-output are developed.

Box 1. **Measurement issues on TFP**

TFP measurement has not yet been reached a credible consensus among researchers, as a result of the use of different underlying economic theories, problems in the definition of both outputs and production factors, type of indexes used etc. Because of this, several shortcomings in the TFP series calculated here should be mentioned.

First, the TFP series in this paper are available only in the form of average growth rates between input-output years which differ across countries. Hence, TFP data cannot avoid disturbances occurred from cyclical movements in underlying variables, whereas most productivity studies have carefully avoided the periods of troughs by choosing peak years.

The second problem concerns sectoral availability of data. Because of the limitation of the lack of sufficiently disaggregated sectoral capital stock data, TFP can only be calculated for broad industrial sectors even if other data are available from the OECD STAN database at ISIC 3 to 4 digit level for manufacturing.

The third is the potential errors accompanying the lack of sufficient information on underlying variables in the model. Since technical change is accompanied by emerging new products and quality change in existing products, it is desirable to use a more appropriate measurement for the volume of products and prices (e.g. hedonic price indexes). Similarly, given the increasing importance of service sectors, appropriate measurement for services production is a serious statistical issue and is expected to significantly change the TFP index of this sector. As Griliches (1994) recently argues, however, the current status of services statistics still leave this sector largely "unmeasurable".

Other problems arise from the accounting of primary inputs. For labour inputs, employment data should be adjusted by hours worked data to reflect precisely the volume of flows of labour services into production. More detailed data on capital services inputs can relax the proportionality assumption between the volume of capital stock and the flows of capital services. Moreover, because of the high degree of heterogeneity, these inputs should be ideally disaggregated by type (sex, occupations, education attainment for labour, and for capital, machinery, land, structures, etc.) in order to reflect different marginal productivity for each category.

Besides the shortcomings in data use, the current TFP formulation has also some theoretical shortcomings. First, TFP indicators do not exactly correspond to technical change if competition does not prevail in both product and factor markets. This is also true in a more realistic setting where various externalities and regulations affect production activities. Moreover, TFP indicators are likely to lump together other factors of technical change which might be better to be separated from pure technical change -- economies of scale, economies of scope, change in work organisation etc. In particular, the effect of economies of scale is likely to be a major part of productivity growth in the capital-intensive industries. In practice the distinction between economies of scale and pure technical change is difficult, but theory suggests the possibility to empirically estimate the contribution of economies of scale to productivity growth.

Finally the growth accounting model is static by its nature, failing to capturing the dynamic features of capital accumulation. To incorporate dynamic elements into the basic model, some have used the Marshallian distinction between short-and long-run and introduced capital as a quasi-fixed factor. In this setting, productivity can be negative during the process of medium-run adjustment, but it may increase in a new long-run equilibrium, through establishing a more efficient long-run average cost curve. Such dynamics can be especially important in the period of economic shocks and careful investigation is necessary to interpret the movements of TFP growth in the transitive periods.

Macroeconomic level analysis

Table 1 reports the growth accounting results for the aggregate private business sector during the 1970s and 1980s for 10 OECD countries. The first panel of the table exhibits Divisia aggregates which were consistently constructed from sectoral production accounts and the second panel presents an aggregate production account based on GDP, labour and capital at the macroeconomic level.[3] While the former takes into account a sectoral production function whose parameters such as marginal productivities and the elasticity of substitution can differ between sectors, the latter is built on an aggregate production function which takes into account neither sectoral differences in production parameters nor changing profiles of sectoral production, employment and capital over time.

The differences between the two aggregates can be then interpreted as the distributional effects of value added, labour and capital among sectors. These effects will be large when production functions are different among sectors and when the economy is undergoing a drastic change in industrial structure. By combining data from the aggregate production account and sectoral production accounts, the rate of aggregate productivity growth is then expressed as the Divisia weighted sum of rates of sectoral productivity growth and terms corresponding to the effects of redistribution of value added, labour and capital input among sectors whose production functions are not identical.

Alternatively, the Divisia index of technical change can be understood as being equal to the aggregate productivity growth plus these redistributional effects. The bulk of the productivity literature (for example, Jorgenson (1980), Syrquin (1984), Chenery *et al* (1986), Kuroda and Shimpo (1991) and Wolff (1994)) has carefully treated this structural effect on the aggregate productivity growth since this component can change the aggregate productivity growth even if the sectoral rates of productivity growth remain unchanged in a given time period, implying that measures of productivity growth estimated from aggregate data might be a misleading indicator of technical change. In what follows, we first focus on the sectoral aggregates and then evaluate the impact of resource reallocation on aggregate TFP growth.

TFP growth trends across the countries

Despite the data limitation noted above, TFP growth rates are shown to play a significant role in medium-term economic performance in most countries. As usual, the growth of aggregate GDP (measured at factor cost price) can be broken down into two parts: the contribution of growth in labour and capital inputs; and TFP growth i.e., the increased efficiency in production per unit of aggregate input. Roughly, the simple average of 10 OECD countries of the Divisia aggregates shows that 42% of average GDP growth during the 1970s and 1980s is explained by TFP growth, 37% by capital input and 21% by labour input.

The size of the contribution of the individual components is significantly different across countries as GDP growth varies, ranging from 1.8% in Denmark (1972-90) to 4.4% in Japan (1970-90). The long-term average figures show that the contribution of TFP explains more than 60% of GDP growth in the Netherlands, Denmark, the United Kingdom, France and Italy, around 30 to 40% in Germany and Japan, and only 10 to 30% in Australia, Canada and the United States. For this last group, the contribution of labour is the highest among the countries (more than 40%), reflecting the higher growth of their labour supply. For the other seven countries, the labour contribution is negative in the Netherlands and Denmark, while it explains around 10 to 20% of GDP growth in Italy, France, Germany and Japan.

The contribution of capital is highest in Japan and Germany (50% and 43% respectively); in the United States, Canada and Australia it exceeds the TFP contribution. In short, TFP growth is the largest source of GDP growth in most European countries except for Germany, accounting for more than 60% of their economic growth over the 1970s and 1980s, while in the United States, Canada and Australia, labour contribution accounted for 40-50% of their GDP growth and for Japan and to lesser extent for Germany, capital accumulation is the most important factor behind economic growth.

Although these growth accounting results are strongly influenced by cyclical fluctuations, it is interesting to see the changing importance of each source of growth over time. First, the labour contribution does not show any clear upwards or downwards tendency over time. Cyclical factors also affect capital input, but it has a declining importance for GDP growth in every country. TFP growth however can be seen to recover in the 1980s in most countries and the results do not show any evidence for a continuing deceleration of productivity growth over the 1970s and 1980s.

As mentioned above, aggregate TFP growth can be affected not only by changes in sectoral TFP growth but also by the changing profiles of sectoral GDP, labour, and capital. More precisely, the aggregate TFP growth rate is equal to the Divisia aggregate of sectoral TFP growth rate plus the resource reallocation effects. Although the growth accounting procedure in this paper is constructed rather under static assumptions, it can generate approximate estimates of such dynamic reallocational effects on aggregate productivity growth (the last panel of Table 1).

Resource reallocation effects

Each term of the resource reallocation effect corresponds to differences between rates of growth of aggregate GDP, labour input, and capital input and weighted averages of GDP, labour input and capital input in all sectors (Jorgenson (1980), Fraumeni and Jorgenson (1981) and Kuroda and Shimpo (1991)). These terms represent the contribution to aggregate TFP growth of GDP, labour input and capital input redistribution among sectors. If GDP deflators or prices of primary inputs are identical across sectors or if the volume of GDP, labour and capital grow at the same rate across sectors, the redistribution terms vanish and aggregate and weighted average of sectoral TFP growth rates become identical. Negative values indicate that redistributional effects had an unfavourable impact on aggregate TFP growth.

However, this can alternatively be interpreted as showing the positive impact on the weighted average of sectoral TFP growth of an increased share of high value added sectors, or of increased efficiency of primary factor use in the sense that labour and capital flowed into sectors with lower wages and capital prices. Conversely, the positive values in these terms indicate that structural change tended to increase macroeconomic TFP growth but alternatively to decrease "true" measures of GDP, or to increase those of labour and capital inputs through increased low-value added sectors or increased inefficiency in the use of labour and capital among sectors.

The results in Table 1 show that on average over the 1970s and 1980s, the redistribution of GDP, labour and capital among sectors enhanced the macroeconomic productivity growth in most countries except for three: Canada, the United Kingdom, and the United States. In France, sectoral shifts in labour had an increasing positive impact on aggregate productivity growth, accounting over 1972-1990 for around 30% of its TFP growth. The positive allocational effect of labour was also strong in Japan increasing by 20% of its TFP aggregate growth. For Germany and Denmark, structural change in value added among sectors was the largest part of the effect, accounting for 18% and 15% of aggregate TFP growth respectively. In Australia, the reallocation effect of capital inputs increased aggregate TFP growth by 14%.

In the cases of Canada, the United States and the United Kingdom, the resource allocation effect has worked to decrease aggregate productivity performance over time. In the alternative interpretation discussed above, this in effect implies that resource reallocation worked efficiently in these countries. It accounted for about 31% of aggregate TFP growth in Canada, 17% in the United States and 10% in the

United Kingdom and the major contributor was improved distribution of labour input among sectors. It was also accompanied by increasing high-value added sectors (the US) or increasing efficiency in capital input use (UK). In terms of productivity performance, this evidence supports the relatively efficient factor markets in these countries. In the Netherlands, the distributional effect was almost neutral, while efficient reallocation of capital had a sizeable effect.

Although a precise evaluation is not possible with static analysis, the above arguments may shed light on an important offsetting impact of resource reallocation on aggregate productivity growth. The impact is relatively large and the five countries where it was positive, it accounted for around 14 to 30% of their TFP growth. In contrast, in Canada, the United States and the United Kingdom where factor markets are relatively flexible, the reallocation effect showed a sizeable negative impact on aggregate productivity growth, lowering aggregate TFP growth rate as compared to the sectoral average rate of technical change. Although it is generally believed that increasing high-value added sectors lead to higher economic growth, the measured size of this effect on productivity is unclear and actually not so large even in the United States.

Labour productivity and TFP growth

An alternative form of growth accounting is the growth decomposition of labour productivity among TFP growth and capital intensity growth (Table 2). Although the productivity slowdown was unclear in terms of TFP growth rates, this partial productivity index -- real value added growth less total employment growth -- revealed more clearly a continuing decline in productivity growth over time in all the countries except for the United States.

The decomposition of labour productivity growth suggests that the diverging trend between TFP and labour productivity growth during the 1970s and 1980s can be traced by the declining role of capital intensity growth: for most countries the TFP contribution is increasing between two decades at the same time as there is a decreasing importance of capital intensity contribution due to the slowdown in the speed of capital accumulation. In short, most of the labour productivity slowdown can be attributed to the slowdown in capital growth and not by TFP decline.

The unweighted average of 10 OECD countries showed that the TFP contribution is around 60% of labour productivity growth; only Japan had a constantly lower ratio over time than the average because of higher capital growth. In general, high-capital growing countries exhibit higher growth of output and employment (notably Japan, Australia, Canada and to a lesser extent the United States). In contrast, slower labour productivity growth, but high TFP growth, coincided with low growth of output, labour and capital in European countries.

Sectoral level analysis

In contrast to the growth accounting based on value added at the macroeconomic level, the growth accounting procedure at the sectoral level uses gross output as the production index and takes into account the contribution of intermediate inputs which were separated into domestic and imported inputs.

Manufacturing versus services

Table 3 shows the sectoral growth accounting results for the 1970s and 1980s for the total business sector, as well as for manufacturing and services separately (including public utilities and construction), as weighted average of sectoral results, with the weights being gross output shares. Although both gross output growth and TFP growth for the total private business sector recovered slightly between the 1970s and 1980s in five out of eight countries for which comparisons over time can be made, the trends of output and TFP growth differ between manufacturing and services.

During the 1970s, manufacturing exhibited slower growth than services in all countries except for the Netherlands. The growth difference between the two sectors was particularly pronounced in the United States where output growth in services was four times higher than that in manufacturing. However, the contribution of TFP growth was negative in both sectors of this country. For other countries, TFP growth explained 25% of manufacturing output growth in the Netherlands, 27% in Japan, 20% in France, 15% in Canada, 20% in the United Kingdom and 8% in Australia.

The contribution of intermediate inputs has played a predominant role to manufacturing output growth. While the impact is generally smaller than that of domestic sources across the countries, the contribution of imported intermediate inputs exceeded that of domestic ones in the Netherlands and the UK and was also relatively high in France and Canada. For primary inputs, the contribution of labour inputs was slightly negative in most countries except for the United States and Canada. Capital input growth explains more evenly around 10-20% of manufacturing output growth across the countries except for the United States where it explains 50%.

In the services, TFP declined in the United States during the 1970s, while it accounted for a large portion of the output growth in Denmark and the Netherlands and to a lesser extent for other countries. Compared with manufacturing, the contribution of intermediate inputs was smaller and accounted for 30-70% of output growth, reflecting the lesser dependency of services on intermediate inputs. Except for Denmark and the Netherlands, the contribution of imported intermediate inputs was the least important among factors. In general, the contribution of primary inputs is the most important source of the services output growth -- on average both together accounted for around half of the production growth. The contribution of labour and capital inputs are almost even in the United Kingdom and the contribution of labour input was significantly higher in the United States, Canada and Australia, while the contribution of capital input was significantly higher in Japan, the Netherlands and Denmark.

During the 1980s, three countries -- the US, the UK and Japan -- attained a higher growth in manufacturing output than in the 1970s. Nevertheless, average manufacturing TFP growth went up in six of the eight countries for which a comparison is possible (the exceptions are Japan and the Netherlands) so that the unweighted average of manufacturing TFP growth across the countries in the 1980s was twice a higher in the 1980s than that in the 1970s. TFP recovery was especially large in the United States and the United Kingdom. As a result, the contribution of TFP has increased in most countries and on average explained around a third of manufacturing output growth.

For other sources of growth, the contribution of intermediate inputs (both domestic and imported) weakened for most countries. Although no clear difference is observed between the two decades, the contribution of labour input rose in the United States and Japan while the labour saving tendency increased in France and in the UK. The contribution of capital inputs has continuously decreased in most countries except for Japan.

In short, output and TFP growth showed different movements between manufacturing and services during the 1970s and 1980s. For manufacturing, average output growth across the countries slowed between the two decades but TFP growth seems to have recovered in the 1980s. For the services, on the other hand, output growth accelerated in the 1980s but productivity growth declined: only the United States and Japan showed a clear recovery of productivity growth of this sector. Regarding other factors of growth, the importance of intermediate inputs declined slightly in manufacturing but increased in services.

A more important difference between manufacturing and services is in labour input: its contribution was almost negligible in manufacturing, but explained a large part of services output growth. For capital input, however, a slightly decreasing role in output growth was observed across the two sectors in most countries. These observations suggest that the disaggregation between manufacturing and services is important for productivity analysis.

ICT cluster and TFP growth

Table 4 presents the ranking of the ten industries with the fastest TFP growth over the 1970s and 1980s for each of the nine countries included in the study. The list of sectoral ranking in terms of productivity performance reveals the importance of information and community technology (ICT) as well as sectoral specificities in each country.[4] The definition of ICT industries varies among existing studies, but it usually covers both manufacturing and services industries such as computer and office equipment, communication equipment and semiconductors, instruments, communication, finance & insurance, business services, etc. (Freeman and Soete (1994)).

As expected, most of industries classified in the ICT cluster are ranked in the top ten in terms of TFP growth in every country. In particular, the communication sector is ranked in the top three in four countries and when the transport and communication sector is also included, this sector is listed in the top five in every country except the United Kingdom. Similarly, the electrical machinery sector which includes the communication equipment and semiconductors, is listed in the top three in five countries -- Japan, France, the United Kingdom, Canada and the Netherlands and in the fifth or sixth for the United States, Germany and Denmark (for Japan this sector also includes the computer and office equipment).

The general machinery sector which includes computers and office equipment is ranked as the second highest TFP growth sector in the US and Canada, while the rank is lower in France, the UK and Japan. Instruments are also ranked in the top and in second place respectively in the US and Japan and appears in fifth place in Germany where computers and office equipment are also included in this sector. Similarly, the real estate and business services sector is ranked first in Canada and fourth in the Netherlands, while the finance and insurance is ranked sixth for Germany and as the finance, insurance, real estate and business services sector (FIRB) it is also listed in the UK. In general, productivity performance in these ICT services is much lower than those in both communication and ICT manufacturers in every country.

For other clusters of industries, it might seem surprising that the primary sector (agriculture, forestry and fishing and mining) appears frequently in the top ten ranking in every country except for Japan. It is hard to know whether this is a real phenomenon or simply due to measurement errors. Natural resource endowments may explain a part of it but productivity performance in these sectors can be too volatile to explain, due to drastic changes in exogenous factors (sudden resource discovery, weather, price changes, etc). Another interesting result is that conventional manufacturing industries such as scale-intensive or low technology manufacturing -- basic metals, paper & pulp, ceramics, chemicals, fabricated metals, textiles, wood, rubber & plastic and other manufacturing -- are also frequently listed in this top ten ranking.

Since the TFP series do not exclude the effect of scale economies, some part of the TFP performance in heavy industries might be attributed to this effect. The productivity performance of light manufacturing industries such as textiles could be explained by downsizing or competition pressures from developing countries. In addition, traditional services sectors such as the wholesale and retail trade (in the US, Japan, Germany, and Denmark), the community, social and personal services (CSPS) sector (France, Canada, Australia) or the utilities (Australia and France) are listed in the top ten. Again, it is difficult to give *a* *priori* explanations for this, but country-specific factors such as changes in regulatory conditions, the introduction of efficient distribution system or power plant could hold part of the answer.

3. TFP growth and R&D : regression analysis

Many factors can explain changes in total factor productivity: product and process innovations, research and development, scale economies, demographic change, change in quality of capital and labour inputs, changes in the organisation of work, technological catch-up factors such as the introduction and imitation of advanced foreign technologies or know-how, etc. (Englander and Gurney (1994a) give a comprehensive survey of the importance of these factors for productivity). This paper focuses on the role of R&D and of technology diffusion among industries in explaining productivity growth. Technology diffusion is taken to be captured by the R&D embodied in production inputs (intermediate and investment goods) purchased domestically or from abroad.

Firms carry out R&D in order to design new products which will provide more value per unit of resources used, or new processes which will reduce the resource requirements of existing products (Griliches and Lichtenberg (1984)). To the extent that TFP measures are appropriate indicators of growth in technological potential, R&D activities may contribute to expanding or shifting the production possibilities frontier in R&D-conducting firms. At the same time, some firms and industries are less R&D intensive but obtain large productivity benefits simply by purchasing technologically sophisticated inputs or capital goods into their production process (i.e., embodied R&D).

By combining TFP growth rates with R&D and embodied R&D variables, this section tries to infer the contribution of R&D expenditures and or embodied R&D for productivity growth at the industry level within the limits imposed by our data. We first present the basic model and then discuss the regression results using various variants of the model and possible combinations of the data.

The model

The model used for the estimation of the relationship between TFP growth and R&D is built on the popular production function approach where R&D is incorporated as one of the production factors as used in many preceding studies. To formulate this relationship, we use the following extended Cobb-Douglas function[5]:

$$X = A e^{\lambda t} K_R^{\gamma} K^{\alpha_K} L^{\alpha_L} M^{\alpha_M} \qquad (1)$$

where X is real gross output, a function of intermediate inputs M, capital K, labour L, and stock of research and development R. λ is an index of technological change unrelated to research and development (a proxy of the rate of change in disembodied technology), A is a constant. α_i (i=K, L, M) are the output elasticities with respect to inputs, K, L and M and constant returns to scale among these three inputs ($\alpha_K+\alpha_L+\alpha_M = 1$) are assumed. γ indicates the output elasticity of R&D stock.

Since the direct estimation of the above production function needs R&D stock data, we adopt the following indirect approach to avoid the difficulties in constructing consistent R&D stock data across the countries. Dividing both sides of the above equation by $K^{\alpha_K} L^{\alpha_L} M^{\alpha_M}$, the level of total factor productivity is defined as follows.

$$TFP \;=\; \frac{X}{K^{\alpha_K} L^{\alpha_L} M^{\alpha_M}} \;=\; AK_R^{\gamma}\, e^{\lambda t} \qquad (2)$$

Differentiating logarithmically (2) with respect to time and using the definition of the output elasticity of R&D stock, γ, we obtain:

where R is *net* R&D investment expenditures and ρ is the marginal productivity of R&D capital stock, or simply the rate of return of R&D expenditures.

$$\frac{\dot{TFP}}{TFP} \;=\; \lambda \;+\; \left(\frac{\partial X}{\partial K_R}\cdot\frac{K_R}{X}\right)\frac{\dot{K}_R}{K_R} \;=\; \lambda \;+\; \left(\frac{\partial X}{\partial K_R}\right)\frac{\dot{K}_R}{X} \;\equiv\; \lambda \;+\; \rho\,\frac{R}{X} \qquad (3)$$

Equation (3) is the basic theoretical model in which the TFP growth rate can be expressed as a function of the R&D intensity of an industry. Assuming that the rate of depreciation of the R&D stock is negligibly small, the net R&D intensity in the equation can be replaced by the *gross* R&D intensity which is the only currently available data. The impact of R&D on productivity growth is then estimated by the coefficient ρ given data on TFP growth and R&D intensity. Since our interest lies not only in the impact of performed R&D but also on that of embodied R&D acquired from the purchase of domestic and imported intermediate products, domestic and imported capital goods, we use the following extended model to answer how and to what extent embodied R&D from other industries or from abroad can affect productivity in the user industries:

$$\frac{\dot{TFP}}{TFP} \;=\; \lambda \;+\; \rho_1\frac{R}{X} \;+\; \rho_2\frac{TINT^d}{X} \;+\; \rho_3\frac{TINV^d}{X} \;+\; \rho_4\frac{TINT^m}{X} \;+\; \rho_5\frac{TINV^m}{X} \qquad (4)$$

where $TINT^d$ is embodied R&D in the purchased domestic intermediate inputs, $TINV^d$ is embodied R&D in the purchased domestic investment goods, $TINT^m$ is embodied R&D in the purchased intermediate inputs, and $TINV^m$ is embodied R&D in the purchased imported investment goods. These four embodied R&D variables were developed in the previous study cited in the introduction (Papaconstantinou et al., 1995; see also Annex 1 for the derivation of the embodied R&D variables).[6]

For the empirical implementation of the model, several considerations had to be taken into account in order to design better statistical experiments within the limits imposed by our data. First, our preliminary correlation analysis revealed a strong multicolinearlity among explanatory variables, particularly between the direct R&D intensity and the embodied R&D intensity in intermediate inputs. As long as reliable econometric methods are not available to solve this problem, some of the explanatory variables in equation (4) had to be aggregated in advance by assuming the same coefficients among variables concerned.

From the theoretical point of view, the following alternative specifications were considered to reconcile the multicolinearity problems :

- R&D or total R&D intensity (sum of all R&D variables)
- R&D and/or total acquired R&D
- R&D and/or the acquired R&D embodied in intermediate inputs and the acquired R&D embodied in investment goods
- Domestic R&D (direct R&D plus domestically acquired R&D) and imported R&D

Note that the R&D data used were only available for manufacturing industries; for services sectors the relevant data are the above four acquired R&D variables only.

The first variant of the model roughly estimates the rate of return of total R&D-related expenditures (direct R&D and embodied R&D). The second model estimates separately the return on direct R&D and that on acquired R&D under the assumption of equal coefficients for different types of acquired R&D. The third in addition distinguishes separately the impact of R&D embodied in intermediate goods as distinct from the R&D embodied in investment goods, irrespective of whether the goods were domestically produced or imported. The fourth, a specification similar to that used in Coe and Helpman (1994), distinguishes different rate of returns for domestically available R&D and R&D inputs obtained through imports, assuming the same R&D coefficients between intermediate and capital inputs and between direct R&D and domestically acquired R&D.

Another issue concerns data handling. In general, TFP and R&D data have three dimensions (periods, countries, and industries). Each dimension has its own shortcomings: a) complete time-series data are not available -- three or four time periods for each country; b) the number of countries to be covered is only 10; c) the sectoral disaggregation is limited for at most 24 sectors with a somewhat different aggregation scheme across countries. Given these limitations on our data, underlying data have been adjusted to build models with cross-country time-series pooled data with sufficiently large samples.

For the sample period, periodical data have been separated into two sub-periods for each country -- the 1970s and 1980s, as we have interested in the possibility of structural change in the R&D and productivity relationship between the two decades. Although this reduces the sample size, this averaging procedure is practically useful in order to avoid the unfavourable impacts of cyclical fluctuation on TFP growth rates in the regression. TFP growth rates in each sub-period were simply averaged in terms of annual rates and periodical average of R&D variables were estimated by weighting the R&D intensity in each time point with as weights the number of years in each sub-period. In this sense, we do not explicitly take into account the time-lags of R&D on productivity growth.

Another adjustment was done for the industrial classification and data were organised in two different classifications. The first grouped industries largely into manufacturing and services sectors assuming the same R&D coefficient (marginal productivity) within the group and across the countries (agriculture and mining were excluded in this model and the services sector was defined to also include electricity, gas and water and construction). This distinction can be legitimate because direct R&D intensity is available only for manufacturing.

Moreover, in order to investigate the R&D impact at a more disaggregated sectoral level, the second model distinguishes the following seven industrial groups: a primary sector, a light-manufacturing sector (food, textiles, other manufacturing sector), a heavy-manufacturing sector (pulp and paper, chemicals, non-metallic mineral products, basic metals), a machinery sector (fabricated metal, general machinery, electrical machinery, transport equipment and instruments), utilities and construction, an ICT services sector (transport and communication, finance, insurance and real estate and business services sector) and another services sector (trade and CSPS).

Further breakdown of industries is not practically possible because different aggregation schemes are used for several countries in our database (for example computer and office equipment is included in general machinery in the United States, but in electrical machinery in Japan). However, this second model mitigates the restricted assumption on R&D coefficients in the first model by allowing different marginal productivities of R&D stock across individual seven industrial group, while we still have to assume the same coefficients across industries within each group and across the countries.

Pooled data were thus constructed for manufacturing and services or for seven industrial groups separately for the 1970s and the 1980s across the 10 OECD countries. Combining these data into one regression allows us to estimate country averages of each R&D coefficient separately for the 1970s and the 1980s for manufacturing, services, or separately for each of the seven industrial groups. For example, when the explanatory variables are aggregated into direct R&D (R) and total acquired R&D (RACQ) and seven industrial groups are distinguished, the regression model can be specified as follows:

where suffix t refers the 1970s or 1980s, i for countries (1,...10), j for each group of industries, k for industries in each group j (k=1,...N_{ij}), a^t_i is the country-specific constant for each period, β^t_j and δ^t_j are the rate of return of R&D and of acquired R&D embodied in purchased products respectively and ε^t_{ijk} is a stochastic error term. Country specific time dummies are introduced in order to allow for country-specific effects in each time-period not attributable to R&D and embodied R&D performance. All the models were estimated by the ordinary least squares (OLS) method.

$$\left(\frac{T\dot{F}P}{TFP}\right)^t_{ijk} = \alpha^t_i + \beta^t_j\left(\frac{R}{X}\right)^t_{ijk} + \delta^t_j\left(\frac{RACQ}{X}\right)^t_{ijk} + \varepsilon^t_{ijk} \quad (5)$$

Regression Results

As several authors have observed from cross-country and time-series data (Englander and Gurney (1994a) and Coe and Helpman (1993)), direct R&D and/or embodied R&D are likely to be positively correlated to aggregate productivity growth across countries (see Graph 1). By applying statistical models introduced in the previous section to actual data, this section analyses more closely the relationships by distinguishing different industrial groupings and types of R&D variables separately for the 1970s and 1980s.

Manufacturing vs. services

Table 5 and 6 present the estimation results separately for manufacturing and services. Since internationally comparable data on R&D expenditures in the services are not currently available, the regression for this sector was conducted only by using data on embodied R&D. The first panel in each table reports the unweighted OLS results and the second reports weighted OLS results with weights of average sectoral shares of gross output during the period concerned. While the former estimate the average R&D impact irrespective of the size of production by sector, the latter model takes that into account in the regression and produces R&D coefficients which are close to those for aggregate manufacturing and services. A major reason to use the weighted regression is that the underlying sectoral classification in our data is somewhat different across countries so that the weighted regression is expected to absorb the impact of such heterogeneous samples across countries (for example, the communication sector which leads in terms of TFP growth is separated out in some countries but not in others).

For manufacturing, both regressions indicate that only direct R&D plays a role in explaining TFP growth. The statistical fit does not in fact improve at all after inserting embodied R&D variables and in regressions with the direct R&D variable embodied R&D variables become insignificant (Eq. (4) to (6)). The estimated 10 country average of the rate of return of direct R&D (equation (1) in Table 5) is about 0.15, i.e., 15% and is almost similar for the 1970s and 1980s. Although similar studies for manufacturing sector by Terleckyj (1982), Griliches and Lichtenberg (1984) and Scherer (1982) have found that the coefficients of the embodied R&D intensity are much larger than those of own R&D intensity, our cross-country results do not significantly support their finding for this sector.

Services tend to be neglected in most similar studies; in this paper, the weighted and unweighted regression show quite striking results for this sector. In the unweighted regressions, embodied R&D variables are quite significant and the rate of return of acquired R&D is very high in both periods and even increasing in the 1980s: 130% in the 1970s and 190% in the 1980s. The contribution of embodied R&D in purchased capital equipment is found to be a major source of the indirect productivity in services sector (Eq. (3) and (4)). Moreover, equation (4) states that foreign R&D has a higher rate of return in the services sector than domestically acquired technology.

This means that international R&D spillovers have been particularly important for productivity gains in the services and the international procurement of R&D-intensive products has led to larger productivity gains than that of domestic procurement. In the weighted regressions, no significant correlation was found except for the embodied R&D in purchased capital equipment (RTC) in the 1980s. The different results between the two regressions can be due to the fact that the weighed regression gives less importance to highly-productive and R&D-intensive services sectors like communication and real estate and business services sector which have relatively small output shares.

Although the above regressions a priori assume that the same coefficients can hold across countries, it is of considerable interest to see whether the rate of return of R&D or embodied R&D reveals significant difference across countries. To check this, a variant of unweighted regression (2) was run by allowing different coefficients of the explanatory variables. Figure 2 and 3 show the estimated rates of return of R&D and embodied R&D variables for manufacturing and services, respectively.[7]

First, the rate of return of R&D for manufacturing revealed a large diversity across countries as well as between periods. In the 1970s, the payoffs to R&D investment was highest in Japan (40%) and Canada, while the Netherlands and the United Kingdom also had a rate of return exceeding 20%. In contrast, the rate of return was only 8% in the United States and was almost trivial in Denmark and Italy (whose coefficients are statistically insignificant). In the 1980s, however, the R&D return exhibited a significant improvement in the United States, Italy and to some extent in Canada. In contrast, it decreased in Japan, France, the United Kingdom and the Netherlands. As a result, Italy and Canada stood as most highly R&D productive countries in the 1980s, while R&D potency was almost equalised between the United States and Japan at around 20%. For European countries except for Italy, it fell to about half of that in the United States and Japan.

For the services, the estimated coefficients of embodied R&D are mostly statistically insignificant except for those of France, Canada, the United States (1970s) and the United Kingdom (1980s). Yet, the results suggest that productivity gains through diffusion of technologies were realised by only a few countries: France, the United Kingdom and Canada. For Japan and the Netherlands, embodied R&D variable is even negatively correlated with TFP growth in this sector. Moreover, countries with higher R&D potency in manufacturing are not always those with higher potency in embodied R&D. For example, while high R&D potency in manufacturing can be observed in Japan and the Netherlands, embodied R&D is almost irrelevant for productivity growth in the services.

In contrast, although manufacturing R&D potency is rather low and even decreased in the 1980s in France and the United Kingdom, embodied R&D potency in services sector were relatively high in these countries and increased in the 1980s. Though not clearly traced, the apparent contradiction between manufacturing and services R&D potency might be attributed to some extent to the effects of international R&D spillovers -- increasing dependency on R&D intensive products from abroad.

Regressions across seven industrial groups

The regressions for manufacturing and services sector can be further refined by breaking down each broad sector into sub-groups and pooling them across the countries in order to assure big enough samples in regressions (see Equation (5) in Page 14). Given the fact that the level of R&D intensities, TFP growth rates and the flows of technology are not similar across industries, different rates of return among R&D variables can be expected in these industry groups.

Table 7 summarises the results of three types of cross-country regressions based on this model, each assuming different coefficients among industrial groups and between the two periods. Though not listed in this table, all the regressions include county-specific dummies for each period and the unweighted OLS estimation was employed. In addition to measuring separately the impact of direct R&D and of embodied R&D variables in every regression, Regression 2 separates embodied R&D by source of origin (domestic or imported products) and Regression 3 distinguishes it by types of products (intermediate and investment goods).

As expected, the regressions exhibit a varied picture of the importance of R&D and its diffusion variables on productivity growth in the seven industrial groups concerned. Within manufacturing, direct R&D coefficients are only significantly positive for the machinery group and even negative signs appear for other two groups though none of them are significant. This indicates that the positive coefficient obtained in the previous regression for manufacturing as a whole is mainly due to this machinery group. The estimated rate of return of R&D for this group is around 0.19 to 0.27 which is slightly higher than the average rate of return for manufacturing sector as a whole in Table 5, and every regression revealed a slightly decreasing potency of R&D over time.

However, for other manufacturing groups, some recovery of R&D potency can be found in the 1980s, though none of their coefficients are statistically significant. Regarding the impact of embodied R&D, regression 1 shows a positive correlation in the light and heavy manufacturing, but the results for other regressions do not allow a clear interpretation on the importance of the sub-factors. The estimated rate of return of embodied R&D however exceed 60% in these groups. Unexpectedly, however, the embodied R&D impact for the machinery sector is estimated to be negative and insignificant in both regressions. This might suggest that productivity gains in the industries in this group depend exclusively on their own R&D efforts.

Embodied R&D plays a significant role in productivity growth in the services and especially in the ICT segment of services, reflecting the large flows of R&D through the investment for R&D-intensive products. Embodied R&D coefficients are significantly positive in the ICT services group for both domestic and imported R&D. The estimated rate of return for total embodied R&D is around 140% and it is slightly increasing in the 1980s. Moreover, the rate of return is higher in imported R&D than in domestically sourced R&D in both periods, though its return tends to have decreased in the last decade.

The result in Regression 3 confirms that the most part of this embodied R&D impact comes from capital investment by the ICT services sectors for R&D-intensive products such as computers and airplanes. For other services groups, the embodied R&D variable does not show any significance, in spite of apparent large flows of manufacturing R&D into these groups through input purchases. In addition to serious measurement errors in service sector TFP, this might suggest that other factors behind slower productivity growth such as regulations and lack of best practice in their work organisation using high-tech products are more important as barriers to realising the productivity potential of new technologies.

By and large, the following picture emerges on the relationship between diffusion of technologies and productivity growth. Productivity gains from R&D and its diffusion were reaped at least until the last decade in very localised industrial groups: the machinery sector and ICT services or perhaps in other words the ICT cluster. Because of the technological closeness among these sectors relative to other clusters of industries, new technologies developed by ICT manufacturers through their own R&D efforts were easily transferred into ICT services industries and enhanced their productivity growth.

In contrast, positive impacts of diffusion of new technologies were not realised in other clusters because technological distance, regulations and long lags to optimally organise new technologies in their production system hampered to do it. Hence, these results support ideas of unbalanced development in technology and productivity growth across sectors in economy which was likely to be amplified by rapid development in ICT technologies during the period in question.

Impact on productivity growth in machinery and in the ICT services

Meanwhile, it is interesting to see how much R&D or R&D diffusion have contributed to actual TFP growth in a specific sector. On the basis of the regression results above, this can be roughly estimated by multiplying the estimated coefficients for individual groups with weighted averages of R&D intensities in each group, using gross output shares as weights. Since the level of R&D variables is different across countries, the impacts of R&D on TFP growth can also differ even though common estimated parameters were used for each country. Given that significant results were only obtained for machinery sector and ICT services, the impact analysis was carried out for these sectors only by using the results of regression 2 above (see Figure 4 and 5).

First, unweighted average TFP growth across the countries in the machinery sector increased during the last two decades from 0.82% in the 1970s to 0.97% in the 1980s, though the performance considerably differed across countries and between the two periods. Figure 4 suggests that the contribution of direct R&D was rather stable in each country in the two periods and if anything a slightly increasing impact can be observed over time in the United States, Japan, France, and Canada. Since the estimated rate of return in Regression 2 shows a small decrease in the 1980s, the rising or stable impact of direct R&D over time is explained by an increase in direct R&D intensities for the machinery sector in the 1980s.

Although assuming a common rate of return of R&D across the countries is disputable, Figure 4 generally confirms a strong positive impact of R&D on TFP growth in the machinery group for every country even though actual TFP performance was poor. In particular, the United States and the United Kingdom revealed a more than 1 percentage point contribution of R&D on productivity growth in the 1970s and for the United States, the contribution rose to 1.4 percentage points in the 1980s. The contribution of R&D was also high in France and the Netherlands for both periods contributing relatively higher growth of their TFP. However, for other five countries the R&D impact was below the cross-country average of 0.7 percentage points in the 1970s and except for Germany and Japan their impact remained low in the 1980s (the German 1970s result is not available due to lack of input-output data).

Although an explanation of this is beyond the scope of the paper, the contribution of estimated country specific constants and other effects included in the residuals of regressions was also important for TFP growth in the machinery sector. Since the country-specific constant in our regression is assumed to be the same across industries in a country, the size of this effect is the same in Figure 4 and Figure 5. For each country, this value corresponds to the intercept when R&D intensities were zero and it is interpreted as the average effects across industrial groups such as disembodied technical change, scale economies, qualitative improvement of capital and labour, catch-up factors, uneliminated business cycle effects, or even measurement errors of TFP and so on, which are unrelated to R&D activities.

On the other hand, other effects or the residuals of the regression also include these non-R&D effects on TFP but it specifies the average deviation within an industry group from the estimated equation. The estimated country specific constant and impact of residuals were very unstable over time which probably makes an interpretation as disembodied technical change difficult. Since these two factors play a dominant role in TFP growth in some countries and in some periods, a more complete model will be needed for the purpose of explaining TFP growth itself.

For the ICT services sector, in turn, the impact of embodied R&D can be traced separately by source of origin: domestic R&D and imported R&D (Figure 5). Although actual TFP growth in this group as a whole was lower than that in the machinery sector (an unweighted average across the countries 0.5 percentage points in the 1970s and 0.3 in the 1980s), embodied R&D had a significant contribution for raising productivity potential in this group. In particular, while R&D obtained from the purchase of domestically produced goods was more important than imported R&D in the United States, Japan and to a lesser extent in Germany, imported R&D played a more significant role in other countries, in particular in smaller countries such as Denmark, Australia, the Netherlands, as well as in Canada. The absolute impact of domestic R&D is however highest in the United Kingdom (0.4 percentage points) for the 1970s which was 50% higher than that in the United States.

In general, compared with the significant inter-country differences in the level of imported R&D, the domestic R&D impact is more even across the countries (0.1 to 0.2 percentage points). Between the 1970s and 1980s, however, the impact of domestic R&D increased in every country except for the United Kingdom and France and it was particular reinforced in the United States, Japan and Germany (roughly 0.5 percentage points), reflecting perhaps increasing domestic linkages with ICT manufacturers in the procurement of advanced products. Meanwhile, the impact of imported R&D decreased in the 1980s in most countries except for the United Kingdom, Canada and the United States in spite of rapid growth of high-tech trade during the 1980s.

In summary, R&D investment and embodied R&D had a significantly positive impact on TFP growth in ICT industries. On average, R&D itself contributed 0.7 percentage points to machinery TFP growth; R&D performed in these industries was diffused across sectors raising productivity in other industries who bought R&D intensive products as inputs into their production process. Because ICT services have strong linkages with ICT manufacturers, the estimated impact of such indirect R&D for ICT services was 0.8 percentage points on average across the countries in both periods, of which 0.3 was from domestic producers and 0.5 from foreign producers. This improved productivity potential of the ICT services can be well considered as being due to the world-wide mechanism of technology diffusion .

4. Comparisons with other studies

The literature on R&D, R&D spillovers and productivity growth is large, fast expanding and varied in the exact approach followed or the questions addressed, with a number of literature reviews cover different aspects (Mohnen, 1990, 1994, Griliches 1992, Nadiri, 1993 are examples). Comparison of the results from the different studies is at best difficult, at worse misleading and meaningless. Studies differ on the data used, and on the methodology employed. Papers in this area that take into account both R&D and some measure of R&D spillovers can be distinguished on a number of dimensions: on whether they use firm-level, industry or aggregate data; on whether they examine intra-industry or inter-industry spillovers; on the kind of weighting scheme used in order to assess the importance of outside knowledge or R&D; on the use of production functions or of the dual cost functions in estimations, on whether they cover domestic effects only or international ones too, etc.

In one of the surveys of work in the area, Mohnen (1994) classifies work attempting to disentangle the effect of own and of "borrowed" R&D on productivity growth into a number of categories. The first measures the influence of R&D spillovers econometrically by treating spillovers as an unweighted sum of the R&D of all other firms or industries. Examples are Levin and Reiss (1984, 1989); Levin (1988); Bernstein (1988); and Bernstein and Nadiri (1989). The second measures the R&D spillover variable as a weighted sum of all external R&D. The papers using this approach can be further subdivided into four subgroups, according to the proximity measure used to construct the weights. Papers in the first subgroup use weights proportional to the flows of intermediate input purchases, as revealed by input-output transactions, as in the work of Terleckyj (1974); Griliches and Lichtenberg (1984); Bresnahan (1986); Goto and Suzuki (1989); and Wolff-Nadiri (1993).

The model of this paper uses a methodology that is close to this approach. The second subgroup uses patent flows, and Scherer, (1982a, 1982b, and 1984) is the best-known example of this approach; others are Schankerman (1979); Pakes and Schankerman (1984b); and Englander *et al.* (1988). The third subgroup focuses on the flows of innovations among firms and industries and includes Robson *et al.* (1988), while the fourth uses patent data and the concept of technological distance (Jaffe, 1988). A third approach adopts a framework in which each outside R&D is introduced directly and separately (e.g. Bernstein, 1989).

Compared with the many studies that already exist on the topic, the value-added of this paper is threefold. First, the use of an internationally consistent data set of R&D expenditures, input-output matrices and bilateral trade flows allows an analysis that covers 10 OECD countries. Most other studies have concentrated on individual countries. Secondly, the level of disaggregation of the data allow the examination of the impact of R&D and of technology diffusion on productivity growth separately for manufacturing and for services, as well as for different segments of each of these. Most other studies have either used aggregate data or when using firm-level or sectoral data have usually focused on the manufacturing sector only. Third, the methodology used allows the separation and contrast of two different channels of technology diffusion: that of R&D embodied in intermediate goods vs. R&D embodied in investment goods; and that of R&D embodied in domestic purchases vs. imported R&D. The international dimension is particularly important, given that most work on international spillovers has either used aggregate data or failed to distinguish between the effects on manufacturing and on services.

Despite the difficulties in comparing results from models with different data and methodologies, a number of stylised facts have emerged from the literature and it is against these that the results from this paper can be judged. First, this paper follows others using a wide range of data sets, methodologies and covering many different time periods to find significant rates of return on outside R&D (Table 8)[8], but does so only for the services sector, and in particular for the ICT segment of services. In many papers, outside or user R&D is often more significant in explaining manufacturing productivity growth than the R&D of the sector of origin (e.g. Scherer, 1984, Griliches and Lichtenberg, 1984, Englander, Evenson and Hanazaki, 1988). This is not the case for this paper; embodied R&D is not significant for manufacturing while own R&D is, and in the services sector a comparison between the rates of return of own R&D efforts and of embodied R&D cannot be made due to the lack of data on R&D expenditures by services industries.

It is worthwhile noting here in terms of the lack of significant results for embodied R&D in manufacturing, that Goto and Suzuki (1989) find for the Japanese electronics industry significant spillovers with an R&D position measure, but not with intermediate goods or investment flow matrices. This is consistent with the results of others (van Meijl, 1994) who suggest that disembodied (“knowledge”) spillovers seem to dominate in high tech sectors, and embodied spillovers via investment goods in the services industries.

The actual estimates of the rates of return of both own and of "borrowed" R&D differ widely between studies, with the bigger differences in the estimates for outside R&D. Rates of return to own R&D effort are typically in the zero to 30% range, with most studies concentrating on the 10%-20% range. The estimated model of this paper is in the same broad band, with rates of return to own R&D in manufacturing of around 15% on average for the whole sample of countries. In terms of outside or "borrowed" R&D, Mohnen (1994) comes up with an average estimate of the excess of the social rate over the private rate of approximately 50% to 100% for the different studies that have included an outside R&D variable. Underlying this average are some extreme estimates of nearly zero as well as others exceeding 400% (Van Meijl, 1994). The estimated rate of return of embodied R&D in this paper is between 130% and 190%, depending on whether one looks at the 1970s or the 1980s and whether the estimation covers the services sector as a whole or its ICT segment.

Another question concerns the impact of different schemes for constructing the outside R&D variable(s) on the estimates of its impact on TFP growth. Mohnen (1994) notes that few studies have confronted different methodologies on the same dataset, and for those that have the results are often conflicting. The strong explanatory power of R&D embodied in investment flows as opposed to that embodied in intermediate inputs for services TFP growth that comes out of this paper is in line with the results of Terleckyj (1974) and Wolff and Nadiri (1993). Ducharne-Mohnen (1991) compare the weights based on patents, the direct input requirements as used by Terleckyj, the total input requirements (i.e., through the use of an Leontief inverse as in this paper), and find that methodology makes a difference: the highest spillovers are produced with the Terleckyj weights, with patents flows next and total requirements matrices last.

International R&D spillovers seem to be of increasing interest, with a number of recent studies exploring this dimension. Results are mixed, with the balance tending to tilt towards the recognition of their existence, if not of their actual magnitude. Coe and Helpman (1993) and Bernstein and Mohnen (1994) find strong and significant inter-country spillovers, while Soete and Verspagen (1992) find no evidence of embodied R&D spillovers, but some evidence for the disembodied kind. Where international spillovers are identified, they are found to be larger for smaller countries than for large ones, and sometimes (but not always) larger than domestic spillovers. The high rates of return to R&D embodied in imports in this paper for the services industry as a whole and for the ICT segment (exceeding 400% in the 1970s and 300% in the 1980s) are on the high side of the various estimates. The contribution of imported R&D to TFP growth in each country in the sample is consistent with the results of other studies that this effect is inversely related to country size.

A final issue concerns the changing potency of R&D over time. Griliches and Lichtenberg (1984) and Sterlacchini (1989) find evidence of a decline in the externality effects of R&D, while Scherer (1982a) accepts this hypothesis on aggregate data but rejects it on disaggregated data. Englander, Evenson and Hanazaki (1988) accept it on disaggregated data but not with grate significance. The evidence from the model in this paper suggests no significant decline in the potency of own R&D efforts in manufacturing over the 1970s and 1980s, and an increasing potency in embodied R&D in the services during the 1980s.

5. Conclusions

The preliminary results in this study have attempted to shed some light on the productivity impacts of both R&D expenditures and of embodied R&D diffusion among sectors and across countries by using a number of unique OECD sectoral databases which cover 10 OECD countries (G7, Australia, Denmark and the Netherlands) and the 1970s and 1980s period (see Annex 3). For this study, new TFP growth indexes were also developed based on input-output accounts. The major findings emerging can be summarised as follows.

- The TFP growth estimates pointed to some recovery of productivity growth in the 1980s in most countries, notably in the United States, with TFP increasingly important for explaining GDP growth in the private business sector. While the contribution of labour inputs is stable over time, the contribution of capital inputs is likely to be declining across the countries. The resource reallocation effect on aggregate TFP growth was positive in Japan, Germany, France, Australia and Denmark accounting for 14 to 30% of their aggregate TFP growth. However, it showed a negative contribution in the United States, the United Kingdom and Canada where flexible factor markets are functioning relatively well.

- Sectoral TFP growth showed different movements in manufacturing and services in the 1970s and 1980s. While manufacturing TFP growth recovered in the 1980s, services TFP growth as a whole decreased. Although the contribution of intermediate inputs accounted for a major part of output growth in both sectors in every country, the contribution of labour inputs has increased in the services while capital inputs showed a decreasing role in output growth in both sectors. Looking at TFP performance at a detailed sectoral level, higher TFP growth was observed in most sectors classified in the so-called ICT industry group (computers and communication services, etc.) in every country. It is worthwhile to note that traditional scale-intensive, low-technology manufacturing sectors were also listed in the top-ten ranking of industries in TFP performance in every country.

- The pooled regressions across countries and across industries for the 1970s and 1980s indicate that the rate of return of R&D investment for manufacturing sector is around 15% and no significant change was observed during the two decades in the unweighted regression. However, it showed a dramatic increase in the 1980s in the weighted regression indicating increasing sensitivity of R&D investment on TFP growth in aggregate manufacturing sector. Meanwhile, because of strong multicolinearity among R&D variables, no robust results were not obtained for embodied R&D variables.

- Embodied R&D, however, revealed a significantly positive impact on TFP growth in the services sector. On average, across 10 OECD countries, the estimated rate of return of embodied R&D on services TFP growth was 130% in the 1970s and 190% in the 1980s in the unweighted regression. The principal sources of such diffusion-based productivity gains in this sector were on the one hand the equipment investment for R&D intensive products and on the other hand foreign procurement through imports. In particular, the increased role of capital investment on productivity growth in services is one of the most robust results in our analysis and the estimated rate of return of capital embodied R&D exceeds 200% in the 1980s. Though it is difficult to make unequivocal statements, intermediate inputs or domestic procurement of R&D seem to be of secondary importance.

- When allowing R&D coefficients to vary across countries, it was possible to estimate country-specific estimates of the rate of return of direct R&D for manufacturing and of total embodied R&D in the services separately for the 1970s and 1980s. The rate of return of direct R&D was the highest in Japan for the 1970s (40%), but for the 1980s it shrunk to almost half of that. However, it improved for the United States in the 1980s and both countries were in the same level in the last decade. For the 1980s, the highest rate of return was registered in Italy with a more than 50% rate of return while in the 1970s it was only trivial in this country.

- Canada is also one of a few countries whose rate of return showed an increase in the 1980s and was 10 percentage points higher than that of Japan and the United States in the 1980s. For other countries, the estimated rate of return was around 10% in the 1980s except for France where the return was significantly decreased in the 1980s. Though robust results were not available, the estimated rate of return of embodied R&D for the services sector also varied across countries and between periods. For the 1980s, it was relatively high in the United Kingdom (430%), Canada(320%) and France (300%), but a negative correlation was found in Japan, the Netherlands and Denmark. For the United States, Germany and Italy, the rate of return was almost similar at around 100%.

- Another cross country regression was also run to closely investigate sectoral differences in the rate of return of R&D and embodied R&D. To do so, seven industrial groups were distinguished and pooled across the countries. Surprisingly, the results showed that direct R&D was significantly positive for the machinery sector and embodied R&D for the ICT services sector, but no significant results for the R&D and productivity relationships were obtained for other industrial groups. The estimated rate of return of direct R&D for the machinery sector was declining over time and stood around 20% in the 1980s. The social rate of return of embodied R&D for the ICT services sector was almost stable over time and around 150% in the 1980s. Among the sources of embodied R&D, the rate of return of imported R&D is three-times higher than domestic R&D and capital investment is an important source of productivity in the ICT services.

- Lastly, percentage impacts of R&D and of embodied R&D on TFP growth were estimated by using the estimated coefficients for machinery and ICT services sectors. The contribution of direct R&D on the machinery TFP growth was very stable between the two periods for each country and a slightly increasing impact was observed in several countries in the 1980s. The estimated R&D impact is around 0.7 percentage points in both periods on average across countries. For the ICT services sector, the average impact of domestic R&D is lower than that of imported R&D in both periods (0.3 vs. 0.5 in the 1980s). However, domestic R&D was a more important source than imported R&D in the United States, Japan and to a lesser extent in Germany.

- Imported R&D played a dominant role in Denmark, Australia, the Netherlands and Canada. The impact of domestic R&D increased in the 1980s in every country except for the United Kingdom and France, notably in the United States and Japan, reflecting perhaps increasing linkages with domestic ICT manufacturers. In contrast, the impact of imported R&D decreased in the 1980s in most countries except for the United Kingdom and the United States in spite of rapid growth of high-tech trade during the 1980s. Yet, the absolute level of imported R&D impact on TFP growth in the ICT services sector is significantly high in Canada (0.85 percentage points), Italy (0.76), the United Kingdom (0.75), and Australia (0.67 percentage points).

The findings in this paper are thus consistent with a broad consensus obtained in other studies in this area: R&D expenditures are an important source of productivity growth in R&D conducting industries but the social rate of return of intersectoral and international R&D spillovers far exceeds such direct productivity gains. In particular, we found from our sectoral data that the ICT cluster of industries has played a major role in the generation and diffusion of new technologies with increasing importance over time. Our estimates confirmed a strong importance of foreign R&D observed by Coe and Helpman (1993) at the macroeconomic level and using disaggregated data we clarified that this comes from increasing international procurement of electronic investment goods done by ICT services sector. Our estimates on the TFP impact of diffusion-based R&D for ICT services are also consistent with their finding that domestic R&D is more important in large countries but in smaller countries foreign R&D is more important.

Finally, we conclude by addressing some fundamental questions about the R&D potency over time and the importance of technology diffusion in the context of policies to enhance productivity performance. Regarding the potency of R&D, the results showed some possibility of the decline in the direct R&D coefficient in manufacturing in the 1980s. At the same time, however, we found an increasingly large impact of R&D spillovers into the services. Considering the importance of services in the economy and the increasing impact of technology diffusion on the ICT services group, it is rather tempting to emphasise the increasing economy-wide benefits of manufacturing R&D activities through domestic and international diffusion.

Some of the pessimism regarding the potency of R&D or the Solow “productivity paradox” is due to the fact that services statistics have not yet shown rapid productivity growth despite the large flows of high-tech products into services. It is therefore important to draw attention to the various economic and institutional factors behind low productivity growth in services as well as to true measurement errors in productivity statistics. Deregulation and any means to use more efficiently new technologies (learning best practices, changes in work organisation) will be important in the process of translating the economic potential of new technologies into measurable productivity growth. Similarly, an open trade and investment regime is important for productivity growth simply because international spillovers of high-tech products benefit both importing and exporting countries. Finally, to the extent that ICT clusters are a major part of the process of the generation and diffusion of technology, continuing policy efforts are necessary to liberalise their markets and to encourage further development of ICT technologies.

Annex 1. Embodied R&D Indicators

The methodology on constructing embodied R&D indicators used in this paper builds on the seminal work of Terleckyj (1974) which used input-output data to measure intersectoral flows of technologies. This type of technology flow indicators focuses on R&D embodied in products purchased by an industry (intermediate inputs and investment goods). The concept of the "R&D embodiment" relies on the fact that market commodity flows among industries can be regarded as the means for the transfer of technology developed by supplying industries. The use of input-output tables can help capture interindustrial flows of technology which are not otherwise observable.

In contrast to a previous OECD work (Sakurai, Wyckoff & Papaconstantinou (1993)) which directly uses input-output tables to capture embodied R&D in purchased products, the current R&D embodiment indicators have been formulated on the basis of a Leontief inverse, taking into account the cumulative nature of interindustrial R&D flows. The merit of the Leontief inverse model enables the measurement of second-round R&D gains for a specific industry of R&D performed by industries elsewhere. Such multiplier effects in R&D embodiment estimates can be important. The semiconductor industry for example undertakes a large amount of R&D in many OECD countries. New models of automobiles or airplanes are increasingly equipped with high-quality electronic components for automatic engine control or advanced navigation systems.

However, these downstream users of electronic products frequently do not directly purchase them from semiconductor industry; instead those products are already embodied in parts which were manufactured by engine and instrument producers. The use of direct input-output coefficients fails to take into account of such technological advance embodied in electronic parts in the calculation of the R&D content of autos or airplanes and only the Leontief inverse model can provide the precise measurement of total R&D embodiment in products by its nature of multisectoral multipliers.

In an input-output framework, two kinds of technological gains can be traced: industrial R&D embodiment and the R&D content of final demand (domestic final demand and exports). The latter aspect was first introduced by Davis (1988). For measuring industrial R&D gains, the input-output database provides four major components of indirect R&D indicators for each industry: (i) R&D gains embodied in purchased domestically produced intermediate inputs; (ii) R&D embodied in imported intermediate inputs; (iii) R&D embodied in purchased domestically produced capital goods; and (iv) R&D embodied in imported capital goods. The imported portions of technology can be further broken down into countries of import origin: for example, in the United States, sourcing countries of the imports are separated into 12 regions: other six G7 countries, Australia, Denmark, the Netherlands, other OECD, DAEs+China and the rest of the world (see below for the description of the trade database). The total R&D gains for a industry is a total sum of these four components.

Using simple algebra, individual R&D variables can be defined as follows. First, the balance equations of gross output in an open static input-output system can be written as:

$$X = A^d X + F^d + E \qquad \text{(A-1)}$$

where X is the vector of gross outputs, A^d is the matrix of domestic input-output coefficients, F^d final demand vector for domestic outputs and E is the exports vector (for simplicity, suffixes of country and years are omitted). Solving the domestic balance equation for X, we obtain the equilibrium production to satisfy given final demand:

$$X = (I - A^d)^{-1}[F^d + E] \qquad \text{(A-2)}$$

We then define the direct R&D intensity as R&D expenditures per gross output for industry *i*.

$$r_i = \frac{R_i}{X_i} \qquad (i = 1,2,\ldots n) \qquad \text{(A-3)}$$

Although it is widely recognised that R&D investment has a certain lag before its commercialisation (average lag is 2-3 years in the existing literature) and as an indicator of product sophistication R&D stock variables are more appropriate than flow ones, current R&D expenditures were employed in estimating flows of technology for a particular year.

Combining equation (A-2) with (A-3), the vector of domestic total R&D embodiment, T^d, can be then defined by pre-multiplying the diagonalised matrix of sectoral R&D coefficients (A-3) to equation (A-2), so that we obtain:

$$T^d = \hat{r}(I - A^d)^{-1}[F^d + E] \qquad \text{(A-4)}$$

where hat (^) denotes a diagonal matrix whose elements consist of the corresponding vector.

Equation (A-4) connects domestic R&D embodiment with final demand components (domestic final demand and exports). The *total domestic R&D embodiment per unit of final demand for industry j* can be then defined as the *j*th column sum of the above coefficients matrix:

$$rf_j = \sum_{i=1}^{n} r_i b_{ij} \qquad (j = 1,2,\ldots,n) \qquad \text{(A-5)}$$

where b_{ij} are the elements of inverse $B = (I\text{-}A^d)^{-1}$. Since the *j*th column sum of the Leontief inverse *B* measures the total (direct and indirect) impacts on domestic production when final demand for the *j*th sector changes by unity, equation (A-5) provides the total amount of R&D per unit of the final delivery of output *j*.

The calculation of total R&D embodiments in purchased intermediate goods for industry *j* is slightly different from the above equation (A-5). The traditional Leontief multipliers *B* tells us how much R&D is directly and indirectly embodied in one unit of final demand for output *j*, but not how much R&D is embodied in industry output *j*. From an industrial aspect, the measure of industry's R&D embodiment thus should be defined from an output basis in order to address the latter question. As shown for example by Miller and Blair (1985) p.328, the modification of the standard Leontief model can be easily done by using the following output-to-output based multipliers:

The above adjusted multiplier vector indicates the direct and indirect output requirements from all the sectors excluding industry *j* to produce one unit of *output* for industry *n* (suppose for convenience that industry *j* = *n*). We thus define the adjusted multiplier matrix as $B^* = [B_1, B_2, .., B_n]$.

$$\begin{bmatrix} 1 - a^d_{11} & -a^d_{12} & \cdots & -a^d_{1,n-1} \\ -a^d_{21} & 1 - a^d_{22} & \cdots & -a^d_{2,n-1} \\ \vdots & \vdots & \vdots & \vdots \\ -a^d_{n-1,1} & -a^d_{n-1,2} & \cdots & 1 - a^d_{n-1,n-1} \end{bmatrix}^{-1} \begin{bmatrix} a^d_{1,n} \\ a^d_{2,n} \\ \vdots \\ a^d_{n-1,n-1} \end{bmatrix} = \begin{bmatrix} \frac{b_{1,n}}{b_{n,n}} \\ \frac{b_{2,n}}{b_{n,n}} \\ \vdots \\ \frac{b_{n-1,n}}{b_{n,n}} \end{bmatrix} = B^*_n \qquad \text{(A-6)}$$

This *output* multipliers are less than or equal to traditional Leontief multipliers defined by *final demand* since the propagation process of interindustrial demand can be reduced by the exclusion of industry *j* in propagation, keeping the industry's output constant during this process and hence R&D amounts conducted by this industry. While the use of the traditional Leontief multipliers cannot avoid the double-accounting of the R&D embodiment of industry *j* by the extent of increase in industry *j*'s output during the propagation, the use of such adjusted multipliers enables us to exactly define total R&D embodiments of industry *j* by the simple sum of direct R&D actually conducted by this industry and indirect R&D embodied in the purchased products (total R&D = direct R&D + indirect R&D). This model is useful to define direct and indirect R&D intensities without including double-counting of these R&D elements.

Using the elements of matrix B^*, the R&D embodied in domestic intermediate inputs for industry *j* can be obtained by pre-multiplying the direct R&D intensity as:

$$TINT^d{}_j = \sum_{i \neq j}^{n-1} r_i b^*_{ij} X_i \qquad \text{(A-7)}$$

The R&D embodied in purchased domestic capital goods for industry j can be defined as:

$$TINV^d{}_j = \sum_{i=1}^{n} r_i \left(\sum_{k=1}^{n} b_{ik} I^d_{kj} \right) \qquad \text{(A-8)}$$

where I^d_{kj} is industry j's investment expenditures for *i*th product. Since investment expenditures are one of the components of final demand, the traditional Leontief inverse can be applied to define the indirect R&D embodied in purchased capital goods. However, the above definition of capital-embodied R&D counts only the R&D embodied in current capital formation and neglects the R&D embodied in the stock of capital operated for production so that actual R&D contribution is likely to be underestimated. Since the revision of this part of the model requires huge additional data (time-series data on investment flows matrix, investment deflators, etc.), the static formulation is retained.

Compared with the treatment of domestic R&D flows, the formulation of imported R&D is quite simple in the sense that current model does not consider the interindustrial propagation effects in acquired R&D counting. First, *R&D embodied in purchased imported intermediate inputs for industry j* is defined simply by multiplying foreign direct R&D intensities with the imported amount of intermediate demand as:

$$TINT^m{}_j = \sum_{i=1}^{n} \sum_{k=1}^{l} r_{ik} \alpha_{ik} X^m_{ij} \qquad \text{(A-9)}$$

where X^m_{ij} is the intermediate demand for product *i* by industry *j* and α_{ik} the import share of country *k* for import *I.*

Similarly, R&D embodied in purchased imported capital goods for industry j can be defined as:

$$TINV^m{}_j = \sum_{i=1}^{n} \sum_{k=1}^{l} r_{ik} \alpha_{ik} I^m_{ij} \qquad \text{(A-10)}$$

where I^m_{ij} is the investment demand for product *i* by industry *j* and α_{ik} the import share of country *k* for import *i.*

Since both equation (A-9) and (A-10) do not take into account indirect effects, the imported R&D elements are generally underestimated in the model. The refinement of current formulae is difficult for some reasons: one difficulty relates to whether such indirect effects should be taken into account by using the inverse of the producing country or that of the importing country; in the former case the model should be solved simultaneously across countries as every country is linked to another by international trade. Another question is whether the indirect ripple of imported R&D should be counted as if it were done for domestic products. In counting indirect R&D, the distinction of imported and domestic products may not be appropriate because down-steam industries (auto) can acquire the R&D gains from imported high-tech machines installed in up-stream industries (iron). Due to such difficulties, we use the above simplest type of equations to evaluate the amount of imported R&D component for both intermediate and capital goods.

Lastly, *total R&D embodiment for industry j* can be defined as the simple sum of these four R&D components:

$$TTTL_j = R_j + TINT^d{}_j + TINV^d{}_j + TINT^m{}_j + TINV^m{}_j \qquad \text{(A-11)}$$

The first term of (A-11) shows the amount of direct R&D and the other four terms denote the measures of indirect R&D embodied in the industry *j*'s purchase of either intermediate or capital goods domestically and from abroad. The intensity version of these indicators, i.e., R&D embodiment per unit of output, can be simply calculated by dividing each term of the above equation by the amount of output X_j..

It is noted that the use of the adjusted Leontief multipliers in equation (A-6) allows the complete separation between direct R&D R_j and its domestic indirect effects $TINT_j^d$, avoiding the double counting of R&D embodiment. In addition, the above formula is also consistent with its intensity version, because $TINT_j^d$ is defined on the basis of the *output* of industry *j*, not of the *final demand* for industry *j*. As shown in the main text, these R&D indicators were used to capture the impact of inter-industrial flows of technology on productivity growth. Since the above indicators are defined not only for manufacturing sectors which are major R&D-conducting sectors but also for non-manufacturing sectors which typically depend on sectors within manufacturing for much of new technology, it is possible to measure the indirect productivity effects in downstream industries which are able to acquire better quality capital or materials produced by research-intensive industries.

Annex 2. Estimation of Total Factor Productivity (TFP)

The OECD input-output database provides the detailed input balance for a specific industry *j*:

$$p_j^* X_j = \sum_{i=1}^{n} p_i{}^d X_{ij}{}^d + \sum_{i=1}^{n} p_i{}^m X_{ij}{}^m + p_j{}^l L_j + p_j{}^k K_j \qquad \text{(A-12)}$$

where P^*_j is the net price of gross output exclusive of net indirect tax (indirect tax minus subsidies), X_j is the volume of output in industry *j*, $P^d{}_i$ is the price of output in industry *i*, X^d_{ij} is the industry *i*'s output purchased by industry *j*, $P^m{}_i$ is the price of the imported product *i* competitive to the output of industry *i*, $X^m{}_{ij}$ is the import *i* purchased by industry *j*, $P^l{}_j$ is the price of labour input in industry *j*, L_j is the volume of labour input, $P^k{}_j$ is the price of capital input in industry *j* and K_j is the capital stock in industry *j*. Based on this sectoral account and following Jorgenson (1980) and Kuroda and Shimpo (1991), sectoral TFP index were derived from the following procedures.

Growth rates of real value added

While the calculated sectoral TFP index uses gross output as a production indicator, value added also plays a important role in the model, especially in building a consistent aggregate TFP index from the sectoral level. We therefore start with defining growth rates of both sectoral and aggregate value added by the Divisia indexes.

From equation (A-12), the nominal value added by industry can be defined as:

$$p_j^v V_j = p_j^l L_j + p_j^k K_j = p_j^* X_j - \sum_{i=1}^{n} p_i^d X_{ij}^d - \sum_{i=1}^{n} p_i^m X_{ij}^m \qquad \text{(A-13)}$$

where p_j^v and V_j is respectively the value added deflator and real value added for industry *j*. Since equation (A-13) holds in every point in time, it can be expressed in differential form between the two points in time. As described below in detail, the *Divisia index* plays an important role in the differential approach.

Differentiating equation (A-13) with respect to time and dividing both sides the equation by $p_j^v V_j$:

$$\frac{\dot{p}_j^v}{p_j^v} + \frac{\dot{V}_j}{V_j} = \left[\frac{p_j^* X_j}{p_j^v V_j} \frac{\dot{p}_j^*}{p_j^*} - \sum_{i=1}^{n} \frac{p_i^d X_{ij}^d}{p_j^v V_j} \frac{\dot{p}_i^d}{p_i^d} - \sum_{i=1}^{n} \frac{p_i^m X_{ij}^m}{p_j^v V_j} \frac{\dot{p}_i^m}{p_i^m} \right]$$
$$+ \left[\frac{p_j^* X_j}{p_j^v V_j} \frac{\dot{X}_j}{X_j} - \sum_{i=1}^{n} \frac{p_i^d X_{ij}^d}{p_j^v V_j} \frac{\dot{X}_{ij}^d}{X_{ij}^d} - \sum_{i=1}^{n} \frac{p_i^m X_{ij}^m}{p_j^v V_j} \frac{\dot{X}_{ij}^m}{X_{ij}^m} \right]$$

where a dotted variable indicates the time derivative of this variable (for *z*, $\dot{z} = dz/dt$). The first parenthesis in the right-hand side of the above equation is the Divisia price index of value added in differential form, and the second the Divisia volume index of sectoral value added. In other words, the Divisia growth rates of sectoral real value added are obtained by subtracting the Divisia price index of value added from the growth of sectoral nominal value added.

In order to apply the above differential equations to the discrete data available, the discrete Divisia approximation, called the *translog index*, is usually employed.[9] The translog index of constant-price value added can be defined for two discrete points of time, say *T* and *T*-1 as:

$$\ln V_j(T) - \ln V_j(T-1) = [\ln p_j^v(T) V_j(T) - \ln p_j^v(T-1) V_j(T-1)]$$
$$- \frac{1}{2}[v_j^v(T-1) + v_j^v(T-1)] \cdot [\ln p_j^*(T) - \ln p_j^*(T-1)]$$
$$+ \sum_{i=1}^{n} \frac{1}{2}[v_{ij}^d(T) + v_{ij}^d(T-1)] \cdot [\ln p_i^d(T) - \ln p_i^d(T)]$$
$$+ \sum_{i=1}^{n} \frac{1}{2}[v_{ij}^m(T) + v_{ij}^m(T-1)] \cdot [\ln p_i^m(T) - \ln p_i^m(T)]$$

where ln is natural logarithm, v_j^v are the reciprocal of nominal value added ratio in industry *j* and v_{ij}^d, v_{ij}^m (*i*= 1,2,.. *n*) are the value shares of domestic and imported inputs in industry *j* relative to the value added, defined respectively as:

$$v_j^v(T) \;=\; p_j^*(T)\, X_j(T) / p_j^v(T) V_j(T) \quad (j \;=\; 1,2,\ldots n)$$

$$v_i^d(T) \;=\; p_i^d(T)\, X_{ij}^d(T) / p_j^v(T) V_j(T) \quad (i \;=\; 1,2,\ldots n;\; j \;=\; 1,2,\ldots n)$$

$$v_{ij}^m(T) \;=\; p_i^m(T)\, X_{ij}^m(T) / p_j^v(T) V_j(T) \quad (i \;=\; 1,2,\ldots n;\; j \;=\; 1,2,\ldots n)$$

Aggregate gross domestic product (GDP) can be defined simply as the sum of sectoral value added:

$$p^v V \;=\; \sum_{j=1}^{n} p_j^v V_j \;=\; \sum_{j=1}^{n} (p_j^l L_j \;+\; p_j^k K_j) \tag{A-14}$$

where p^v and V are GDP deflator and real GDP in factor price, respectively.

The growth rate of real GDP, however, cannot be derived directly from the simple sum of sectoral real value added because of the underlying aggregation problem emanating from different movements of sectoral deflators of value added. To avoid such aggregation bias, we use the Divisia index of real GDP as follows.

By differentiating equation (A-14) logarithmically with respect time, we obtain:

$$\frac{\dot{p}^v}{p^v} \;+\; \frac{\dot{V}}{V} \;=\; \sum_{j=1}^{n} \frac{p_j^v V_j}{p^v V} \frac{\dot{p}_j^v}{p_j^v} + \sum_{j=1}^{n} \frac{p_j^v V_j}{p^v V} \frac{\dot{V}_j}{V_j} \tag{A-15}$$

The above equation shows that the nominal GDP growth rate can be expressed as the sum of the Divisia price index of GDP deflator (the first term in the right-hand side) and the Divisia quantity index of aggregate real GDP growth rate. The discrete approximation for the Divisia growth rate of the real GDP can be thus defined as:

$$\ln V(T) \;-\; \ln V(T-1) \;=\; [\ln p^v(T) V(T) \;-\; \ln p^v(T-1) V(T-1)]$$
$$-\; \sum_{j=1}^{n} \frac{1}{2} [w_j^v(T) \;+\; w_j^v(T-1)] \cdot [\ln p_j^v(T) \;-\; \ln p_j^v(T-1)]$$

where $w_j^v(T)$ is the value share of value added for industry j in time T: $w_j^v(T) \;=\; p_j^v(T) V_j(T) / p(T) V(T)$.

As mentioned above, the translog price index (p^v) shown at the second term of the right-hand side of equation (A-15) is not necessarily equal to the implicit deflator of aggregate GDP, $\tilde{p}^v$, which is calculated by dividing nominal GDP by the simple sum of the sectoral real value added. The following relationship holds between the two price indexes.

$$p^v V \;=\; \sum_{j=1}^{n} p_j^v V_j \;=\; \tilde{p}^v \sum_{j=1}^{n} V_j \tag{A-16}$$

They are only equal if and only if the sectoral value added deflator p_j^v is identically equal to (p^v) across the sectors and value added shares w_j^v are constant over time across the sectors.

Sectoral TFP index

Total factor productivity (TFP) is generally defined as the ratio of the volume of production *Y* relative to total volume of input *Q* (*TFP*=*Y*/*Q*). The growth rate of TFP is thus computed as:

$$\frac{\dot{TFP}}{TFP} = \frac{\dot{Y}}{Y} - \frac{\dot{Q}}{Q} \qquad \text{(A-17)}$$

TFP growth is thus the residual between the rate of change in production and that in production inputs. If the rate of change in production is equal to the rate of change in inputs between two points in time, TFP can be zero so that there is no change in technological efficiency between the two years. On the other hand, if production increases more rapidly than the growth of inputs, positive TFP growth is assumed to reflect improvements in technological efficiency in production.

The detailed information on various factor inputs available from the input-output data enables us to formulate the index of sectoral TFP in the disaggregated form of Divisia input indexes as:

$$\frac{\dot{TFP}_j}{TFP_j} = \frac{\dot{X}_j}{X_j} - \sum_{i=1}^{n} \frac{p_i^d X_{ij}^d}{p_j^* X_j} \frac{\dot{X}_{ij}^d}{X_{ij}^d} - \sum_{i=1}^{n} \frac{p_i^m X_{ij}^m}{p_j^* X_j} \frac{\dot{X}_{ij}^m}{X_{ij}^m} - \frac{p_j^l L_j}{p_j^* X_j} \frac{\dot{L}_j}{L_j} - \frac{p_j^k K_j}{p_j^* X_j} \frac{\dot{K}_j}{K_j}$$

where various factor inputs are weighted averages of rate of change in individual factor inputs by their value shares in gross output. The translog indexes of sectoral TFP can be thus expressed as the difference between successive logarithms of sectoral output less a weighted average of the differences between successive logarithms of sectoral intermediate (separated by domestically produced and imported), labour and capital inputs with weights given by average value shares between two points in time:

$$\begin{aligned}
\ln TFP_j(T) - \ln TFP_j(T-1) = {} & [\ln X_j(T) - \ln X_j(T-1)] \\
& - \sum_i \frac{1}{2}[s_{ij}^d(T) + s_{ij}^d(T-1)][\ln X_{ij}^d(T) - \ln X_{ij}^d(T-1)] \\
& - \sum_i \frac{1}{2}[s_{ij}^m(T) + s_{ij}^m(T-1)][\ln X_{ij}^m(T) - \ln X_{ij}^m(T-1)] \\
& - \frac{1}{2}[s_j^l(T) + s_j^l(T-1)][\ln L_j(T) - \ln L_j(T-1)] \\
& - \frac{1}{2}[s_j^k(T) + s_j^k(T-1)][\ln K_j(T) - \ln K_j(T-1)]
\end{aligned}$$

where:

$$s^d_{ij}(T) = p^d_i(T)X^d_{ij}(T)/p^*_j(T)X_j(T) \quad (i = 1,2,\ldots,n;\ j = 1,2,\ldots n)$$

$$s^m_{ij}(T) = p^m_i(T)X^m_{ij}(T)/p^*_j(T)X_j(T) \quad (i = 1,2,\ldots,n;\ j = 1,2,\ldots,n)$$

$$s^l_j(T) = p^l_j(T)L_j(T)/p^*_j(T)X_j(T) \quad (j = 1,2,\ldots,n)$$

$$s^k_j(T) = p^k_j(T)K_j(T)/p^*_j(T)X_j(T) \quad (j = 1,2,\ldots,n)$$

Aggregate TFP Inde

From the definition of the Divisia index of real value added, the above TFP formula can also be expressed in value added terms as: [10]

$$\frac{\dot{TFP}_j}{TFP_j} = \frac{p^v_j V_j}{p^*_j X_j}\frac{\dot{V}_j}{V_j} - \frac{p^l_j L_j}{p^*_j X_j}\frac{\dot{L}_j}{L_j} - \frac{p^k_j K_j}{p^*_j X_j}\frac{\dot{K}_j}{K_j} \tag{A-18}$$

As shown below, this alternative sectoral TFP formula facilitates to construct aggregate TFP index from sectoral TFP series. The sectoral aggregate TFP can be then defined as the weighted average of sectoral TFP in the following way.

$$\sum_{j=1}^{n}\frac{p^*_j X_j}{p^v V}\frac{\dot{TFP}_j}{TFP_j} = \sum_{j=1}^{n}\frac{p^v_j V_j}{p^v V}\frac{\dot{V}_j}{V_j} - s_L\cdot\sum_{j=1}^{n}\frac{p^l_j L_j}{\sum_j p^l_j L_j}\frac{\dot{L}_j}{L_j} - s_K\cdot\sum_{j=1}^{n}\frac{p^k_j K_j}{\sum_j p^k_j K_j}\frac{\dot{K}_j}{K_j} \tag{A-19}$$

where:

$$s_L = \sum_j \frac{p^l_j L_j}{p^v V}, \quad s_K = \sum_j \frac{p^k_j K_j}{p^v V}$$

Note that this aggregated measure of TFP is constructed by the Divisia aggregate indexes of sectoral value added, labour and capital inputs, not by simply aggregating sectoral data on value added, labour and capital.

Resource allocation effects

The disaggregated framework explained here enables us to incorporate the impacts of structural change or resource allocation effects on economic growth. The importance of this effect may be clear from the fact that the improvement of the allocation of resources can contribute to growth even though technical change does not occur. In a simple aggregate productivity analysis, this effect is usually ignored and included into "the residual" in the growth accounting. However, since the bottom-up, sectoral approach used here needs to make a clear link between sectoral productivity and aggregated productivity, it must be treated as a distinguished source of economic growth with the residual factor. Development of this section relies on the formulation of Kuroda and Shimpo (1991).

Aggregate TFP is also measurable by directly using already aggregated data in macroeconomic accounts, not by following the Divisia aggregation of sectoral data. In this case, the aggregated social balance equation is shown as:

$$p^v V = p^l L + p^k K \qquad \text{(A-20)}$$

The aggregate TFP can be then defined as:

$$\frac{\dot{TFP}}{TFP} = \frac{\dot{V}}{V} - s_L \frac{\dot{L}}{L} - s_K \frac{\dot{K}}{K} \qquad \text{(A-21)}$$

where:

$$V = \sum V_j \quad L = \sum L_j \quad K = \sum K_j \quad s_L = \frac{p^l L}{p^v V} \quad s_K = \frac{p^k K}{p^v V}$$

The difference between Divisia aggregation and the simple sum of each variable is thus equivalent to assuming the equality of value added and factor price deflators across different sectors as well as the homogeneity of such volume variables as value added, labour and capital regardless of the sectors. Accordingly, if these two assumptions hold, the Divisia price indexes of value added, labour and capital (p^v, p^l, p^k) become equal to their implicit deflators ($\tilde{p}^v$, $\tilde{p}^l$ and $\tilde{p}^k$) so that the Divisia volume indexes for these variables are reduced to the growth rate of the simple sum of each variable across the sectors shown as below:

$$\frac{\dot{V}}{V} = \Sigma \frac{p_j^v V_j}{p^v V} \cdot \frac{\dot{V}_j}{V_j} = \Sigma \frac{\tilde{p}^v V_j}{p^v V} \cdot \frac{\dot{V}_j}{V_j} = \Sigma \frac{V_j}{V} \cdot \frac{\dot{V}_j}{V_j} = \frac{\Sigma \dot{V}_j}{V}$$

$$\frac{\dot{L}}{L} = \Sigma \frac{p_j^l L_j}{p^l L} \cdot \frac{\dot{L}_j}{L_j} = \Sigma \frac{\tilde{p}^l L_j}{p^l L} \cdot \frac{\dot{L}_j}{L_j} = \Sigma \frac{L_j}{L} \cdot \frac{\dot{L}_j}{L_j} = \frac{\Sigma \dot{L}_j}{L}$$

$$\frac{\dot{K}}{K} = \Sigma \frac{p_j^k K_j}{p^k K} \cdot \frac{\dot{K}_j}{K_j} = \Sigma \frac{\tilde{p}^k K_j}{p^k K} \cdot \frac{\dot{K}_j}{K_j} = \Sigma \frac{K_j}{K} \cdot \frac{\dot{K}_j}{K_j} = \frac{\Sigma \dot{K}_j}{K}$$

Rearranging the terms of equation (A-32) by using equation (A-32), the following relationships between sectoral TFP and the aggregate TFP index can be obtained:[11]

$$\frac{\dot{TFP}}{TFP} = \sum_j \frac{p_j^* X_j}{p^v V} \frac{\dot{TFP}_j}{TFP_j} + \sum_j \frac{(\tilde{p}^v - p_j^v) V_j}{p^v V} \frac{\dot{V}_j}{V_j} + \sum_j \frac{(p_j^l - \tilde{p}^l) L_j}{p^v V} \frac{\dot{L}_j}{L_j} + \sum_j \frac{(p_j^k - \tilde{p}^k) K_j}{p^v V} \frac{\dot{K}_j}{K_j}$$

The above equation indicates that the aggregate TFP growth given by equation (A-21) can be decomposed into the following four components. The first term of the right-hand side of the equation presents the weighted average of sectoral TFP growth with weights defined by the sectoral proportion of nominal gross output to nominal value added (reciprocal of sectoral value added ratios). Since the sum of the weights are necessarily more than unity, *ceteris paribus*, the aggregate TFP growth rate becomes larger than the simple average of the sectoral TFP growth.

The factors responsible for the difference between these two TFP indexes can be broken down into the other three terms in the right-hand side which represent the TFP contributions of reallocational change in value added, labour and capital inputs among the sectors. To see these resource allocation effects on growth more easily, the above equation can be rearranged by substituting it with equation (A-21) as:

$$\frac{\dot V}{V} - \sum_j \frac{(\tilde p^v - p_j^v)V_j}{p^v V}\frac{\dot V_j}{V_j}$$
$$= s_L \frac{\dot L}{L} + \sum_j \frac{(p_j^l - \tilde p^l)L_j}{p^v V}\frac{\dot L_j}{L_j} + s_K \frac{\dot K}{K} + \sum_j \frac{(p_j^k - \tilde p^k)K_j}{p^v V}\frac{\dot K_j}{K_j} + \sum_j \frac{p_j^* X_j}{p^v V}\frac{\dot{TFP}_j}{TFP_j}$$

The left-hand side of this equation indicates that Divisia aggregate GDP growth rate is decomposed into two elements: GDP growth rate estimated from the simple aggregate account and the structural factor emanating from the difference of value added deflators among sectors. Hence, if the sectors whose value added deflators are higher than the average deflator have rapidly grown, the second-term in the left-hand side becomes negative and Divisia aggregate GDP growth is enhanced. Since the value added deflator can be defined as value added per unit of net output, the increasing share of high-value added sectors alongside with economic development is likely to bring about higher economic growth.

Aggregate GDP growth in the left-hand side of the equation can be decomposed into three contributing factors: labour, capital and technical change. Factor input contributions can be decomposed into that due to the growth of aggregate volume of labour and capital as well as reallocation effects of labour and capital among different sectors whose marginal productivity are not even. Therefore, if labour is released from lower-wage to higher-wage sectors, the fourth term is likely to become positive. The same is also true for capital input. Finally, the last term in the right-hand side of the equation indicates the weighted average of sectoral TFP growth as mentioned on the above. A crucial advantage of the above growth accounting is that this formulation enables us to separate resource allocation effects from the "residual" which were included in the early aggregate growth accounting studies (for example, see Solow (1957).

Annex 3. The OECD databases used

A number of OECD databases were used in the paper: the so-called STAN database family developed in the Directorate for Science, Technology and Industry (R&D expenditures, input-output tables, bilateral trade and industrial STAN) as well as the International Sectoral Database (ISDB) developed in the Statistics Department.

The STAN database family attains a relatively finer level of manufacturing disaggregation (22 industries), using a common industrial classification (ISIC Revision 2) which allows the identification of technology- and trade-intensive industries such as pharmaceutical, aerospace, computers, and communication equipment & semiconductors (see Table A-1). This industrial detail helps identify clusters of industries that share R&D through embodiment and analyse the role of international trade in the acquisition of technology developed abroad. The databases explained below commonly cover all the 10 OECD countries analysed in the project -- Australia, Canada, Denmark, France, Germany, Italy, Japan, the Netherlands, the United Kingdom and the United States.

Analytical Database of Business Enterprise R&D (ANBERD)

The ANBERD database was constructed with the objective of creating a consistent data set of R&D performed by the business sector that overcomes the problems of international comparability and time discontinuity associated with the official Business Enterprise R&D (BERD) data provided to the OECD by Member countries. To achieve this level of consistency, many of the data points have been estimated on the basis of additional information available in Member countries and through the use of pure statistical interpolation techniques (spline function). The first version of the database is described in OECD (1992b).

The database includes time-series data of sectoral intramural R&D expenditures for 22 ISIC manufacturing and several service sectors from 1973 to 1991, though this project does not use its services segment due to the underlining availability problems in several countries. This time series data set is currently available only in current prices. The countries currently covered are Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, the United Kingdom, and the United States. Although an R&D stock variable is more appropriate to investigate the level of technological knowledge in industries, reliable data to construct this variable are not sufficiently provided, especially for sectoral R&D deflators and the rate of depreciation.

Input-Output tables

Input-output tables constitute the core data of our analysis. The OECD input-output database was originally developed to assist the OECD Industry Committee in making international comparisons of structural adjustment in industry (see OECD (1992a)). The database currently covers the 10 OECD countries cited above.

The OECD input-output tables distinguishes interindustrial flows of domestically produced and imported products (i.e., non-competing import type) and consists of the following five sub-matrices:

- Domestic flows matrix (industry × industry)
- Imported flows matrix (industry × industry)
- Domestic investment flows matrix (industry × industry)
- Imported investment flows matrix (industry × industry)
- Value added components matrix (value added category × industry)

Except for the value added component matrix, these matrices are available in both current and constant price in national currency basis (the base-year of price deflators differs across the 10 countries). Industries are disaggregated into 36 ISIC sectors, of which the 22 manufacturing sectors are comparable with those of ANBERD and other databases. Available years of the data are different by country, but typically contain three to five points of years, spanning from the early-1970s to the mid-1980s or to 1990 which allows a historical analysis of industrial structure: Australia; 1968, 1974, 1986 and 1990; Canada; 1971, 1976, 1981, 1986 and 1990; Denmark; annually from 1966 to 1990; France; 1972, 1977, 1980, 1985 and 1990; Germany; 1978, 1986, 1988 and 1990; Italy; 1985 only; Japan; 1970, 1975, 1980, 1985 and 1990; Netherlands; 1972, 1977, 1981 and 1986; United Kingdom; 1968, 1979, 1984 and 1990; United States; 1972, 1977, 1982, 1985 and 1990.

The current sectoral disaggregation of the I-O database, however, has been suffering from several missing sectors for most countries which preclude exact sectoral comparison internationally. In particular, the extent of missing sectors is more serious in the disaggregation of investing industries (i.e., column sectors) in capital flow matrices than in intermediate flows matrix across the countries (see Table A-2).

These missing sectors set a limit to establishing consistency between the databases in STAN. For example, other OECD data used in our analysis (R&D, employment and trade, etc.) should be more aggregated by sector within a country, even though other data have complete sectoral profiles. For international comparisons, further aggregation must be made to keep sectoral consistency across the countries so that the original information can be lost in every step of such aggregation process.

Bilateral Trade Database

The bilateral trade database includes detailed trade flows for manufacturing industry from one country or geographical area to another. For each importing/exporting country, exports to and imports from the full list of partner countries or regions is provided (see OECD (1994a). The data have been drawn from the foreign trade component of the OECD Statistics Directorate's COMTAP (Compatible Trade and Production) Database.

Industry coverage is 22 manufacturing sectors, following the same manufacturing classification as in used at input-output and ANBERD databases. The period covered spans from 1967 to 1992, providing manufacturing imports and imports in current US dollars of 14 OECD countries from and to the trading partners (14 OECD countries, the rest of OECD, 12 developing countries, and the rest of the world). In this project, trading partners were further aggregated for each of 10 OECD countries concerned into 12 trading partners or regions: other 9 OECD countries, the rest of the OECD, China plus the so-called Dynamic Asian Countries (Hong Kong, Malaysia, Singapore, South Korea, Thailand and Taiwan), and the rest of the world. The data were then combined with input-output database to generate regional distribution of exports and imports in input-output tables by those 12 regions.

For the productivity analysis, the following two additional OECD databases are used to obtain such sectoral series as sectoral employment, capital stock, income shares of labour and capital.

Industrial STAN Database

The Industrial STAN database was created to facilitate international comparisons of industrial structure and performance in detailed sectoral level. It fills the gap that exists between detailed survey level data which lacks international comparability and the System of National Accounts that is internationally comparable but only available at fairly aggregated industrial levels. It must be noted that this detailed and international comparable data is achieved through an estimation process by the Secretariat own (see OECD (1994b).

The database currently covers 16 countries (Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Korea, Mexico, Netherlands, Norway, Sweden, United Kingdom and the United States) for the years 1970 to 1991 in two different industrial classification based on the ISIC Revision 2. The first classification uses 49 industries and the second, which is compatible with other STAN family databases, has 26 adjusted industry groupings. The following main five variables are currently available in current price only in OECD National Accounts compatible form: Production (gross output), Value added (sectoral GDP), Gross fixed capital formation (investment for construction and machinery & equipment), Number engaged (employees plus self-employed, owners proprietors and unpaid family workers) and Labour compensation (wages & salaries and other supplementary labour costs such as employer's compulsory pension, medical payments, etc.). It also provides exports and imports by sector, obtainable as the regional aggregate from the above bilateral trade database.

International Sectoral Database (ISDB)

The International Sectoral Database has been created by the OECD Statistics Department as part of the continuing study of industrial structure and economic performance in OECD Member countries (Meyer zu Schlochtern (1994)). The database uniquely combines a range of data series related primarily to sectoral output and primary factor inputs (labour and capital) in a compatible manner with the OECD National Accounts Statistics.

This annual database covers at maximum the period 1960 to 1990 but comparable only from 1970 for 14 OECD countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, the United Kingdom and the United States. Major variables included are: gross domestic product, total employment (engaged persons) and employees, gross fixed capital formation and gross capital stock, compensation of employees, gross operating surplus and net indirect taxes. Since most of them are available in both current and constant prices and for the latter case 1985 local currency or US dollars converted values using 1985 purchasing power parity are employed.

The ISDB database has an unique advantage in covering a significant number of variables concerning output and resource allocation in both current and constant prices. It also complements the STAN industrial database by extending beyond the manufacturing sector to include primary and services sectors. Its manufacturing detail, however, is limited to 13 industries (almost corresponding to ISIC two-digit sectors). Thus for detailed manufacturing analysis for productivity and employment, a combined data set for such variables as total employment, factor shares of income had to be created. Since the only source of capital stock data at the time of writing was ISDB, the calculation of sectoral TFP was done following the ISDB sectoral disaggregation (at maximum level 24 sectors in economy as a whole).

NOTES

1. G. Papaconstantinou, N. Sakurai, A. Wyckoff, "Embodied Technology Diffusion: An Empirical Analysis for 10 OECD Countries", STI Working Papers, 1996/1, OECD.

2. A related recent study (OECD, 1992) used input-output data to conduct a demand-side decomposition of sectoral output and analysed structural change after the first oil shock for seven OECD countries in terms of changes in the level and structure of intermediate demand, final demand and international trade. For an application of this model to employment growth, see Sakurai (1995).

3. This paper focuses only on the private business sector, which excludes two public services industries: producers of government services and other services producers in the SNA classification. Thus, both production accounts are not concerned with economy-wide GDP, labour, capital and TFP. The main reason for the exclusion of these sectors in the accounting is that the comparability in input-output accounts is not established in these sectors.

4. The growth rates of sectoral TFP are available only at a rather aggregated sectoral level and because of different industry aggregations used across the counties industries are not directly comparable. See Annex 3 for the industrial aggregation scheme used in this study.

5. The Cobb-Douglas formulation is not consistent with the TFP estimates derived from sectoral accounts in the Divisia index form (see Milana (1995) on this criticism). Although consistency can be achieved when the translog function is employed, this problem is neglected in this paper because of insufficient data to estimate the parameters of this function.

6. Although similar models have been used in the literature, there are potential difficulties in interpreting the results. Among others, Schankerman (1981) has pointed out the double counting of research inputs. This generally happens because the capital, labour and intermediate inputs used in R&D activities are already included in the inputs used to calculate TFP growth rates. An important implication of this double counting is that estimated coefficients ρ should be interpreted as an *excess* rate of return, in other words, social benefits of R&D, which is the amount of the total return which remains after the private return for capital and labour has already been removed. If the adjustment is made for inputs to eliminate such double counting effects, the estimated coefficients can provide an estimate of the total impact of research, including both the private and social returns. The other important difficulty occurs from possible duplication of R&D activities among firms. R&D investment is duplicated in the sense that some firms duplicate R&D conducted by other firms and/or invent around previous patents by developing slightly improved or somewhat different versions of existing products. In addition, a large part of R&D expenditures is directed towards gathering information already known, regenerating results once known, or perhaps systematising and reordering prior results. Hence, R&D expenditures will overstate the true increase in the stock of technological knowledge. Since the independent variable in equation (3) or (4) will then systematically be too large, the estimated regression coefficients may correspondingly be subject to substantial downward bias. See the US Bureau of Labour Statistics (1989) for more complete reviews on the shortcoming underlying the model.

7. The results for Australia are excluded from the Figures.

8. The results from the various studies presented in Table 8 are restricted to papers that examine domestic and international R&D spillovers using aggregate and sectoral data and employing the "primal" approach (i.e. using production functions in the econometric estimations). This leaves out all the studies that have relied on firm-level data and those that have used the "dual" (cost function) approach.

9. Let $y=(X_1, X_2,...X_n)$ and define the growth rate between the time T and T-1 by the logarithmic growth formula ln $y(T)/y(T\text{-}1)$. The translog quantity index or the so-called Törnqvist-Theil index is then given by

$$\ln\frac{y(T)}{y(T-1)} = \sum_{i=1}^{n}\frac{1}{2}(s_i(T) + s_i(T-1))\ln\frac{X_i(T)}{X_i(T-1)}$$

where $s_i(T) = [\partial y(T)/\partial X_i(T)\cdot X_i(T)]/[\Sigma\partial y(T)/\partial X_i(T)\cdot X_i(T)]$ is the share of X_i at time T. Since mean weights are used, an interaction term can disappear in discrete decomposition. The index has been extensively used in the literature as a discrete approximation of the Divisia index. As Diewert (1974) has shown, it is exact for an homogenous translog function. Since this function provide a second-order approximation to an arbitrary function, it is also superlative.

10. From this equation, the sectoral TFP series whose production variable is defined by value added, not by gross output in our TFP definition have the following relationship:

$$\frac{\dot{TFP}_j^v}{TFP_j^v} = \frac{p_j^* X_j}{p_j^v V_j}\cdot\frac{\dot{TFP}_j}{TFP_j}$$

Namely, the gross output based TFP is equal to the value-added based TFP deflated by the value added ratio.

11. The derivation of this equation is as follows.

$$\frac{\dot{TFP}}{TFP}\cdot p^v V = \sum_j \tilde{p}^v\dot{V}_j - \sum_j \tilde{p}^l\dot{L}_j - \sum_j\tilde{p}^k\dot{K}_j = \sum_j\tilde{p}^v\dot{V}_j - \sum_j p_j^v\dot{V}_j + \sum_j p_j^v\dot{V}_j - \sum_j\tilde{p}^l\dot{L}_j - \sum_j\tilde{p}^k\dot{K}_j$$

$$= \sum_j\left(\frac{\dot{TFP}_j}{TFP_j}\cdot p_j^*X_j + p_j^l\dot{L}_j + p_j^k\dot{K}_j\right) + \left(\sum_j\tilde{p}^v\dot{V}_j - \sum_j p_j^v\dot{V}_j\right) - \sum_j \tilde{p}^l\dot{L}_j - \sum_j\tilde{p}^k\dot{K}_j$$

$$= \sum_j \frac{\dot{TFP}_j}{TFP_j}\cdot p_j^*X_j + \sum_j(\tilde{p}^v - p_j^v)\dot{V}_j + \sum_j(p_j^l-\tilde{p}^l)\dot{L}_j + \sum_j(p_j^k-\tilde{p}^k)\dot{K}_j$$

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Table 1 Growth Accounting Results at Macroeconomic Level

(%)

	Divisia Aggregates	Aggregate Account	Resource reallocation effects**

Table 2 Decomposition of Labour Productivity Growth*

		Labour Productivity Growth	TFP Growth	Capital Intensity Change	TFP Contribution	GDP Growth	Labour Growth	Capital Growth	Capital Intensity Growth
United States	1972-90	0.85	0.42	0.45	49.2	2.83	1.98	3.43	1.45
	1972-77	0.59	0.06	0.55	9.6	2.58	1.98	3.75	1.77
	1977-82	-0.24	-0.92	0.70	391.1	1.30	1.53	3.82	2.29
	1982-85	2.39	2.29	0.13	95.7	5.21	2.82	3.25	0.43
	1985-90	1.26	0.99	0.29	78.7	3.19	1.93	2.83	0.90
Japan	1970-90	3.19	1.41	1.82	44.0	4.38	1.19	7.06	5.87
	1970-75	3.49	0.52	3.01	14.9	4.43	0.94	10.29	9.35
	1975-80	3.26	1.79	1.51	55.0	4.37	1.11	6.50	5.39
	1980-85	3.06	1.74	1.35	56.8	4.02	0.97	5.41	4.45
	1985-90	2.96	1.58	1.42	53.2	4.70	1.74	6.03	4.29
Germany	1978-90	1.70	0.94	0.78	54.9	2.31	0.60	2.81	2.21
	1978-86	1.50	0.51	0.99	34.2	1.61	0.11	2.94	2.83
	1986-88	1.98	1.35	0.64	68.3	2.67	0.69	2.46	1.77
	1988-90	2.24	2.21	0.06	98.6	4.73	2.49	2.65	0.16
France	1972-90	2.29	1.57	0.62	68.7	2.59	0.30	3.00	2.70
	1972-77	3.08	2.04	1.05	66.3	3.43	0.36	4.35	3.99
	1977-80	1.28	0.53	0.71	41.0	1.51	0.22	3.54	3.32
	1980-85	2.20	1.91	0.58	87.0	1.54	-0.66	2.28	2.94
	1985-90	2.19	1.39	0.19	63.5	3.44	1.24	2.06	0.81
United Kingdom	1968-90	2.02	1.43	0.59	71.1	2.13	0.11	2.32	2.21
	1968-79	2.05	1.29	0.76	62.9	1.91	-0.14	2.71	2.84
	1979-84	2.26	1.45	0.79	64.2	0.75	-1.51	1.38	2.89
	1984-90	1.76	1.68	0.12	95.8	3.68	1.93	2.39	0.46
Canada	1971-90	1.30	0.77	0.64	59.0	3.28	1.98	4.49	2.51
	1971-76	1.88	1.34	0.58	71.4	4.68	2.80	4.95	2.15
	1976-81	0.61	-0.03	0.68	-5.4	3.02	2.40	4.90	2.50
	1981-86	2.09	1.10	1.00	52.6	2.52	0.42	3.91	3.49
	1986-90	0.47	0.65	0.23	138.5	2.82	2.35	4.11	1.76
Australia	1968-89	1.63	1.05	0.63	64.5	3.73	2.10	4.44	2.34
	1968-74	2.44	1.55	0.95	63.5	4.86	2.42	6.05	3.63
	1974-86	1.11	0.55	0.60	49.4	2.72	1.61	3.83	2.23
	1986-89	2.10	2.09	0.08	99.1	5.49	3.39	3.64	0.25
Denmark	1972-90	1.97	1.21	0.76	61.3	1.77	-0.20	2.66	2.86
	1972-77	1.70	0.72	0.97	42.3	1.11	-0.59	3.24	3.83
	1977-80	2.47	1.63	0.81	66.2	1.58	-0.88	2.54	3.42
	1980-85	2.09	1.61	0.49	77.0	2.42	0.33	2.18	1.85
	1985-90	1.81	1.03	0.78	57.0	1.90	0.09	2.63	2.54
Netherlands	1972-86	2.93	1.88	1.06	63.9	2.74	-0.20	2.95	3.15
	1972-77	5.49	4.22	1.27	76.9	5.16	-0.33	3.59	3.92
	1977-81	0.64	-0.33	0.96	-51.2	0.70	0.07	3.00	2.93
	1981-86	2.21	1.29	0.92	58.3	1.93	-0.28	2.27	2.55
Unweighted Average	1970-1990	1.99	1.19	0.82	59.6	2.86	0.87	3.68	2.81

*) Estimates by Divisia aggregation.

Table 3. Growth Decomposition Results at a broad Sectotal Level

Per Cent

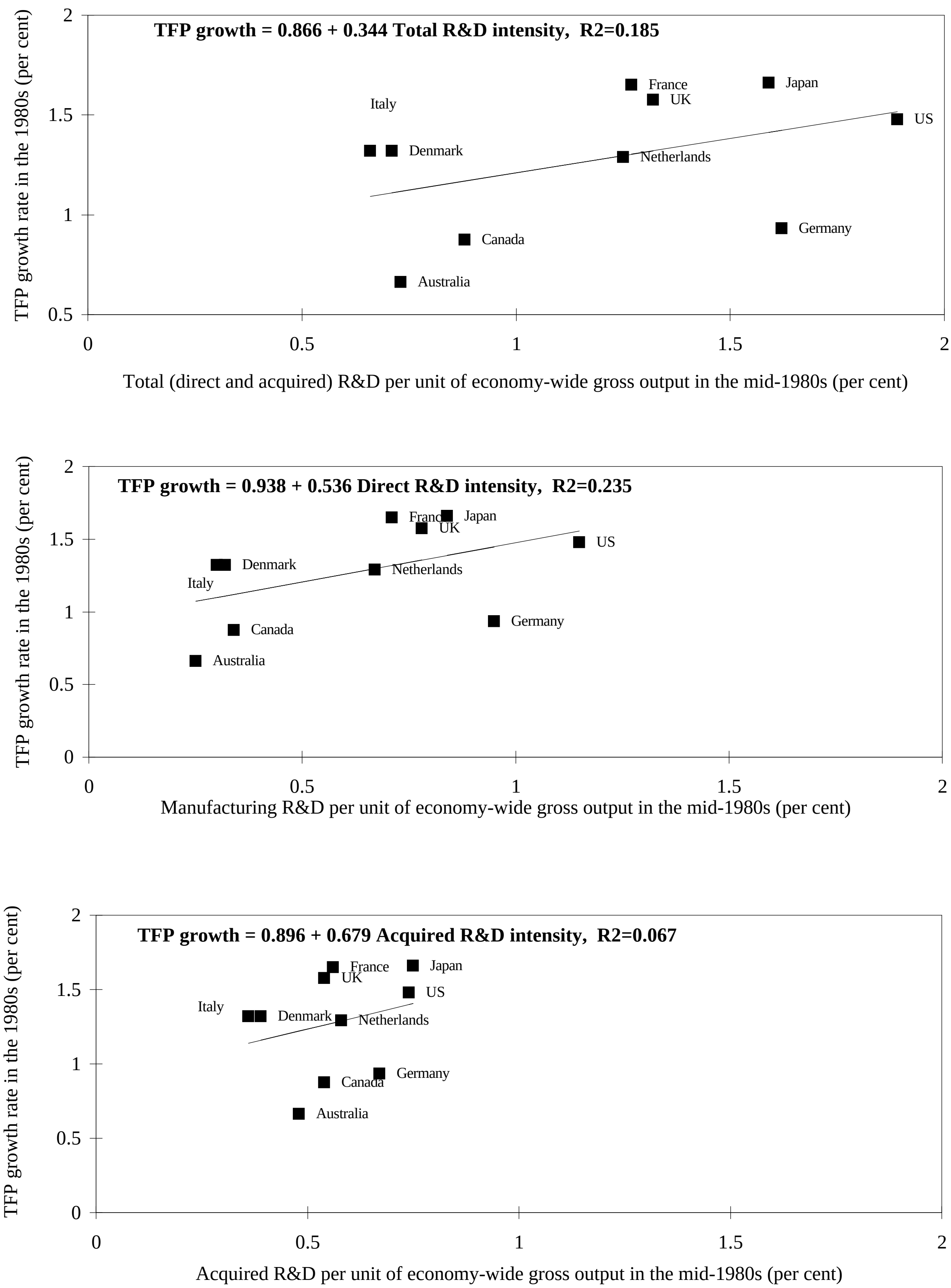
					Total Private Business Sector							
United States	**1.86**	**0.84**	**0.11**	**0.58**	**0.57**	**-0.25**	**3.37**	**1.20**	**0.20**	**0.78**	**0.47**	**0.72**
					Manufacturing Sector							
United States	**0.68**	**0.38**	**0.15**	**0.02**	**0.35**	**-0.22**	**3.19**	**1.21**	**0.40**	**0.12**	**0.19**	**1.28**
					Private Services Sector							
United States	**2.83**	**1.14**	**0.09**	**0.99**	**0.73**	**-0.12**	**3.66**	**1.35**	**0.09**	**1.28**	**0.67**	**0.27**

Table 4. Ten Highest TFP Growth Industries

	US 1972-90	Japan 1970-90	Germany 1978-1990	France 1972-90	UK 1968-1990	Canada 1971-1990	Australia 1968-1989	Denmark 1972-1990	Netherlands 1972-1986
1	Instrument 2.68	Elec. mac. 2.70	Commu. 2.75	Commu. 4.76	Agriculture 2.85	Real estate 5.55	Trans & comm 3.31	Mining 7.58	Agrriculture 2.71
2	General mac. 2.06	Instrument 2.19	Agriculture 2.63	Agriculture 3.31	Elec. mac. 2.57	General mac. 2.04	EGW 2.12	Commu 2.79	Mining 2.36
3	Commu. 1.93	Trade 1.98	Transport 1.42	Elec. mac. 2.05	Mining 2.16	Elec. mac. 1.69	Paper 1.45	Agriculture 2.70	Elec. mac. 2.26
4	Textiles 1.28	Trans & comm 1.37	Instrument 1.29	Basic metal 1.51	Basic metal 1.87	Trans & comm 1.47	CSPS 1.38	Basic metal 1.48	Real estate 2.22
5	Transport 1.21	Basic metal 1.18	Elec. mac. 1.27	Textiles 1.14	Textiles 1.65	Textiles 0.94	Agriculture 1.29	Trade 1.40	Trans & comm 1.64
6	Elec. mac. 1.01	General mac. 1.08	Finance 1.06	Wood 1.11	Instrument 1.53	Basic metal 0.92	Textiles 1.12	Elec. mac. 1.11	Other man. 1.46
7	Agriculture 0.95	Textiles 1.07	Trade 0.78	CSPS 1.03	Ceramics 1.24	Wood 0.71	Basic metal 1.11	Textiles 0.73	Ceramics 1.40
8	Wood 0.81	Fab. metal 0.96	Basic metal 0.71	Fab. metal 0.97	Gen. mac. 1.13	CSPS 0.62	Other man. 0.30	Food 0.69	Rubber 1.38
9	Trade 0.62	Other man. 0.81	Other man. 0.60	General mac. 0.83	Trans & comm 0.99	Trans. equip. 0.52	Mining 0.25	Real estate 0.58	Wood 1.19
10	Ceramics 0.55	Chemicals 0.71	Ceramics 0.55	EGW 0.72	FIRB 0.96	Agriculture 0.43	Food 0.24	Transport 0.43	Chemicals 1.14

Notes: Major industry codes are follows: General mac. = general machinery, Commu.= communication services, Agriculture = agriculture, forestry & fishery, Elec.mac.= electrical machinery, Wood = wood product & furniture, Ceramics = stone, clay & glass, Trans & comm = transportation and communication services, Other man = other manufacturing, Finance = finance & insurance, FIRB = finance, insurance, real estate & business services, Real estate = real estate and business services, Fab. metal = fabricated metals, Rubber = rubber & plastic products, CSPS = community, social and personal services, Foods = food, beverage & tobacco, EGW = electricity, gas & water.

Figure 1   R&D and Productivity Performance in the 1980s



Source: Secretariat estimates.

Table 5 TFP and R&D Regression: Manufacturing Sector

Unweighted regressions

	Right hand variables (estimated coefficients and t-statistics in parenthesis)																
	RD		RTL		RTA		RTI		RTC		RDA		RMA		RDT		Adj.
Eq.	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	R2
(1)																	0.13
(2)	0.17	0.15															0.21
	(3.10)	(3.40)															
(3)			0.15	0.13													0.21
			(3.17)	(3.29)													
(4)	0.14	0.17			0.29	-0.16											0.21
	(2.01)	(2.94)			(0.74)	-(0.56)											
(5)													0.04	0.09	0.16	0.13	0.20
													(0.08)	(0.26)	(2.62)	(2.43)	
(6)	0.13	0.17									1.05	-0.87	0.00	0.12			0.21
	(1.94)	(2.92)									(1.28)	-(1.49)	-(0.01)	(0.34)			
(7)	0.14	0.17					0.28	-0.15	-2.08	-0.80							0.20
	(2.10)	(2.94)					(0.70)	-(0.53)	-(0.75)	-(0.36)							

Weighted regressions with average sectoral shares of gross output

	Right hand variables (estimated coefficients and t-statistics in parenthesis)																
	RD		RTL		RTA		RTI		RTC		RDA		RMA		RDT		Adj.
Eq.	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	R2
(1)																	0.27
(2)	0.12	0.14															0.31
	(2.33)	(3.37)															
(3)			0.11	0.12													0.31
			(2.39)	(3.34)													
(4)	0.09	0.14			0.24	0.00											0.31
	(1.38)	(2.53)			(0.61)	(0.01)											
(5)													0.20	0.12	0.10	0.12	0.31
													(0.44)	(0.37)	(1.72)	(2.44)	
(6)	0.09	0.14									0.42	-0.45	0.19	0.13			0.30
	(1.31)	(2.59)									(0.45)	-(0.72)	(0.43)	(0.42)			
(7)	0.10	0.14					0.25	0.00	-2.65	0.09							0.31
	(1.53)	(2.50)					(0.64)	(0.00)	-(1.07)	(0.04)							

1. Dependent variable is the average annual TFP growth in each period.
2. All regression models include country-specific dummies in both period. Therefore, the coefficients in each explanatory variables tend to explain resulting variance across the industries and countries in a period.
3. All the explanatory variables are in terms of the R&D amount per unit of gross output, ie, intensities. Abbrebiation for each variable are: RD= direct R&D, RTL=total (direct plus acquited) R&D , TRA=total acquired R&D, RTI=R&D embodied in purcahsed intermediate inputs, RTC=R&D embodied in purchased investment goods, RDA=domestically acquired R&D, RMA = acquired R&D through imports and RDT =direct R&D plus domestically acquired R&D.

Table 6 TFP and R&D Regression: Services Sector

Unweighted regressions

	Right hand variables (estimated coefficients and t-statistics in parenthesis)										
	RTA		RTI		RTC		RDA		RMA		Adj.
Equation	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	R2
(1)											-0.03
(2)	1.34	1.91									0.11
	(2.81)	(3.50)									
(3)					1.67	2.51					0.17
					(3.35)	(4.31)					
(4)							0.69	1.22	4.22	3.64	0.13
							(1.15)	(1.64)	(2.39)	(2.59)	
(5)			-0.90	-0.41	1.69	2.50					0.16
			-(0.67)	-(0.37)	(3.36)	(4.26)					

Weighted regressions with average sectoral shares of gross output

	Right hand variables (estimated coefficients and t-statistics in parenthesis)										
	RTA		RTI		RTC		RDA		RMA		Adj.
Equation	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	R2
(1)											-0.05
(2)	0.40	1.32									-0.01
	(0.71)	(2.30)									
(3)					1.07	2.29					0.05
					(1.62)	(3.32)					
(4)							-0.25	0.34	2.90	3.46	0.01
							-(0.33)	(0.41)	(1.45)	(2.39)	
(5)			-1.37	-0.40	1.14	2.28					0.05
			-(1.28)	-(0.44)	(1.71)	(3.31)					

1. Dependent variable is the average annual TFP growth in each period.
2. All regression models include country-specific dummies in both period. Therefore, the coefficients in each explanatory variables tend to explain resulting variance across the industries and countries in a period.
3. All the explanatory variables are in terms of the R&D amount per unit of gross output, ie, intensities. Abbrebiation for each variable are: RD= direct R&D, RTA=total acquired R&D, RTI=R&D embodied in purcahsed intermediate inputs, RTC=R&D embodied in purchased investment goods, RDA=domestically acquired R&D, RMA = acquired R&D through imports and RDT =direct R&D plus domestically acquired R&D.

Figure 2. The Rate of Return of Direct R&D by Country
(Manufacturing industries)

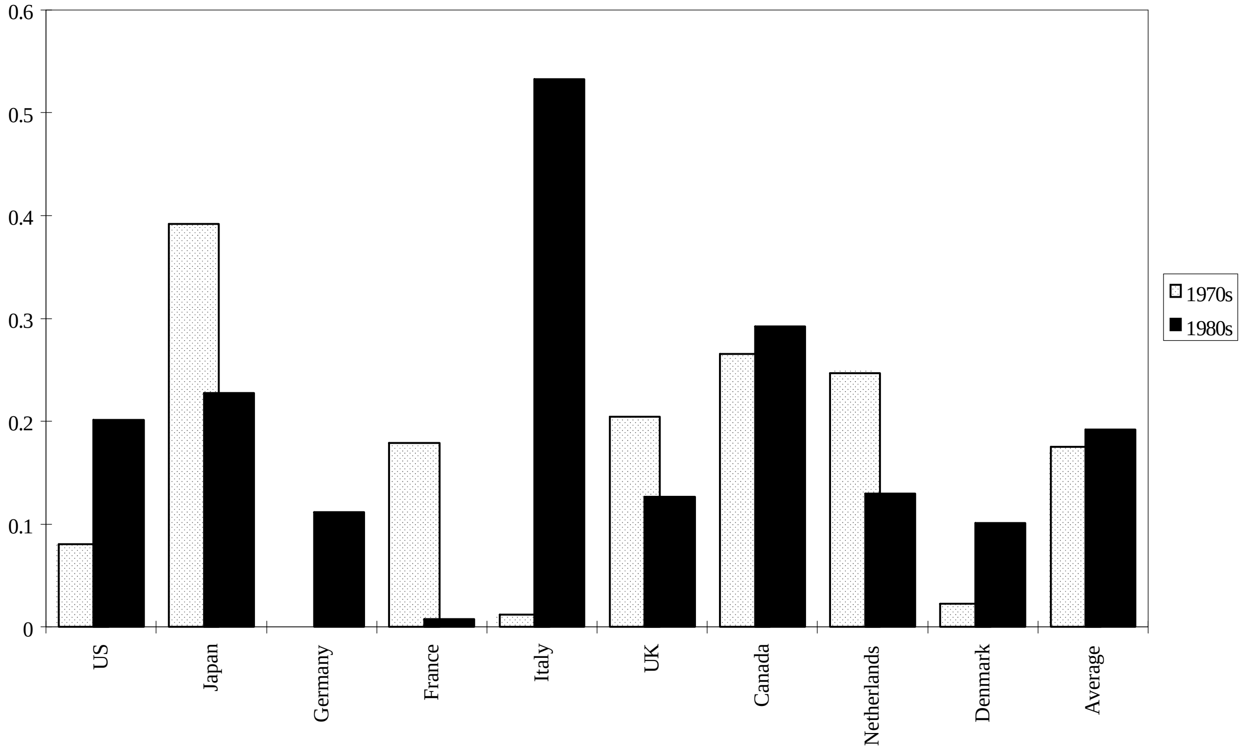


Figure 3. The Rate of Return of Embodied R&D by Country
(Service industries)

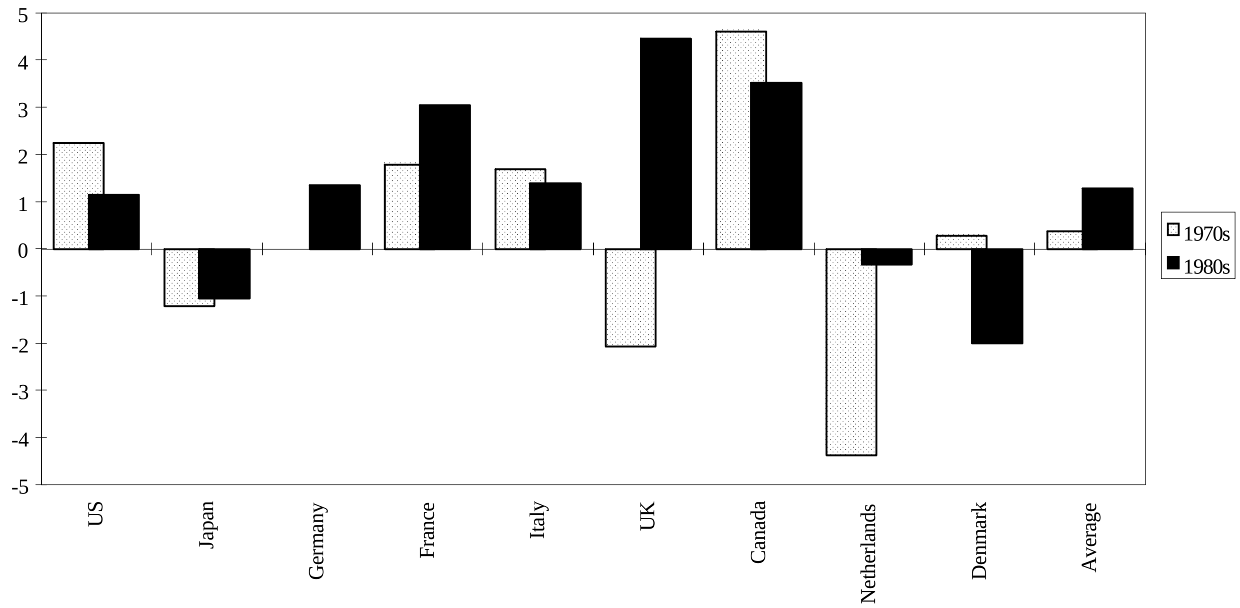
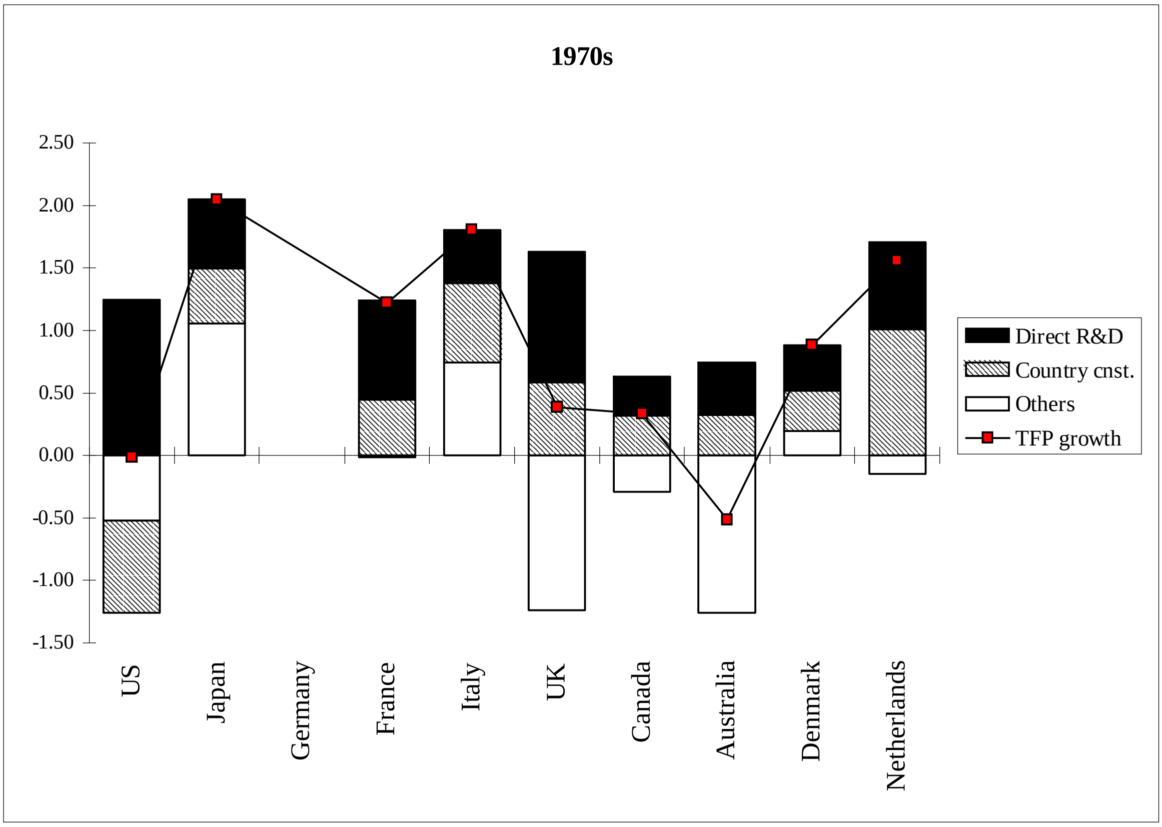


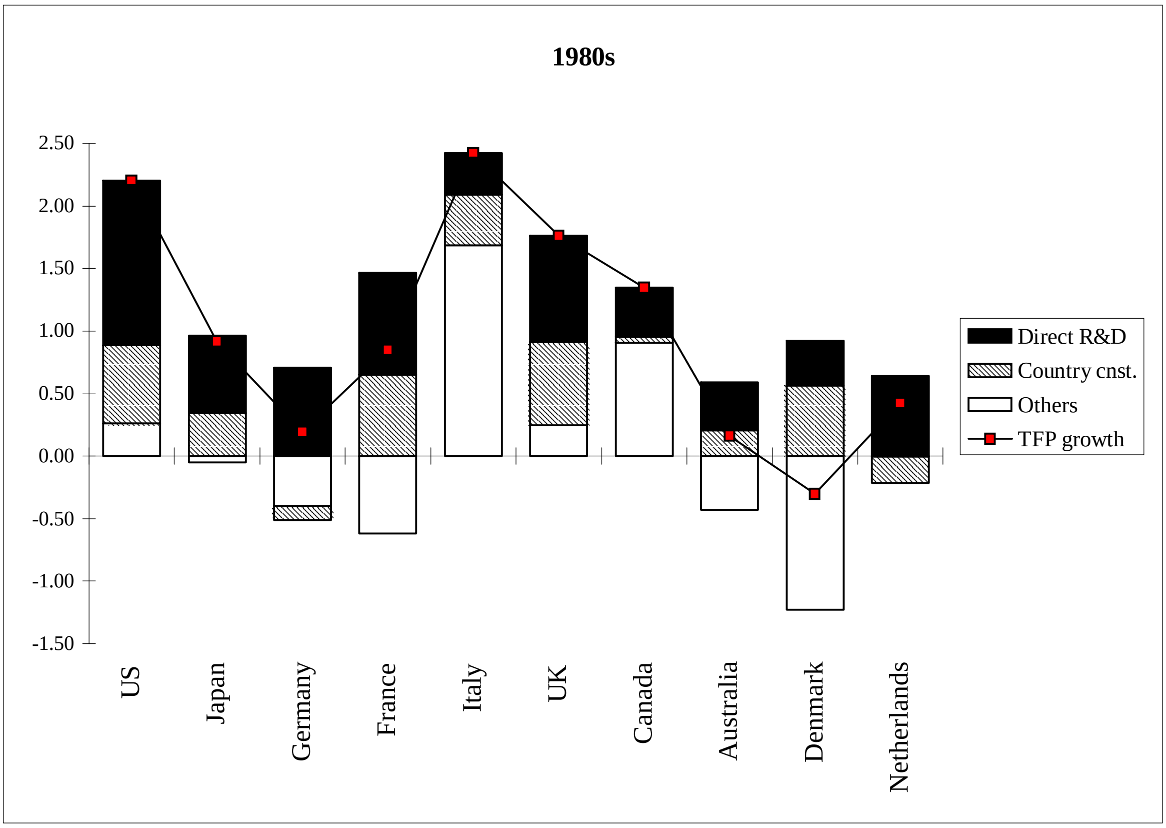
Table 7. TFP and R&D: Regressions by group of industries (unweighted OLS

Industry groups	Regression 1			Regression 2			Regression 3		
		1970s	1980s		1970s	1980s		1970s	1980s
Primary sector	Embodied R&D	-0.39	2.52						
(Agriculture,		(-0.34)	(2.99)						
Mining)				Domestic	0.50	-1.07	Capital	-10.57	10.32
					(0.28)	(-0.79)		(-2.34)	(2.55)
				Imported	-2.67	17.56	Intermediate	7.01	-2.51
					(-0.59)	(4.57)		(1.91)	(-0.98)
Light Manufacturing	Direct R&D	-1.36	-0.40	Direct R&D	-1.81	-0.44	Direct R&D	-1.41	-0.36
(Food,		(-1.19)	(-0.40)		(-1.48)	(-0.45)		(-1.24)	(-0.36)
Textiles,	Embodied R&D	2.00	0.67						
Wood,		(1.59)	(0.73)						
Other manufacturing)				Domestic	3.46	0.93	Capital	0.50	2.27
					(1.67)	(0.70)		(0.06)	(0.31)
				Imported	0.16	0.42	Intermediate	1.87	0.23
					(0.06)	(0.21)		(1.02)	(0.14)
Heavy Manufacturing	Direct R&D	-0.37	0.18	Direct R&D	-0.39	0.15	Direct R&D	-0.36	0.18
(Paper & pulp,		(-1.17)	(0.67)		(-1.21)	(0.54)		(-1.16)	(0.65)
Chemicals,	Embodied R&D	0.60	0.68						
Stone, clay & glass,		(0.57)	(0.81)						
Basic metals)				Domestic	0.51	1.12	Capital	0.97	0.76
					(0.31)	(0.82)		(0.23)	(0.22)
				Imported	1.15	0.61	Intermediate	0.04	0.57
					(0.65)	(0.45)		(0.02)	(0.41)
Machinery sector	Direct R&D	0.26	0.21	Direct R&D	0.24	0.19	Direct R&D	0.27	0.21
(General machinery,		(2.20)	(2.00)		(1.95)	(1.85)		(2.25)	(2.00)
Electrical machinery,	Embodied R&D	-0.27	-0.10						
Instruments,		(-0.50)	(-0.26)						
Transport machinery,				Domestic	0.18	-0.10	Capital	-2.74	-1.76
Metal products)					(0.18)	(-0.13)		(-0.48)	(-0.46)
				Imported	-0.38	0.06	Intermediate	-0.25	0.03
					(-0.56)	(0.11)		(-0.37)	(0.06)
Utility Services	Embodied R&D	-0.86	-0.74						
(Electricity, gas & water,		(-1.08)	(-1.05)						
Construction)				Domestic	-1.19	-0.28	Capital	-0.70	-1.43
					(-1.04)	(-0.27)		(-0.55)	(-1.16)
				Imported	0.95	-2.28	Intermediate	-1.59	-0.27
					(0.37)	(-0.90)		(-1.10)	(-0.23)
ICT Services	Embodied R&D	1.40	1.48						
(Transport,		(3.14)	(3.26)						
Communication,				Domestic	0.71	1.02	Capital	2.49	2.36
Finance & insurance,					(1.18)	(1.46)		(3.26)	(2.79)
Real estate & busin. serv.)				Imported	4.92	2.93	Intermediate	-3.53	-1.38
					(2.77)	(2.24)		(-1.20)	(-0.57)
Other services	Embodied R&D	-0.40	-0.55						
(Trade,		(-0.47)	(-0.69)						
Hotels & restaurants,				Domestic	-0.03	-0.37	Capital	-1.60	3.73
CSPS)					(-0.02)	(-0.30)		(-0.86)	(1.52)
				Imported	-1.47	-1.00	Intermediate	0.49	-4.77
					(-0.31)	(-0.34)		(0.21)	(-2.01)
Adj. R2	0.10			0.14			0.12		
Sample size	384			384			384		

Note: Not reported in the table, each regression includes country-specific time dummies for each period .

Figure 4 R&D Contribution to TFP Growth in the Machinery Sector





Note: The contributions of R&D and country specific dummies were calculated by using the estimated parameters of Regression 2 in Table7. Averaging both hand-side variables over the industries in the machinery group was done by using gross output shares of each industry.

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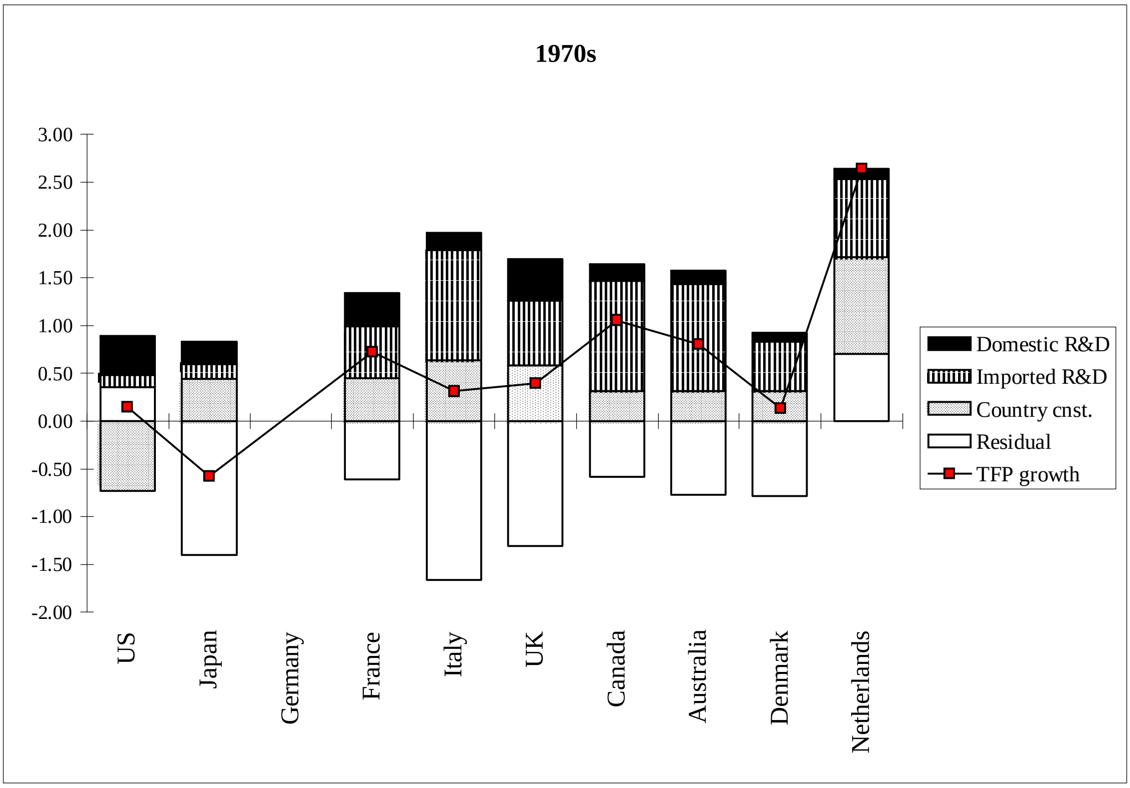
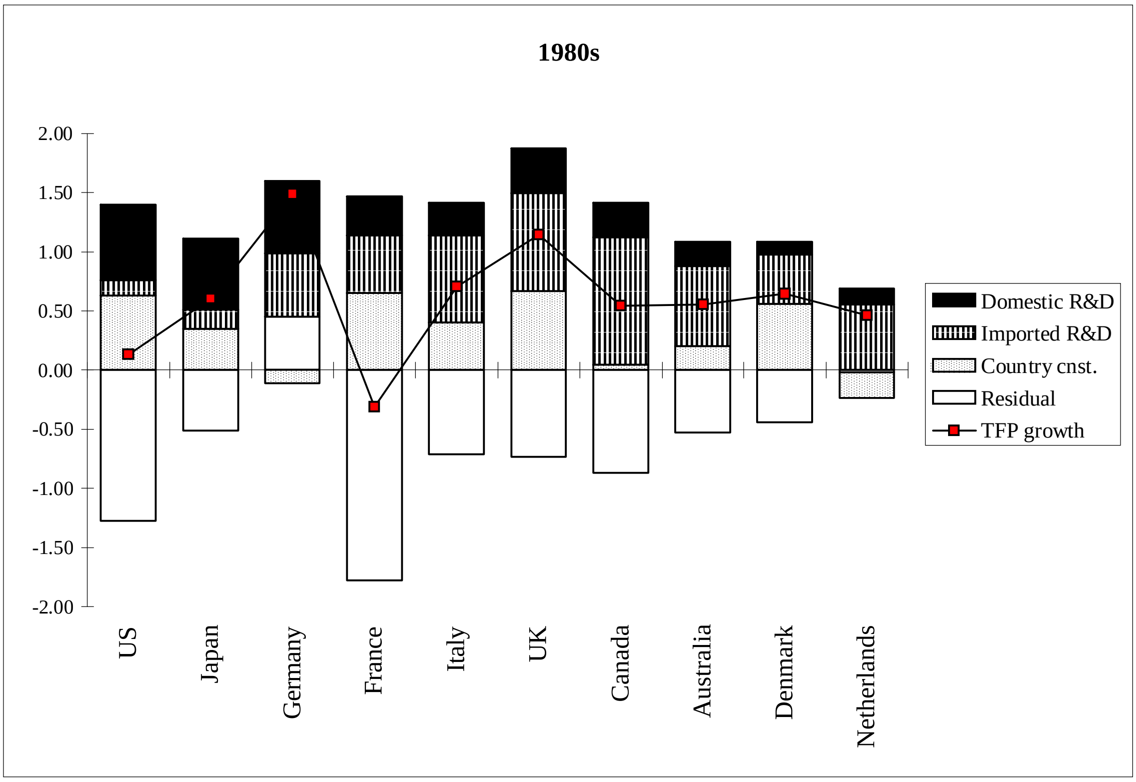
Figure 5 R&D contribution to TFP growth in the ICT services sector





Note: The contributions of R&D and country specific dummies were calculated by using the estimated parameters of Regression 2 in Table7. Averaging both hand-side variables over the industries in the machinery group was done by using gross output shares of each industry.

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Table 8. Comparisons of results of various studies

Study	Data	Weighting Matrix	Rate of return on outside R&D
Terleckyj (1974)	20 manuf. ind. US	IO flows	45% (total), 78% (private)
		investment flows	50% (total)
	13 non manuf. ind. US	IO flows	187%
		investment flows	762%
Terleckyj (1980)	20 manuf. ind. US	IO flows	183%
Odagiri (1985)	15 manuf. ind. Japan	IO flows	0%
Wolff-Nadiri (1993)	50 manuf. ind. US	IO flows	0% (private or total)
		investment flows	11% (private)
Goto-Suzuki (1989)	50 industries Japan	IO & investment flows	80%
	45 industries Japan	position vector in R&D space	4.30%
Sveikauskas (1981)	102 industries US	investment flows	861%
Scherer (1982, 1984)	36 to 87 ind. US	patent flows	147%
Griliches-Lictenberg (1984b)	193 manuf. ind. US	patent flows	0% to 90%
Englander et. all (1988)	16 ind., 6 countries	Canadian patent flows	-11% to 50%
Doucharme-Mohnen (1989)	25 ind. Canada	patent flows	30% to 685%
Sterlacchini (1989)	15 manuf. ind. UK	IO flows	9% to 12%
		innovation flows	14% to 30%
Hanel (1994)	19 industries Canada	patent flows	0.60%
Van Meijl (1994)	30 industries France	IO flows	41% to 46%
		investment flows	415% to 569%
		patent flows	19% to 24%
Fecher (1992)	8 manuf. ind., 11 OECD	sum of sectoral R&D from 5	0%
Soete-Verspagen (1993)	aggregate 23 countries	foreign technology payments	0%
		sectoral R&D from 9 sectors	0%
Coe-Helpman (1993)	aggregate 22 countries	Import weighted foreign R&D	0.03% to 0.18% (1)
Hanel (1994)	19 industries Canada	percentage sales from foreign	0.20%
Sakurai et al. (1995)	15-24 ind., 10 countries	IO flows	0% (manufacturing)
		IO intermediate flows	0% (services)
		IO investment flows	167%-250% (services)
		IO domestic flows	69%-127% (services)
		IO imported flows	420%-360% (services)

(1) Output elasticity.
Note: Adapted from Mohnen (1994).

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