Measuring Multifactor Productivity Growth
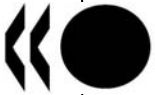
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OECD

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development **15-Oct-2007**
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English text only

DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INDUSTRY

MEASURING MULTIFACTOR PRODUCTIVITY GROWTH

STI WORKING PAPER 2007/5

Anita Wölfl and Dana Hajkova

JT03233949

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MEASURING MULTIFACTOR PRODUCTIVITY GROWTH

Anita Wölfl[*], Dana Hajkova[**],[1]

ABSTRACT

This paper quantifies and examines the contribution of capital, labour and multifactor productivity (MFP) to GDP growth and analyses the role of measurement of capital and labour inputs for the MFP estimate, using a comprehensive growth accounting exercise for 14 OECD countries. For most OECD countries, the strongest contributions to GDP growth over the past decade have come from growth in total capital input and MFP. This is to some extent related to an increasing role of information and telecommunication technologies in economic growth, particularly over the 1995-2003 period. The importance of measurement issues varies substantially with the type of measurement issue being considered. Substantial differences are observed between employment and hours worked based MFP growth rates. Also, the respective weights with which capital and labour enter the growth accounting equation, and thus, the assumptions concerning the efficiency of production and competition in product markets, significantly influence the resulting MFP estimate. Finally, the results suggest that policy conclusions on the basis of different empirical studies should be made very carefully, in particular as regards the time period for which the respective studies have been undertaken, as well as whether actual or trended time series are being considered.

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MESURE DE LA CROISSANCE DE LA PRODUCTIVITÉ GLOBALE DES FACTEURS

Anita Wölfl[*], Dana Hajkova[**],[1]

RÉSUMÉ

Ce document évalue et examine la contribution du capital, de la main-d'œuvre et de la productivité globale des facteurs (PGF) à la croissance du PIB, et analyse le rôle de la mesure des apports de capital et de travail dans l'estimation de la PGF, par un travail complet de quantification comptable de la croissance portant sur 14 pays de l'OCDE. Dans la plupart des cas, c'est la croissance des apports totaux de capital et celle de la PGF qui ont contribué le plus fortement à la croissance du PIB ces dix dernières années. Cette évolution est liée dans une certaine mesure au rôle de plus en plus grand des technologies de l'information et de la communication dans la croissance économique, en particulier pendant la période 1995-2003. L'importance des questions de mesure varie beaucoup en fonction de leur type. On observe des différences considérables entre les taux de croissance de la PGF fondés sur l'emploi et sur les heures travaillées. En outre, la part relative du capital et du travail dans l'équation comptable de la croissance et, par conséquent, les hypothèses concernant l'efficacité de la production et la concurrence sur les marchés de produits, influent sensiblement sur l'estimation de la PGF obtenue. Enfin, il semble qu'on ne puisse tirer de conclusions des différentes études empiriques qu'en exerçant la plus grande prudence, en particulier en vérifiant la période à laquelle ces études ont été effectuées, et en déterminant si les séries chronologiques considérées sont des séries réelles ou des séries de tendances.

TABLE OF CONTENTS

MEASURING MULTIFACTOR PRODUCTIVITY GROWTH

1.   Introduction

Capital deepening and growth in multifactor productivity (MFP) have obviously been important drivers of economic growth since the 1990s. However, assessment of the size of their growth contribution can be greatly influenced by measurement issues. In their seminal paper of 1967, Jorgenson and Griliches, for instance, found that the contribution of multifactor productivity to output growth declined from initially about 47% of total output growth to about 2.7% after correcting for potential errors in measuring output, capital and labour input, as well as the method of aggregation. They concluded that *"If quantities of output and input are measured accurately, growth in total output is largely explained by growth in total input"*. In this case, *"...the observed growth in total factor productivity is negligible."*

The present paper re-examines the contribution of capital, labour and multifactor productivity to GDP growth, using a comprehensive growth accounting exercise for several OECD countries. The main contribution of this paper is to draw attention to the importance of the measurement of MFP. The growth accounting methodology breaks GDP growth down into the weighted sum of growth rates of the main factor inputs, labour and capital, and the growth of MFP. Growth in MFP is measured as the so-called Solow residual, *i.e.,* the part of GDP growth that cannot be explained by the growth of capital and labour input. The paper contrasts the presented MFP measure with those based on different assumptions and examines how to measure growth in these factor inputs and their weights in total costs or income.

This paper builds on the OECD Productivity Database (PDB), which makes it possible to compute more precisely the contributions of growth factors, including the contribution of different capital assets.[2] The paper is structured as follows. The next section starts with an overview of the composition of GDP growth over time, and investigates whether GDP growth during 1990-2003 was driven by compositional changes, such as a shift from labour to capital or a shift towards ICT capital. The third section examines the effect of capital input and labour input measurement on the resulting MFP growth. This starts with a theoretical outline of the main measurement issues. The impact of different methodologies and assumptions on the resulting MFP estimate is then analysed using a sensitivity analysis similar to that undertaken in Jorgenson and Griliches (1967). The fourth section concludes.

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2.   For technical reasons the paper uses data from December 2003 for the sensitivity analysis in Section 3. Recent results from the OECD Productivity Database are presented in Section 2. For a comparison of the results, see Table A1 in the appendix. For regular updates of the OECD Productivity Database, see www.oecd.org/statistics/productivity.

2. Growth in GDP and productivity – empirical results

2.1. The growth accounting framework and the data

This paper examines the contributions of labour and capital inputs and multifactor productivity to economic growth using the general growth accounting framework. The basic principle of this methodology is that growth in GDP can be broken down into the weighted sum of growth rates of the main factor inputs, labour and capital, with the respective weights being the shares of labour remuneration and capital income in total income or costs.[3] The part of GDP growth that cannot be explained by the rate of growth of capital and labour, the so-called Solow residual, is assumed to be the growth in MFP. Let $\dot{Y}/Y$ represent the growth rate of output, $\dot{K}/K$ the growth rate of capital input, $\dot{L}/L$ the growth rate of labour input and g growth in multifactor productivity, the general growth accounting framework can be written as:

$$\dot{Y}/Y = s_K \cdot \left(\dot{K}/K\right) + s_L \cdot \left(\dot{L}/L\right) + g \qquad (1)$$

It is useful for the interpretation of the empirical results later on to distinguish two different definitions of MFP growth, or g. The classical approach used by Solow sets growth in MFP equal to technological progress, in the form of a shift over time in the technology that is underlying the production function. The other approach is to think of MFP growth in a broader sense; in addition to pure technological change, it may involve the effect of unobserved factors, like changes in the efficiency of production, for instance, due to non-constant returns to scale or imperfect competition. Given that gauging the contribution of pure technological change would require quantifying the effect of the unobserved factors and would involve making additional assumptions, the latter definition of MFP (called "apparent" MFP in Schreyer, forthcoming) has been adopted in the paper. Since, in this case, the strict assumptions of constant returns to scale and perfectly competitive markets are not applied; total costs in the form of labour and capital remuneration do not have to be equal to total factor income. As a consequence, the weights in equation (1), *i.e.,* the shares of capital and labour, s_k and s_l, are the shares of capital and labour in total costs and not in total income, as they would be in the neoclassical growth accounting framework.[4]

The growth accounting exercise in this paper uses the OECD Productivity Database (PDB). The methodology used in PDB will be described in more detail in the third section of this paper. There are, however, two features of the PDB that are important for the interpretation of the main patterns shown in the second part of the paper. The first one relates to the nature of capital services as compared with measures of capital stock used in many other studies. The OECD Productivity Database constructs a measure of capital input which comes very close to the theoretical concept of the productive capital stock instead of a gross or wealth capital stock. It incorporates a so-called 'age-efficiency' function which reflects the loss in productive capacity of a capital good over time, *i.e.,* the rate at which the physical contribution to production of a capital good declines over time.

The second important aspect is that the OECD Productivity Database differentiates between capital assets. This implies that it takes into account the differences in growth rates across capital assets, enabling the analysis of the effects of capital composition on growth in GDP and MFP. In particular, the role of information and communications technology (ICT) for growth in GDP and MFP can be analysed thanks to

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3. Within the neoclassical growth accounting framework, total income is equal to total costs due to the assumptions of constant returns to scale and perfect competition in input and product markets.

4. For a more detailed presentation and discussion of these issues, see Schreyer (forthcoming).

the differentiation between ICT and non-ICT capital.[5] ICT-related capital assets include hardware, communication equipment and software. Non-ICT capital assets include transport equipment and non-residential construction, products of agriculture, metal products and machinery other than hardware and communication equipment, and other products of non-residential gross fixed capital formation. In order to account for rapid quality changes of ICT-capital assets, a harmonised hedonic price index is used.[6]

The results in the remaining part of section 2 are based on the model described by equation 1.[7] The change in capital input is defined as the change in capital services aggregated over assets and computed using the age-efficiency function and hedonic prices. Labour input is defined as total number of hours worked. Growth in MFP is the residual GDP growth unexplained by the sum of contributions of capital and labour, *i.e.*, their growth rates weighted by their respective shares in total factor cost.

2.2. *Growth in GDP and its components*

Figure 1 suggests that GDP growth in most OECD countries over the 1990s was for a large part driven by growth in capital and MFP. In many countries, growth in capital accounted for around one third of GDP growth from 1995 to 2003. A strong contribution of capital can in particular be observed in the United States, the United Kingdom, Denmark, Italy, Germany and Japan, and to a lower degree in Canada. For some countries, growth in MFP is the main driver of GDP growth in the 1995-2003 period. This is in particular the case for Ireland, Finland, Portugal, Australia, Sweden and France. Growth in labour input was also important for a few countries over 1995-2003, notably in Ireland, Canada and the Netherlands.

Figure 1 and Figure A1 in the annex indicate that the contribution of capital to GDP growth is less linked to economic cycles than the contribution of labour. While the contribution of labour was negative in many OECD countries during the first half of the 1990s, the contribution of capital was positive. This is even clearer when examined over a longer time period; in absolute terms, the contribution of labour has fluctuated more strongly than the contribution of capital for most countries while the contribution of capital has stayed relatively constant since 1980 (Figure A1). As will be discussed below, this is mainly due to higher variability in the growth rate of labour input as compared to capital input, and only to some degree due to changes in the relative shares of labour and capital.

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5.   Since this paper analyses the role of ICT within a growth accounting framework, it offers a **non-parametric** analysis of the effect of ICT on economic growth. Effects from ICT which are not measured by the contribution of ICT capital assets, such as spillovers from ICT, are only indirectly captured within the growth rate of MFP. For an empirical assessment of spillovers from ICT, see, for instance, Stiroh (2001). For an overview of estimations of the capital coefficient, *i.e.,* the elasticity of output with regard to capital input, see for instance Jorgenson (1999). See Schreyer (2001) for a discussion of hedonic price indices.

6.   A hedonic price index accounts for the changes in the quality of a product by making use of the relation of the prices of different varieties of a product and the amount of the characteristics in each of the variety that have an influence on the price (for a comprehensive treatment of hedonic indexes see Triplett, 2004). The hedonic price index for ICT-related components is harmonized by using the ratio of US price indices for ICT and non-ICT related goods (see also part 3.1).

7.   The reference scenario is described in more detail in section 3. This is also the approach that is used in the OECD Productivity Database.

Figure 1. **Contribution of capital, labour and MFP to GDP growth, 1990-1995 and 1995-2003[*], in percent**
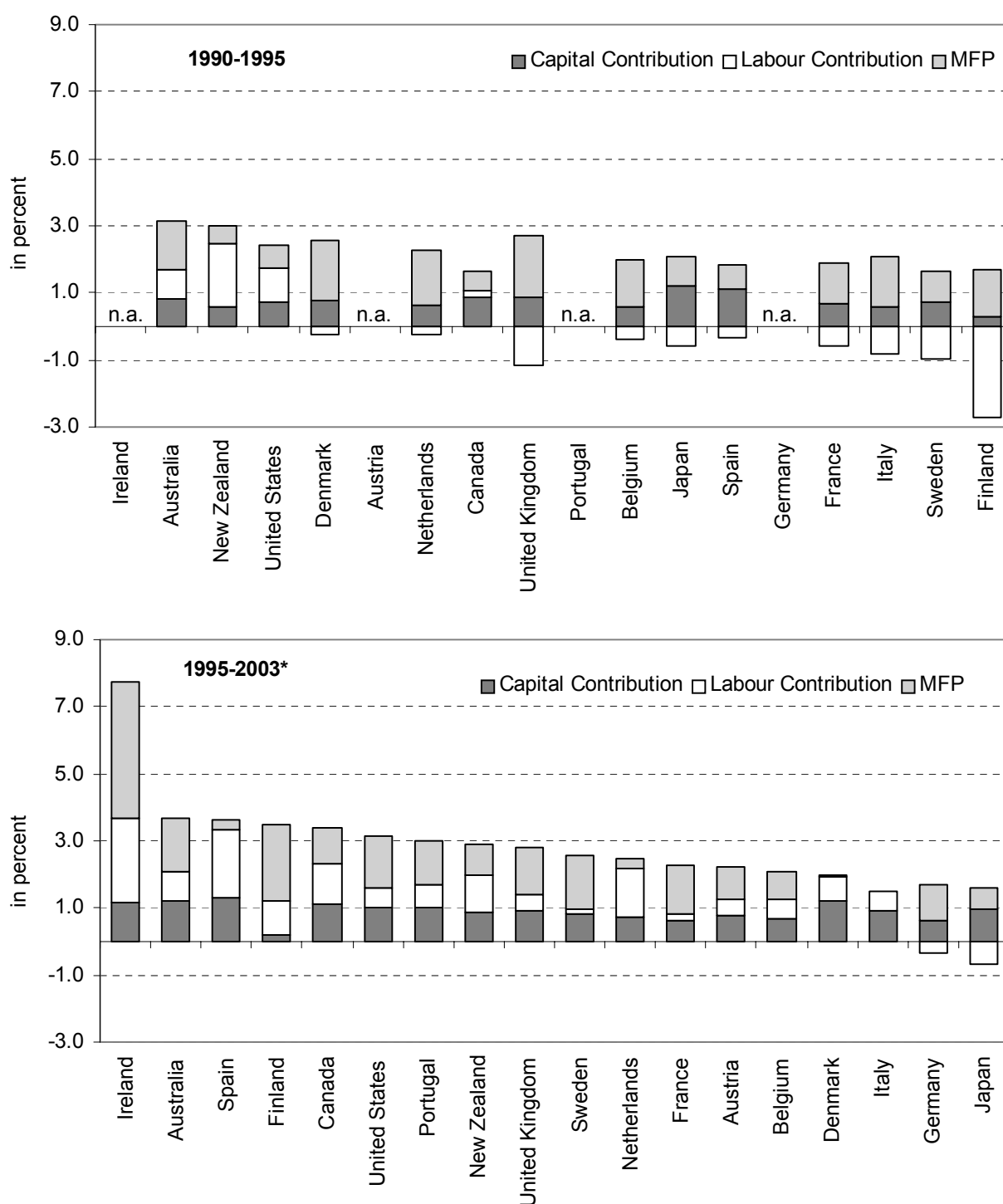
Note: *) or nearest year available.

Source: OECD Productivity Database, June 2006.

The importance of capital growth as a driver of GDP growth is partly due to strong investment in modern information and communication technologies (Figures 2 and 3).

9

Figure 2. **The contribution of growth in ICT capital assets to GDP growth**

1990-1995 and 1995-2003[*], in percentage points
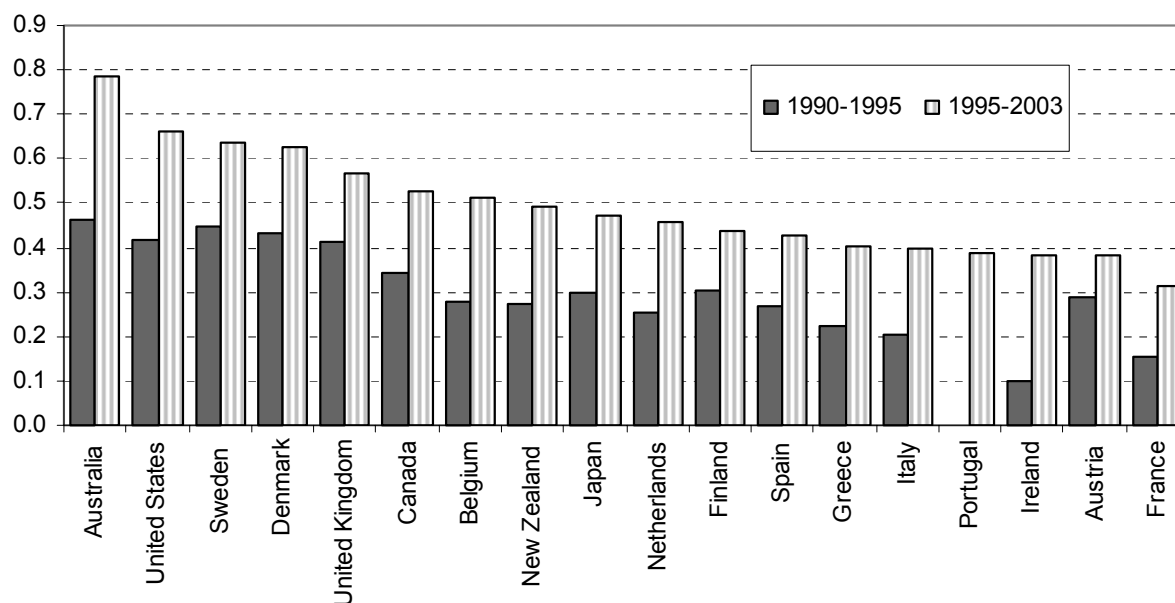
Note: *) or nearest year available.

Source: OECD Productivity Database, June 2006.

From 1995 to 2003, ICT capital contributed on average about 0.5 percentage points to GDP growth in OECD countries (Figure 2). Very strong contributions of ICT capital to GDP growth can be observed in the Australia, United States, Canada, the Netherlands and, where ICT capital explains about one quarter of GDP growth over 1995-2003. Figure 2 shows also that the contribution of ICT capital to GDP growth has strongly increased since the first half of the 1990s. In relative terms, the contribution of ICT capital to GDP growth increased from about 15% of total GDP growth to about 20% during the two periods.

To some extent, growth in GDP over the 1990 and in the beginning of the 2000s was influenced by a shift in the composition of capital services towards capital assets with stronger growth. This is, for instance, reflected in the increasing share of ICT capital in total capital input (Figure 3). While in the 1990-1995 period, it was non-ICT capital that contributed most to capital growth, ICT capital contributed to more than half of total capital growth over the 1995-2003 period in ten OECD countries. Throughout the 1990s, hardware accounted for the largest part of the contribution of ICT capital to growth in total capital, but software and communications equipment have become increasingly important.

Figure 3. **The contribution of growth in ICT capital to growth in total capital input**

1990-1995 and 1995-2003[*], in percentage points

1990-1995

1995-2003*

Note: *) Or nearest year available.

Source : OECD Productivity Database, 2003.

11
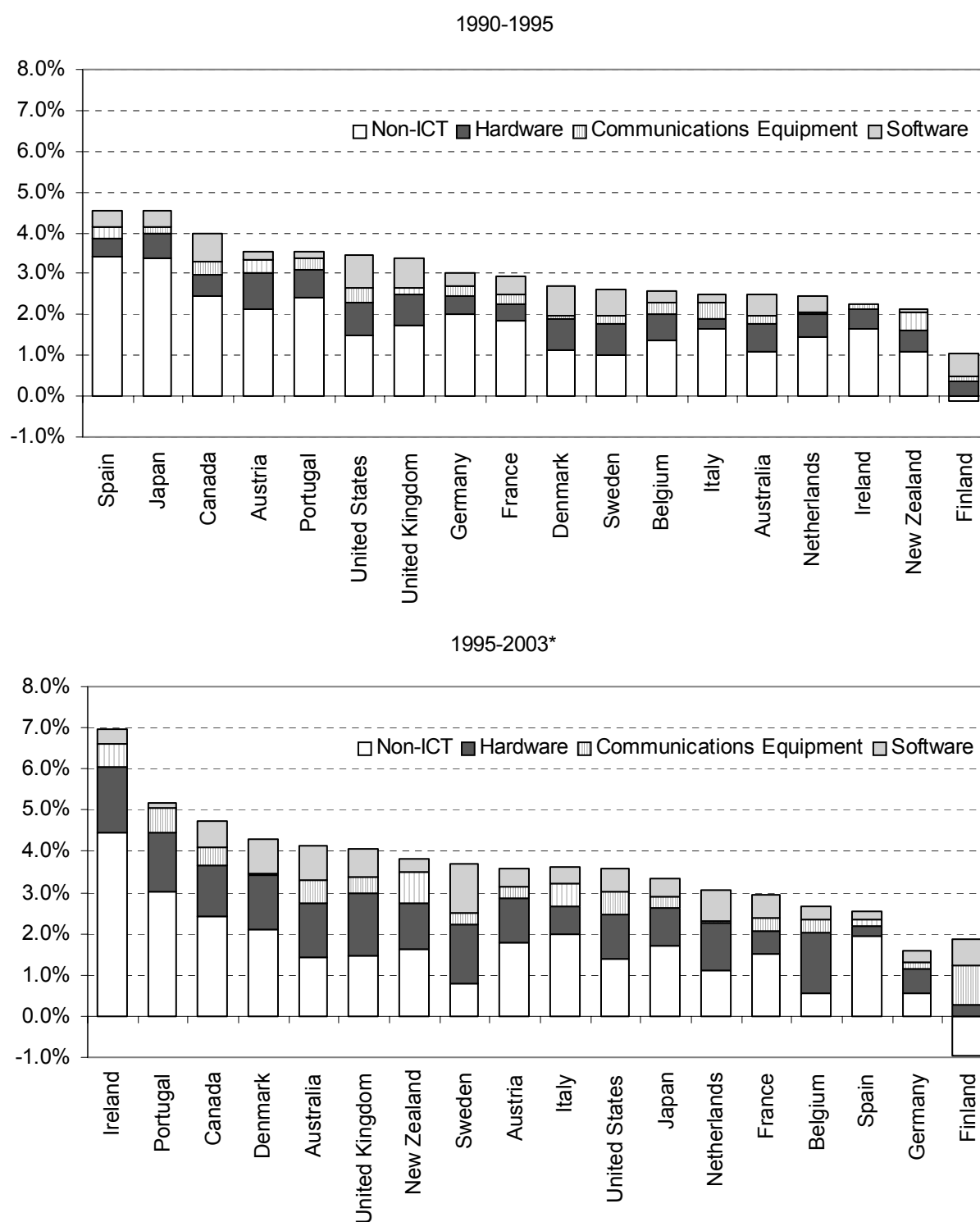
Figure 4 shows that the growth rate of multifactor productivity accelerated in several countries in 1995-2003 as compared to the first half of the 1990s. This is the case for Australia, France, Sweden and the United States, and particularly in Finland and Ireland, where MFP growth accelerated by more than 1 percentage point. In Ireland and Australia, MFP increased by about 1.5 to almost 2 percentage points from the 1980s to the 1990s. The relatively small increase in MFP growth over time in the United States as opposed to the relatively strong increases in other countries may be related to a catching-up effect of the other countries from relatively low levels of MFP.

Figure 4. **Growth in multifactor productivity, annual percentage growth**
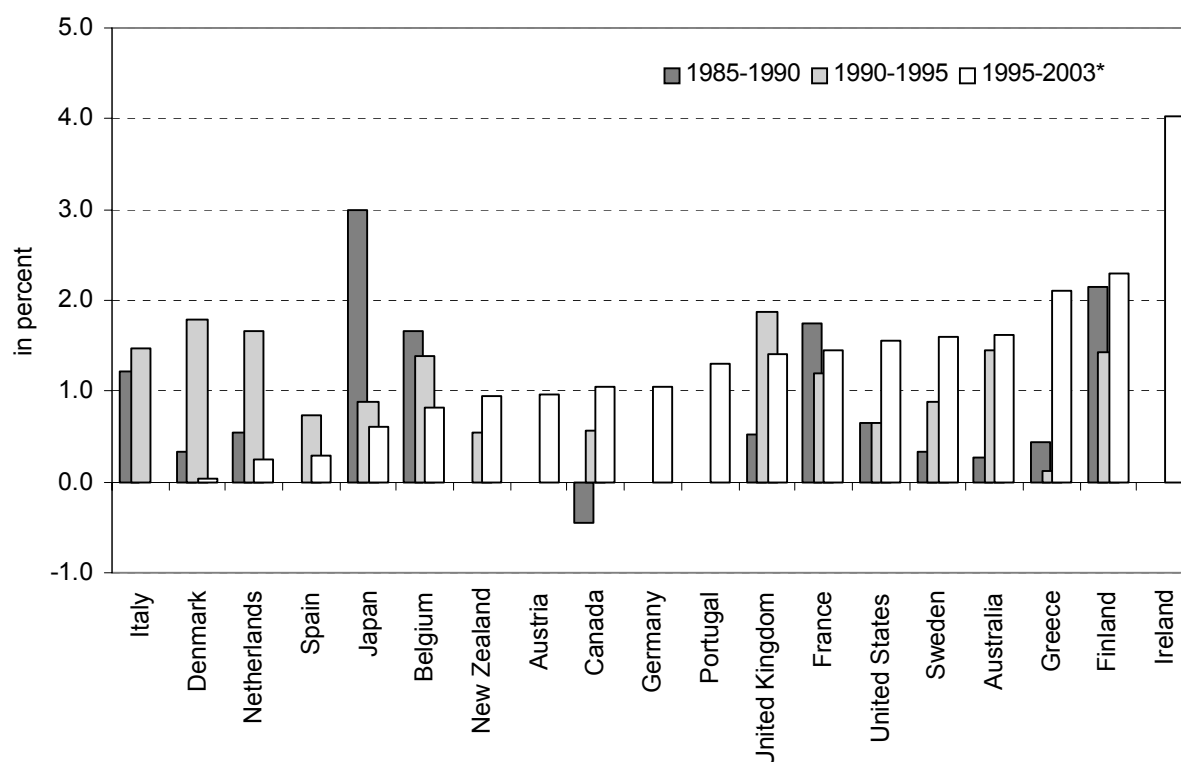
Note: *) Or nearest year available.

Source : OECD Productivity Database, 2006

Figure 4 ignores, however, that there have been strong fluctuations in MFP growth over time. This becomes clear from Figure 5, which presents the development in the growth rates of labour productivity, capital deepening, and MFP since 1980, and from Figure A2, which presents the annual average growth rates of GDP, labour, capital and MFP over time. There are two main results from this analysis. First, in most OECD countries, the growth in labour productivity, as measured by the growth of GDP per hour worked, moves almost in line with the growth in MFP. The visibly negative correlation between capital deepening and hours per worker clearly contributes to this result. Moreover, both MFP and labour productivity show a similar development to capital deepening in some countries and over certain time periods (Figure 5). These patterns support the observation made above that growth in OECD economies is mainly driven by capital deepening and the growth in MFP; a finding that also holds over long time periods. The lagged and weaker link between fluctuations in capital input and productivity may be due to two factors. The first is the additive nature of computed capital services. While investment may fluctuate considerably over time, these changes only show up as incremental changes in the accumulated capital stock. The second reason is that possible changes in the utilisation of capital are not reflected in the measures of capital services.

Figure 5. **Movements of growth in labour productivity, capital-deepening, and MFP, annual growth rates in percent**
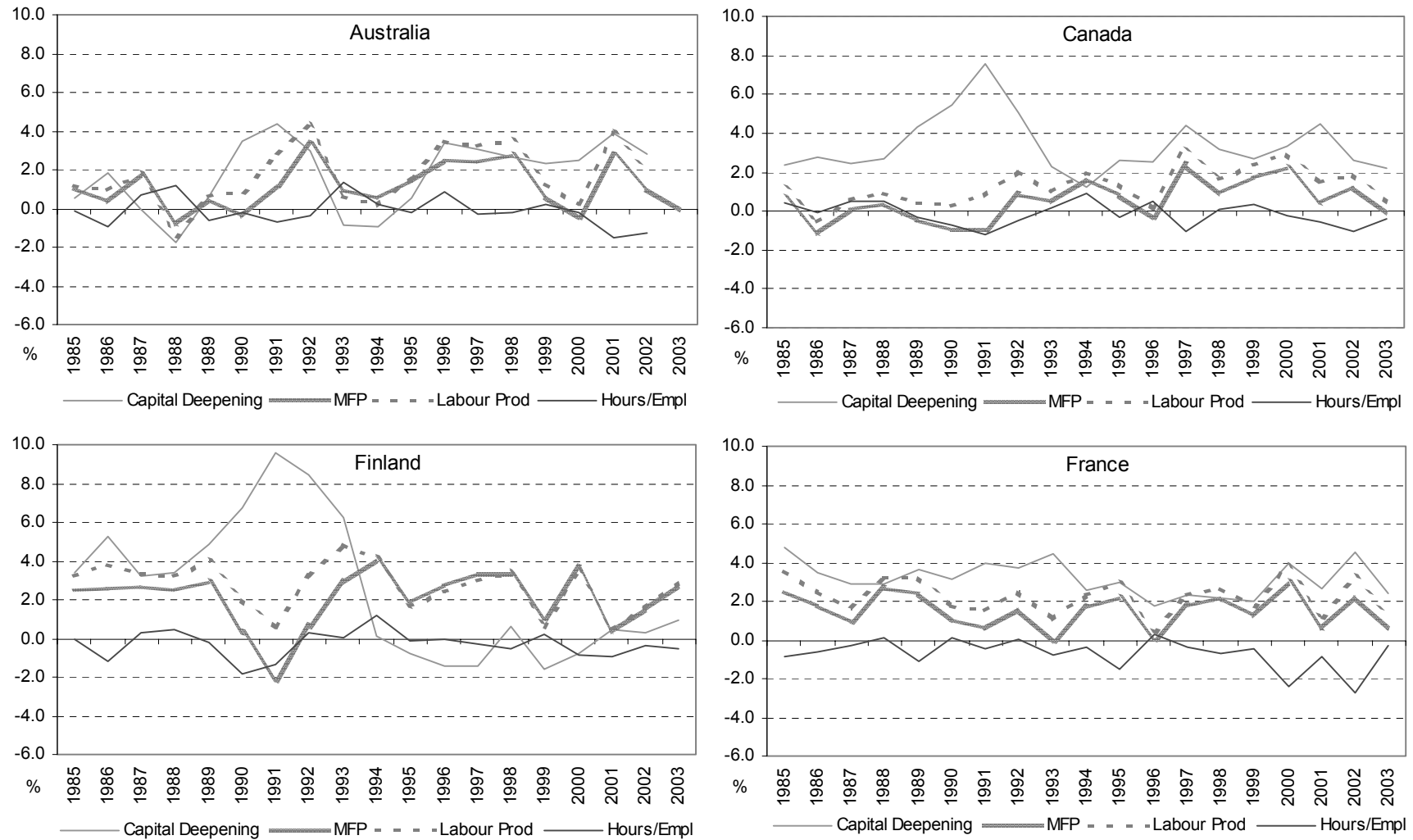
Source : OECD Productivity Database, 2006.

Figure 5. **Movements of growth in labour productivity, capital-deepening, and MFP, annual growth rates in percent**
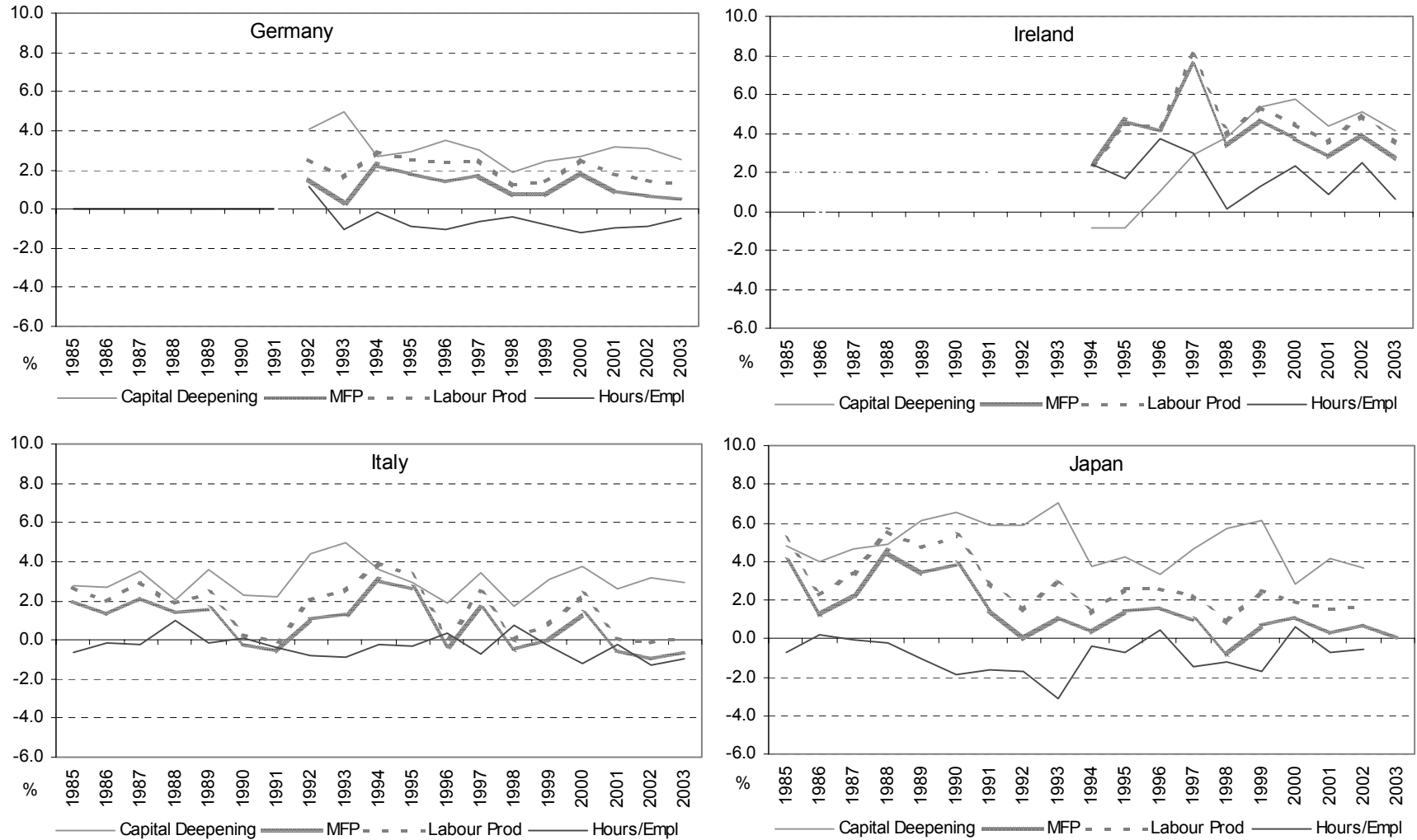
Source : OECD Productivity Database, 2006.

Figure 5. **Movements of growth in labour productivity, capital-deepening, and MFP, annual growth rates in percent, continued**

Source : OECD Productivity Database, 2006.

15

The second result from the analysis is that MFP growth shows strong fluctuations which are similar to GDP growth (Figure A2). There are typically four explanations for the pro-cyclical nature of MFP growth (Basu and Fernald, 2000; Basu *et al.*, 2001). First, MFP measures should pick up changes in technology. Thus, if the rate of technological change fluctuates over time, this will show up in cycles of output and productivity growth. Second, cycles in productivity growth may be related to imperfect compe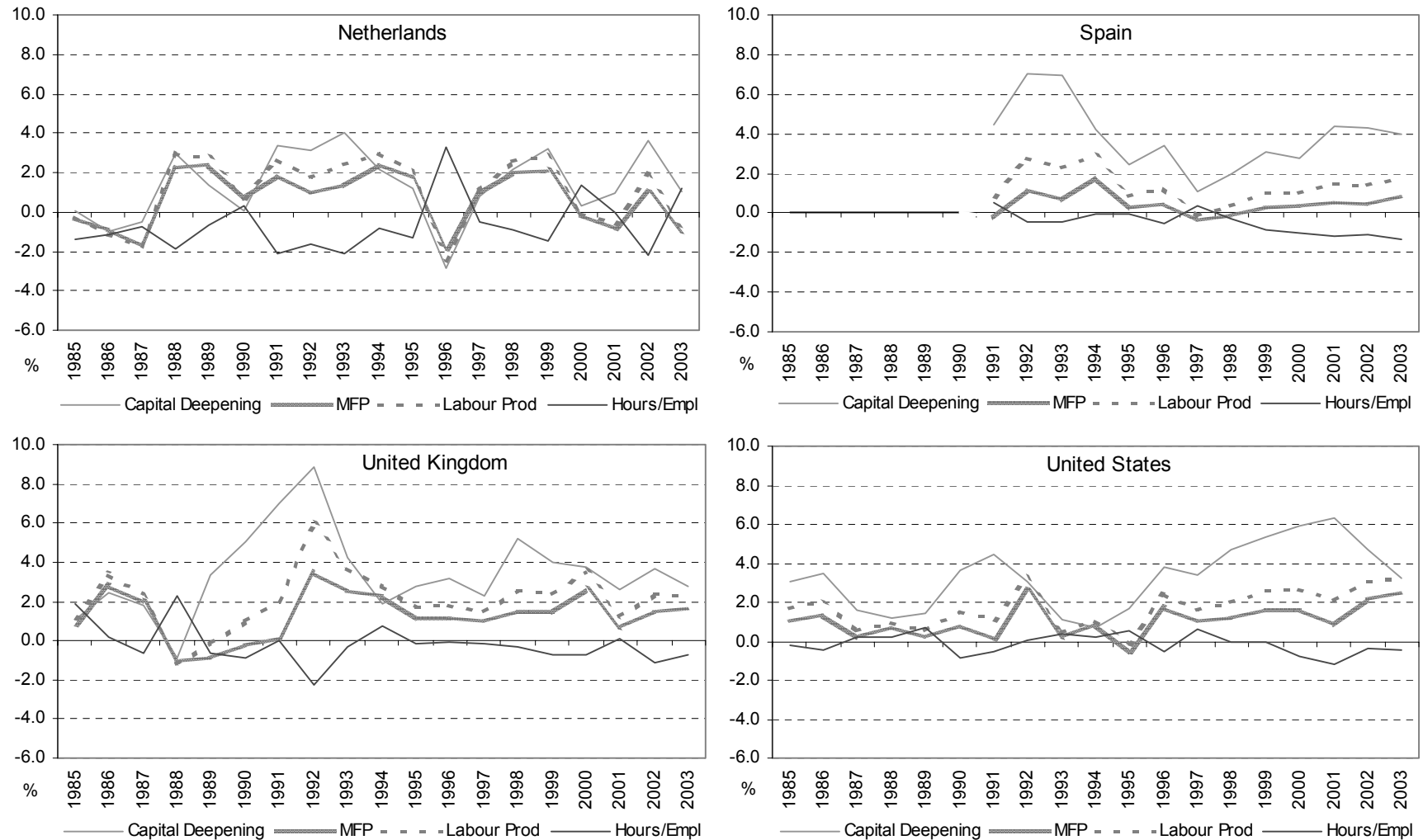tition and increasing returns to scale. Figure 5 shows strong cyclical behaviour in inputs, notably labour inputs. With imperfect competition and increasing returns to scale, increases in inputs may result in productivity increases. Third, not only investment in inputs but also their utilisation may vary over the business cycle. A cyclically-related reallocation of resources across uses with different marginal products (e.g., industries with different market power) is a fourth possible reason for the cyclicality of aggregate MFP.

3. Growth in MFP and the role of measurement

The empirical results above confirm a strong contribution of capital growth and MFP growth to growth of GDP. Both the contribution of capital as well as the rate of growth of MFP depend, however, on the way labour and capital inputs are measured. The following section examines the role of measurement for the growth rate of MFP. It starts with an overview of issues of MFP measurement as derived from the theoretical literature. It then analyses the sensitivity of measured MFP to different assumptions regarding the measurement of labour and capital.

3.1. *Measuring MFP in a growth accounting framework - basic concepts and methodologies*

The main measurement issues discussed here are those associated with the computation of capital services and labour input. Measurement issues related to capital concern, in particular, how 'productive capital' is defined and how differences in the productivity of capital assets over time or across assets are taken into account. One major capital-related measurement issue is also how to construct an underlying price index that can take account of rapid quality changes in some capital assets, notably ICT. The main labour-related issue is how to correctly measure the quality and utilisation of labour. Yet another set of results is obtained when MFP is computed based on trend values of underlying variables. These measurement issues are described in more detail below.[8]

The general framework

In general, (multifactor) productivity is defined as output per unit of factor input. In order to measure multifactor productivity, Solow started from a neoclassical production function $Y_t = G_t \cdot F(K_t, L_t, t)$ (Barro, 1998; Hulten, 1990).[9] In this formulation, the Hicks-neutral shift parameter G_t measures the shift in the production function at given levels of labour and capital. Growth in multifactor productivity is then defined as the Hicks-neutral and exogenous shift of the production function over time:

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8. This section provides a rough overview of relevant measurement issues. It is far from comprehensive and does not treat all issues in detail. See, for instance, Schreyer (forthcoming) for a more detailed theoretical and empirical analysis of the role of exogenous versus endogenous rates of return for MFP measurement.

9. See Griliches and Jorgenson (1966), Nadiri and Schankerman (1981), Harper (1997), Jorgenson (1999), Steindel and Stiroh (2001) for more detailed descriptions and discussions of growth accounting and MFP measurement.

$$\frac{G_t}{G_0} = \frac{Y_t/Y_0}{F(K_t, L_t)/F(K_0, L_0)}. \tag{2}$$

Solow addressed the key question of measuring G_t by using the total differential of the production function and thus a non-parametric index number that does not impose a specific form on the production function.[10] Let $\dot{Y}/Y$ represent the growth rate of output, $\dot{K}/K$ the growth rate of capital input and $\dot{L}/L$ the growth rate of labour input. Then, multifactor productivity growth is the part of GDP growth that cannot be explained by the rate of growth of capital and labour as:

$$g = \dot{Y}/Y - \left(\frac{F_K K}{Y}\right) \cdot \left(\dot{K}/K\right) - \left(\frac{F_L L}{Y}\right) \cdot \left(\dot{L}/L\right). \tag{3}$$

In this formulation, F_K and F_L stand for the factor marginal products $\partial F/\partial K$ or $\partial F/\partial L$. Using logarithmic terms, equation (3) becomes:

$$g = \frac{d\ln Y}{dt} - \frac{F_K K}{F} \cdot \frac{d\ln K}{dt} - \frac{F_L L}{F} \cdot \frac{d\ln L}{dt}. \tag{4}$$

When product and factor markets are competitive and under constant returns to scale, a profit-maximising firm will hire labour and invest in capital such that inputs are paid their marginal products. This means that the marginal product of capital is equal to the real user cost or rental price per capital, $F_K = u/P$; and the marginal product of labour is equal to the average wage rate per employed person or per hour, $F_L = w/P$. Let wL represent total compensation of labour and uK total remuneration of capital (in time t), then the standard primal estimate of the rate of growth of MFP follows from:

$$g = \frac{d\ln Y}{dt} - s_K \frac{d\ln K}{dt} - s_L \frac{d\ln L}{dt}. \tag{5}$$

with s_K and s_L being the share of labour and capital in total costs or income.[11]

From equation (2) to (5) it becomes clear that, in theory, g is equal to the growth rate of the Hicksian efficiency parameter. In practice however, g is a '*measure of our ignorance*', as Abramovitz (1956, cited in Hulten (1990)) called it, precisely because g is a residual. Or as Hulten (1990) puts it: *"This ignorance covers many components, some wanted (like the effects of technical and organisational innovation), others unwanted (measurement error, omitted variables, aggregation bias, model misspecification)."*

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10.   The link between the change in the shift parameter and the index number can be seen by comparing G_t with

the general formulation of index number: S_t: $\dfrac{S_t}{S_0} = \dfrac{Q_t/Q_0}{(r_o K_t + w_0 L_t)/(r_o K_0 + w_0 L_0)}$. Since data are not

continuous over time, but come in discrete time units, the continuous Divisia index is approximated by the Törnquist index. This means that the continuous-time income shares s_k and s_l are replaced by the average between-period shares of period t and t-1. The starting values are the shares for the first year for which respective data were available.

11.   The choice between total costs or total income as the reference for the input shares depends on the assumptions underlying the production function and factor and product markets. See more below on the measurement of the capital and labour shares.

Measuring physical capital[12]

The appropriate measure for capital input within the growth accounting framework is the flow of productive services that can be drawn from the cumulative stock of past investments in capital assets. Flows of productive services of an office building, for instance, are the protection against rain or the comfort and storage services that the building provides to personnel during a given period (Schreyer *et al.*, 2003). The price of capital services per asset is measured as their rental price. If there were complete markets for capital services, as is the case for an office building, for instance, rental prices could be directly observed. For some assets, however, rental prices have to be imputed. The implicit rent that capital good owners 'pay' themselves gives rise to the terminology user costs of capital.

Total remuneration for capital, or total capital income, is the product of the quantity of capital services for each asset of a specific generation (or vintage), $K_{t,s}^{i}$, and the user costs, or the price, of capital services that are derived from an s-year old capital good of type *i* in year *t*, $u_{t,s}^{i}$.[13] The growth rate of total physical capital results then as the weighted sum of growth of services from each asset, with the share of capital income from each asset in total capital income, $\dfrac{u_i K_i}{\sum\limits_{j} u_j K_j}$, as the weight:

$$\frac{d \ln K}{dt} = \sum_{i=1}^{N} \frac{u_i K_i}{\sum\limits_{j} u_j K_j} \frac{d \ln K_i}{dt}$$

(6)

Measuring capital services per asset

Capital assets differ in their growth rates and in their marginal productivity, and how well these differences are taken into account is a determinant of the accuracy of the measured MFP growth. Theoretically, one could distinguish between three different forms of variations in the quantity of capital services: changes in the volume of a particular vintage of an asset over time (where vintage stands for a particular model with a particular technology), changes in the quantity of capital services between successive vintages of a particular asset, and changes in the overall asset composition of productive capital stocks.[14] Within the OECD Productivity Database, such variations are captured in two ways. First, the changes in capital services between different vintages are captured by the use of quality-adjusted price indices for investment in the computation of productive stocks. Second, differences in the productivity across assets are captured by applying user cost weights in order to aggregate across different types of assets. It can be shown that user cost weights, approximate the elasticity of production of individual assets.

The growth accounting literature has emphasised the role of changes in capital quality over time. Technological progress does not fall like manna from heaven as is assumed in the neoclassical model of growth accounting (Greenwood and Jovanovic, 1998, Hulten, 1992). New capital is better than the old

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12. The following description of the OECD approach concentrates on measurement issues that are relevant for the sensitivity analysis below.

13. Total payments for capital services are expressed in current prices but for convenience it is assumed that these current price payments can be broken down into a price component uk_t^i and a quantity component K_t^i.

14. Empirically, it is almost impossible to disentangle these three different forms of quality differences as this would require data on a level of detail that is not publicly available. However, the sensitivity analysis below will try to come as close as possible to an empirical assessment of these different forms of differences or variations in capital quality.

capital because of wear and tear, but also because the new capital is more productive than the old one was when *it* was new. As a consequence, the measured MFP growth will overstate true MFP growth if it fails to account for the changes in the composition of factor inputs towards assets of higher quality (Barro, 1998).

In order to capture changes in productivity of assets over time, notably across different generations, Hulten (1992) proposes to compute investments and the capital stock, or the services that can be derived from the existing capital stock, in terms of efficiency units. The capital stock in efficiency units can be identified as the product of the capital stock in natural units and the average embodied technical efficiency, defined as the weighted average of the best-practice efficiency levels associated with each past vintage of investment.[15]

To the extent possible, the data on productive capital services used in the OECD Productivity Database take such changes in capital quality into account. The productive stock of asset i at the end of period $t-1$, S_{t-1}^i, is computed as the accumulation of past investments, I_{t-s-1}^i, taking into account changes of productivity per asset over time, as represented by the retirement function, F_s^i, and the age-efficiency-function, h_s^i. The productive capital stock at the end of period *t-1* can thus be written as:

$$S_{t-1}^i = \sum_{s=0}^{t-1}(h_s^i \cdot F_s^i \cdot I_{t-s-1}^i) \,. \tag{7}$$

Equation (7) starts with the assumption that the flow of capital services from an *s*-year old asset is in proportion to the volume of investment of that asset *s* years ago. This assumption is made since typically neither the flow of capital services nor the length of lags between purchases of investment goods and their actual use in the production process are known. The quantity of investment of asset *i* in year *t*, I_{t-s-1}^i, is either measured in physical units if a truly homogenous asset can be observed or is obtained as the deflated value of current price investment.

The function F_s^i in equation (7) reflects the retirement pattern, which is needed to describe how assets are withdrawn from service. Typically, a retirement pattern is a distribution around the expected or mean service life. For instance, each truck in a fleet of identical vehicles of the same age has the same expected service life (Schreyer *et al.*, 2003). In practice, however, some of the trucks are retired before or after the expected service life. For present purposes, F_s^i is assumed to be non-negative and decreasing in *s*, the age of an asset. For a new asset with *s=0*, F_0^i takes a value of one.

The function h_s^i in equation (7) reflects the age-efficiency function. The rationale behind this function is that a cost-minimising producer will choose a composition of capital assets of different vintages such that the relative productivity of two different vintages is just equal to their relative user costs. The age-efficiency function reflects the loss in productive capacity of a capital good (of a particular generation) over time or the rate at which the physical contribution of this capital good to production declines over time. For the purpose at hand, the age-efficiency function is called h_s^i, with non-negative values that

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15.   Instead of computing the ratio between the quantities of investment, or of the capital stock, in natural and efficiency units, it is also possible to compare the prices of capital goods in natural and efficiency units. The invariance property of Hulten (1992) or Jorgenson (1966) states that the total amount spent on investment goods is invariant to the units in which the goods are measured. That is, if capital goods are measured in efficiency units, the prices of the capital goods are such that that the total amount spent in capital measured in natural units is equal to the total amount spent in capital measured in efficiency units.

decline with rising age s: $h_s^i = 1$ for a new capital good ($s=0$) and $h_s^i = 0$ for a capital good that has reached its maximum service life . In this general formulation, no other assumptions are made concerning the shape of h_s^i.

Measuring capital stock or prices in efficiency units captures, however, both, the variation in quality of capital goods with increasing age or time of utilisation, as well as the variation from one generation to another, the so-called vintage capital effect. Theoretically, these two cases could be disentangled.[16]

Measuring user costs per asset

The computation of user costs is derived from a basic relation in capital theory (Jorgenson, 1967) which states that the market price of an asset equals the discounted value of the rentals that the asset is expected to generate in the future. In the absence of complete markets, this relation can be re-formulated to state that the value of an asset equals the discounted marginal revenues from using the asset in production in the future. If vintage prices are not observable, Hulten (1990) shows that the user cost of capital for an s-year old asset $u_{t,s}^i$ can be expressed as the product of the purchase price of this asset ($q_{t-1,s}^i$) multiplied by the gross rate of return (GRR) on this asset. The computation of user costs in the OECD Productivity Database follows this idea (Schreyer *et al.*, 2003). The gross rate of return is defined as the sum of the discount rate r (or net rate of return), plus the rate of depreciation ($d_{t,s}^i$) minus the rate of asset price change ($\zeta_{t,s}^i$) plus an interaction term of depreciation and asset price change $d_{t,s}^i \cdot \zeta_{t,s}^i$. User costs of an s-year old asset i at time t are thus computed as: [17]

$$u_{t,s}^i = q_{t-1,s}^i (r + d_{t,s}^i - \zeta_{t,s}^i + d_{t,s}^i \cdot \zeta_{t,s}^i) \tag{8}$$

Quality adjusted price indices

Measurement problems may also occur since it is often difficult to separate the quantity and quality of different consumption and investment goods. This is particularly important in the case of goods or capital assets where quality changes rapidly, such as ICT investment. The literature proposes here to use quality adjusted price indices (Triplett, 2004). The results in the Section 2 of this paper are based on a harmonised

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16. If we suppose that firms invest every year in capital goods of the same characteristics as regards their age-efficiency profile *and* of the same generation, the average embodied technical efficiency would not change, the change in the quality of capital stock in natural and efficiency units would be identical. If we assume, however, that firms invest every year in capital goods of identical characteristics, but of different generations, average embodied technical efficiency would be identical to the changes in technical efficiency from one generation or vintage to the other. Hulten (1992) derives theoretically that the main driver of change in quality of the capital stock is the vintage capital effect, *i.e.*, the change in quality from one generation of capital assets to another. The results of the sensitivity analysis suggest, in line with this hypothesis; that the vintage effect is much more important as a driver of quality change than different assumptions as regards the age-efficiency-profile per capital asset.

17. For more information on the expected price change and the assumptions underlying the depreciation, see Schreyer *et al.* (2003)

hedonic price index for ICT-related components, which uses US price indices for ICT and non-ICT related goods.[18]

In contrast to other studies where the harmonisation is achieved by the use of the exchange rate, a polynomially smoothed ratio of the ICT and non-ICT related price index is used in the OECD Productivity Database as the relevant tool for the harmonisation.[19] Let $\lambda = P_{ict}^{i,usa} / P_{non\,ict}^{usa}$ be the ratio of the US price of an ICT capital asset i and the price of non-ICT assets. This ratio is assumed to be similar across countries. Then the harmonised hedonic price index for ICT-related assets for another country, for instance indexed by *deu* for Germany, is computed as the product of the price index for the non-ICT-related assets from Germany and the smoothed ratio of price indexes (λ) from the USA, $P_{ict}^{i,deu} = P_{non\,ict}^{ideu} \cdot \lambda$.

Aggregation across assets

The standard one-sector Solow model of growth accounting does not take into account that firms produce with different production functions. Firms might for instance differ in the mix of capital assets that they use for production. And, as seen above, capital assets may themselves differ in their relative productivity, not only across time but also within one period of time and generation. This difference is, for instance, central to the theoretical and empirical discussion about above-average positive effects of ICT technology on productivity growth, as discussed above. The sensitivity analysis below will calculate the capital composition effect, i.e., we derive what would happen if differences in productivity across capital assets were not appropriately taken into account in the contribution of capital to GDP growth. Differences in the marginal productivity of assets are captured by the user cost per asset, which is the appropriate weight for the aggregation across assets to calculate the volume of capital services. If, in contrast, market prices of the assets are used for the aggregation of the different assets, an aggregate measure of the net capital stock would be constructed.

Let $uK = \sum_i u_i K_i$ represent the total remuneration of capital, measured as the sum of the values of capital services for each individual asset type i, $u_i K_i$.[20] The total volume change in capital services is then the weighted average of the changes in capital services supplied by each asset, *i.e.* $d \ln K / dt = \sum_i u_i K_i / uK \cdot (d \ln K_i / dt)$. This implies the following for measured MFP growth:

$$g = \frac{d \ln Y}{dt} - \frac{uK}{C} \cdot \sum_{i=1}^{N} \frac{u_i K_i}{uk} \cdot \frac{d \ln K_i}{dt} - \frac{wL}{C} \cdot \frac{d \ln L}{dt} = \sum_{i=1}^{N} \frac{u_i K_i}{C} \cdot \frac{d \ln K_i}{dt} - \frac{wL}{C} \cdot \frac{d \ln L}{dt}, \qquad (9)$$

where $C = uK + wL$. The effect of cross-asset differences in capital productivity on measured MFP growth may be substantial.[21]

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18. Comparing the MFP estimates based on these different price assumptions comes close to the approach proposed by Hulten (1992) to estimate the average embodied technological efficiency of the capital stock by the ratio of prices of these capital goods in efficiency and natural units (footnote 16).

19. See also Schreyer (2000, 2001).

20. In Schreyer *et al.* (2003), the user costs of asset i are based on an exogenous expected net rate of return.

21. The literature, notably Jorgenson and Griliches (1967), Barro (1998) as well as Greenwood and Jovanovic (1998), therefore stress the importance of adjusting for differences in capital assets for the estimation of MFP. The differences in growth rates among capital assets and changes of the structure of capital assets may result in biased MFP estimates if they are not accounted for. The possible size of such an effect is illustrated by Table A2, which depicts the differences and trends in individual capital assets' growth rates and their share in total capital. ICT assets play a very significant role, both due to the very high growth rates of ICT capital assets and also because of the shift in shares towards these assets.

This can be seen by comparing g with the growth rate of MFP, $\widehat{g}$, where differences in marginal productivities across capital assets are not taken into account.

$$\widehat{g} = \frac{d\ln Y}{dt} - \frac{uK}{C} \cdot \sum_{i=1}^{N} \frac{m_i K_i}{WK} \frac{d\ln K_i}{dt} - \frac{wL}{C} \cdot \frac{d\ln L}{dt} = g + \frac{uK}{C} \sum_{i=1}^{N} \left(\frac{u_i K_i}{uK} - \frac{m_i K_i}{WK} \right) \cdot \frac{d\ln K_i}{dt} \quad (10),$$

where m_i stands for the market price of each asset and $WK = \sum_{i=1}^{N} m_i K_i$ is the measure of net (wealth) capital. The composition effect (net of other measurement issues discussed) thus reflects the difference in the sets of weights used for aggregation; in contrast to $\widehat{g}$, the measure g puts more weight on (and hence excludes from the measured MFP) the growth in the stock of productive assets with shorter lives and high user cost, whose effect thus will be entirely associated with the contribution of capital.

Measuring labour input

Similarly to capital input, the overall contribution of labour input to GDP growth in a growth accounting framework is computed as the product of the growth in labour input (or services) and the share of labour income in total product, $s_L \cdot (d\ln L/dt)$. Labour income, wL, is calculated as the compensation of workers. Data on worker compensation are, however, only available for employees, not for self-employed persons. Compensation of self-employed persons is typically computed by assuming that the average compensation per self-employed person is identical to the average compensation per employed person.

In the reference scenario of MFP labour input is measured as total hours worked as opposed to total employment. The measure of total hours worked captures the use of labour better than total employment and is thus an appropriate measure of labour input within a growth accounting framework. As average hours worked per worker vary substantially across different OECD countries, using hours worked as a measure of labour input does also improve the cross-country comparability of productivity measures.

The literature on growth accounting stresses the role of adjusting labour input for the quality of labour.[22] This is best done by adjusting labour input by the change in the skill composition of total employment. The intuition behind this is parallel to that behind the adjustment for differences in the quality of physical capital and states that productivity growth is influenced by differences in competencies or the level of human capital of each worker. Scarpetta *et al.* (2000), for instance, distinguish six different employment groups: three education levels (below upper secondary, upper secondary and tertiary education) for each gender. As in the case of total capital services, total change in labour 'services' results from the weighted sum of growth in labour services per gender-education group; the weights are based on relative marginal productivity (proxied by relative wages) and employment shares of each gender-education group. Let L_j be the hours worked per gender-education type, j, and w_j their respective relative wage rate. The change in the total labour services can then be expressed as:

$$\frac{dL}{dt} = \sum_j v_j \frac{dL_j}{dt}, \quad \text{where} \quad v_j = \frac{w_j \cdot L_j}{\sum_i w_i L_i}. \quad (11)$$

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22. The composition of labour input is not *yet* adjusted in the OECD Productivity Database, although some work is underway.

It is assumed that the rate of change in average hours worked is identical across education and gender groups. This implies $L_j = e_j L$, where L is a measure of total labour input (*i.e.* hours worked) and e_j is the employment share of gender-education group j in total employment. The weight hence reflects the cost share of each type of labour input in the total cost of labour.

In order to separate the effect of labour composition, or labour quality, and the effect of hours worked a measure of labour quality, independent of hours worked, is constructed as:

$$\frac{dLQ}{dt} = \sum_j v_j \cdot \frac{de_j}{dt} \ .$$ (12)

Measuring labour and capital shares

As indicated in equation 5, the growth accounting framework can be written as the weighted average of the contribution of growth in labour and capital. If wL represents total compensation of labour and uK total remuneration of capital (in time t), the standard primal estimate of the rate of growth of MFP follows from:

$$g = \frac{d \ln F}{dt} = \frac{d \ln Y}{dt} - s_K \cdot \frac{d \ln K}{dt} - s_L \cdot \frac{d \ln L}{dt} \ .$$ (13)

In the classical growth accounting framework, s_k and s_l are the respective shares of each factor payment in total output. The results above do, however, allow for non-constant returns to scale and imperfect competition, and reflect, thus, a more general interpretation of MFP, the so-called apparent MFP. In this case, total costs in the form of labour and capital remuneration do not have to be equal to total factor income. As a consequence, the weights in equation (1) and (5), *i.e.,* the shares of capital and labour, s_k and s_l, are the shares of capital and labour in total costs and not in total income, as they would be in the neoclassical growth accounting framework.[23]

3.2. *The impact of measurement on MFP growth – a sensitivity analysis*

The following section presents results from a sensitivity analysis which assesses the empirical impact of labour- and capital-related measurement issues on measured MFP growth. This is done by computing MFP growth on the basis of different scenarios of measuring capital services and labour where each of these scenarios addresses one key measurement issue, namely: a) assessing the effect of an age-efficiency profile of capital assets over time by using a measure of gross capital stock instead of capital services; b) taking account of differences in productive capacity across capital assets by the computation of the composition effect of capital input; c) assessing the impact of quality adjusted price indices, using national price indices instead of the harmonised hedonic price index for ICT capital assets; d) assessing the utilisation and composition of labour input; and e) smoothing fluctuations in annual MFP growth measures by computing a trend series of MFP.

This sensitivity analysis is primarily intended to show the potential size of the difference in measured MFP growth based on different assumptions. It provides an initial picture of the impact of different measures of capital and labour on the growth of MFP and explains to some degree why MFP estimates are

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23. Schreyer (forthcoming) provides an extensive discussion and argumentation on how capital and labour shares could or should be computed when total costs are not equal to total income.

different in various empirical studies.[24] It is meant as a first step in analysing crucial measurement issues which, therefore, does not touch on all possible measurement issues.[25] Moreover, while it is the intention of this sensitivity analysis to analyse particular measurement issues, it is not possible to totally disentangle the measurement problems. For instance, the computation of the composition effect of capital input may capture to some degree an effect related to the general age-efficiency of capital assets as well as an effect due to differences in capital productivity between ICT- and non-ICT capital. It is, therefore, not possible to calculate the total impact of measurement as the sum of the individual effects analysed.

The measurement issues analysed

In what follows, different approaches of measuring capital and labour input will be separately compared with the reference scenario that has been used in section 2 above. In this reference scenario, MFP is measured using total hours worked; capital services, based on a particular age-efficiency profile per capital asset and taking into account different capital assets; shares of capital and labour input in total costs; harmonised hedonic prices of ICT-capital assets; and actual time series.

The measurement issues that are analysed in this sensitivity analysis are:

1. Labour input:

    - *Total hours worked versus total employment*

    - *Labour composition:* The measure of *labour* composition that is used in the sensitivity analysis follows the procedure presented in section 3.1 above. It is based on data on the level of education attainment from Scarpetta *et al.* (2000), complemented with information from the Barro and Lee (1996) database. Data on relative wages are from Jean and Nicoletti (2002) for Canada, Denmark, Spain, France, the United Kingdom, Ireland, Italy, Sweden, and the United States, and complemented with data from Scarpetta *et al.* (2000) for Australia, Germany, Finland, the Netherlands, and Portugal. For Japan, data by four educational categories are available that are not directly comparable with the other countries. However, for this country, full information on wages and employment for the years 1985, 1990, 1995, 2000 can be used.

2. Capital input:

    - *Capital services versus a measure of gross capital stock:* The measure of capital stock used in the sensitivity analysis assumes a one-hoss-shay efficiency function. This assumes that the existing capital assets can be used with full efficiency over the entire lifetime of the asset; their productivity drops to zero after they are retired, however (see also OECD, 2001).

    - *Capital composition:* This sensitivity analysis compares the reference scenario of capital services, with an alternative scenario, which approximates the volume of capital stock per capital asset by market prices for each capital asset. Aggregating in each scenario over capital assets with different rates of change in the quality or efficiency levels and comparing the resulting MFP growth rates, reveals the contribution of quality changes in capital to the MFP measure.

    - *Harmonised versus national price indices of ICT goods*

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24.   See also Schreyer (forthcoming).

25.   Among the list of possible further measurement issues are, for instance, questions related to cross-country differences in capital tax regimes, the treatment of own-account software and private versus public sector investment.

3. Cost versus income shares:

To see how MFP estimates are influenced by the way the weights of capital and labour are computed, a variant of the neoclassical MFP estimate is computed. This uses the assumptions of constant returns to scale and perfect competition in the input and output markets and computes endogenous rates of returns to capital. It departs from the simple measure of labour share s_L as computed by $s_L = wL/PY$, where wL is the value of the compensation of labour and PY is the value of gross domestic product in market prices. Assuming constant returns to scale and competitive markets, the capital share s_K is equivalent to $1 - s_L$. Generally, this measure would give more weight to the capital contribution and MFP would thus be reduced in times of more buoyant development in capital input than in labour input.[26]

4. Actual versus trend series:

The sensitivity analysis uses the Hodrick-Prescott filter (Hodrick and Prescott, 1997) to cyclically adjust the time series of GDP, employment, hours per person, capital services and stock and the employment shares. Under this method, trend values of a variable y, y^{trend}, are defined such that they minimize:

$$HP(\lambda) = \sum_t (y_t - y_t^{trend})^2 + \lambda \sum_t [(y_{t+1}^{trend} - y_t^{trend}) - (y_t^{trend} - y_{t-1}^{trend})]^2 \qquad (14)$$

where λ is the parameter of the importance given to the smoothness of the trend series as opposite to its proximity to actual values. The standardized OECD smoothing procedure is used. The end-of-sample-bias is reduced by applying the growth rates of the related series (business sector capital stock for total economy capital stock and services) in the OECD Medium-Term Reference Scenario forecasts to the existing data up to 2008.[27]

The estimate of trend MFP growth is then obtained as the difference between trend GDP growth and the sum of the contributions of trend growth in labour and capital input, weighted by their shares as defined above. Trend labour input is defined as the product of trend series of employment and hours per person. Labour input is not adjusted for composition in this case.[28]

Empirical results for 8 OECD countries

Figures 8a-8g show the impact of measurement for selected OECD countries. For each country, a deviation of measured MFP in percentage points related to each measurement issue is presented. In general, three main conclusions can be drawn from these results. First, different measures typically change the *level* of the growth of MFP in a rather systematic way, but not the growth *pattern* over time. In almost all scenarios, the impact of different measurement issues is a relatively stable deviation of the level of MFP

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26. The increase in the weight of capital is due to the calculation of the capital share as $s_K = 1 - s_L$, and depends on the assumption that the rate of return is endogenously determined. Assuming exogenous rates of return, but using the income and not the cost share would reduce both, capital and labour shares, as opposed to the apparent MFP measure based on exogenous rate of returns, and would assign a stronger role to MFP growth and a smaller role to the factor inputs.

27. OECD (2003b).

28. Another possibility to measure trend MFP that was not pursued here is to apply the HP filter (13) on MFP estimates based on non-trend values.

growth which means that the alternative MFP growth rates move relatively parallel to the MFP growth rates of the reference scenario. One obvious exception is the measure based on trend values of MFP growth, in contrast with the rather volatile development of the measure based on actual series. Another exception, albeit not as marked, is the effect of measurement of labour input by total employment instead of hours worked. For several countries, notably Canada, France, Japan and the United Kingdom, and in particular for the time period before 1995/1996, the deviations fluctuate and reflect the substantial difference of the employment-based measure of MFP from the one based on hours worked.

Second, the size of the measurement effect varies substantially across scenarios and depends on the measurement issue that is analysed. Substantial differences in MFP growth can be observed in the first graphs in Figures 8a-8g, where employment-based MFP growth rates are compared with MFP growth rates using total hours worked. In the case of Germany and Japan for instance, employment-based MFP growth rates differ by up to or more than 1 percentage point from MFP growth rates based on hours worked. For most countries, the MFP measure is much lower if based on the total number of employed persons than the ones based on total hours worked. This is compatible with the observation that annual growth rates of total employment have been higher than those of total hours worked; in other words, growth of average hours worked per person employed has been decreasing since the 1980s in most OECD countries.[29]

Adjusting labour input for compositional changes may both increase or decrease the contribution of labour input. In general, the effect is limited. Canada, France, Japan and the United Kingdom, show, for some periods, relatively strong effects of the adjustment for labour composition, however. In these cases, the MFP measure where labour input is adjusted for its composition is lower than the reference scenario. In general, a non-zero effect results as changes in the composition of labour are attributed to labour and not to MFP. The lower MFP growth in the alternative scenario suggests that the composition changes of labour in the 1990s have had a positive impact on labour input growth in these countries. This implies changes in the composition of labour towards more productive employees, as measured by higher compensation per employee.

The second graphs in Figures 8a-8g compare MFP growth rates where capital input is computed using different assumptions as regards the age-efficiency function and the composition of capital assets. Comparing the MFP measures where capital input is computed as a gross capital stock with those where capital services are computed assuming the age-efficiency profile from the OECD Productivity Database shows very similar patterns. Equivalent with theory is the direction of the effect: the MFP time series of the alternative scenario are slightly lower than the ones of the reference scenario for most countries analysed. Assuming full efficiency of capital assets of one particular generation over the whole life time would overestimate the contribution of capital input to production growth as compared to the more realistic assumption of decreasing efficiency over time.

The results concerning the capital composition are more evident. The series labelled 'capital quality' show the effect on measured MFP of approximating capital input in natural units as compared to the reference scenario where the measure of capital input approximates capital services in efficiency units. These series labelled 'capital quality' do *not* account for changes and variations in quality across different forms or generations of capital assets within the contribution of capital to output growth; hence, these variations are ascribed to MFP. The graphs show that for most countries, this 'unadjusted' alternative scenario of MFP growth is higher compared to the reference scenario, and this reflects strong growth in the quality of capital. Together with the previous findings concerning the age-efficiency of capital, these results support the hypothesis of Hulten (1992), that changes in the quality of capital are mainly driven by changes or variations in quality across different forms or vintages of capital assets and only to a small degree by changes in efficiency of capital asset of one particular generation over time.

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29.   This is partly due to the growth of part-time employment.

The effects are relatively modest with regard to the choice of the price index (third graphs in Figures 8a-8g). This relatively weak, but growing effect over time may be due to the still relatively small, but growing, share of ICT-capital goods in total capital. The direction of the changes is as indicated in the theoretical discussion above: using hedonic prices takes into account that the quality of some capital assets may change rapidly over time. Since these rapid changes in quality are 'adjusted for' in the capital measure itself, this reduces the size of the MFP measure. Comparing the MFP estimates based on these different price assumptions comes close to the approach proposed by Hulten (1992) to estimate average embodied technological efficiency by the ratio of prices of capital goods in efficiency and natural units. The results, notably the growing effect due to quality adjusted price indices for ICT capital assets in most recent years, reflects, therefore, that changes in the quality of capital and, thus the contribution of capital, are mainly driven by changes in the composition towards capital assets of higher efficiency, such as ICT.

A very important impact on the MFP estimate can be found as regards the share with which labour and capital enter the growth accounting framework (third graphs in Figures 8a-8g). In several countries, such as Canada, France, Japan, the United Kingdom and the United States, the MFP measure using income shares (*i.e.* assuming endogenous rates of return to capital and constant returns to scale) is up to 1 percentage point lower than the MFP estimate using cost shares (*i.e* assuming exogenous rates of return that allow for non-constant returns to scale and imperfections on input and product market). This emphasises that the interpretation of MFP growth matters. Furthermore, the importance of the assumptions about returns to scale stands out. For most countries analysed here, the relative contribution of labour and capital is biased towards a stronger contribution of capital to output growth if the capital share is computed as 1 minus the share of labour remuneration in total output.

Finally, while the general pattern of MFP growth is not strongly influenced by different ways of measuring capital and labour, the size of the impact of measurement changes over time and depends on the time period and country that is analysed. This is notably the case if one compares MFP growth rates of different scenarios in the 1995-2001 period with those for earlier periods. For instance, increasing effects of measurement over time can be observed for most countries analysed whenever capital is adjusted for its quality. This is the case as regards the computation of the composition effect of capital services as well as computing hedonic price indices of ICT capital assets. Over time increasing effects can also be observed when MFP growth on cost versus income shares of labour and capital. The time period that is chosen to calculate MFP rates is therefore relevant for the interpretation of the results; a finding that is also important when comparing MFP growth rates that have been calculated by different empirical studies. Computing trend values of MFP growth may be therefore informative and give an idea of the long-term development. Moreover, it may help overcome the problem of choosing start and end dates when averages over time are computed. The smoothing effect of using the trend values is shown in the third graphs in Figures 8a-8g.

Figure 8a.   **Deviations of MFP growth from reference values under different scenarios
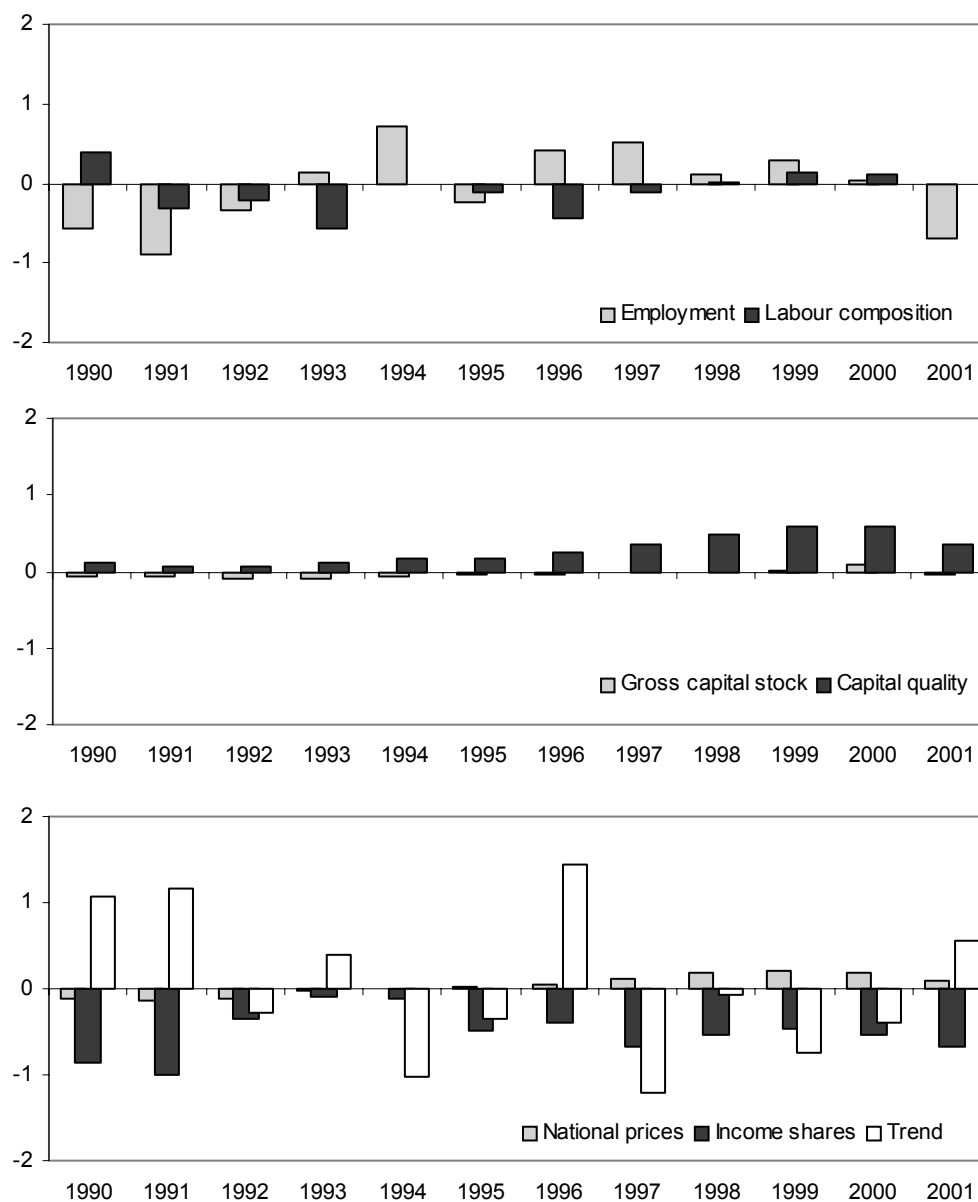of measurement of capital and labour**

Australia, 1990-2001, deviations of annual growth in percentage points
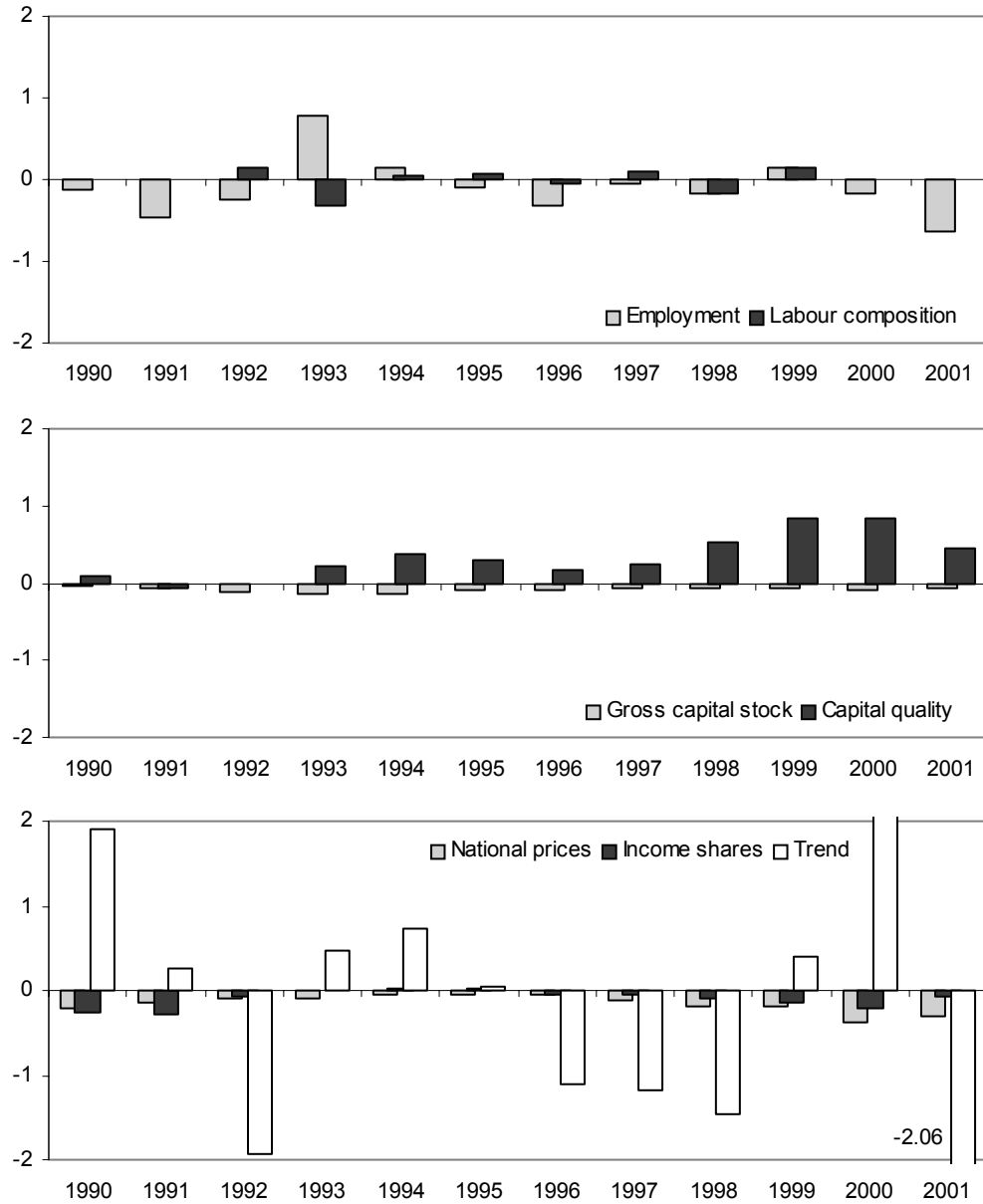
Figure 8b. **Deviations of MFP growth from reference values under different scenarios of measurement of capital and labour**
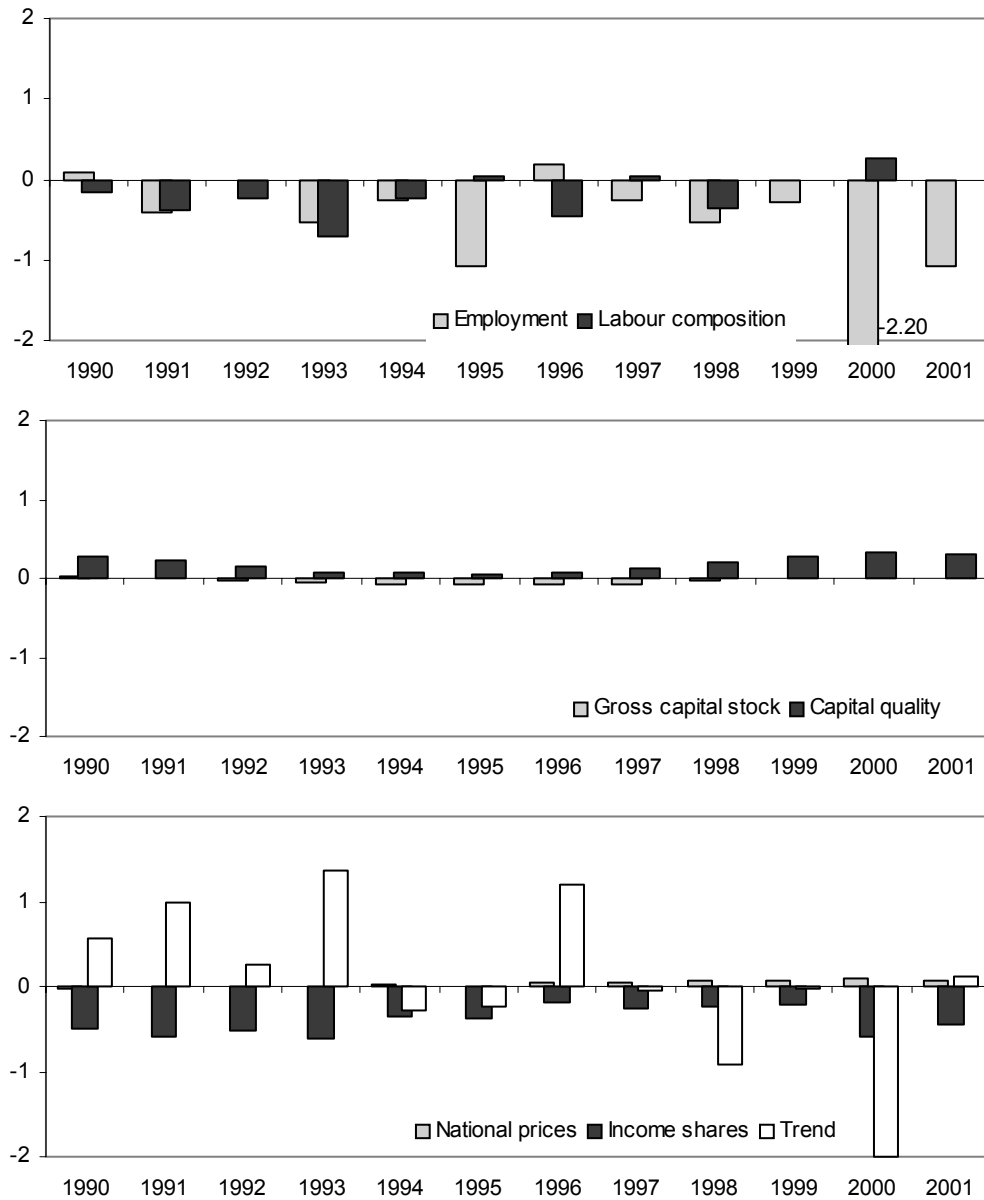
Canada, 1990-2001, deviations of annual growth in percentage points

Source : OECD Productivity Database, 2003.

Figure 8c. **Deviations of MFP growth from reference values under different scenarios of measurement of capital and labour**
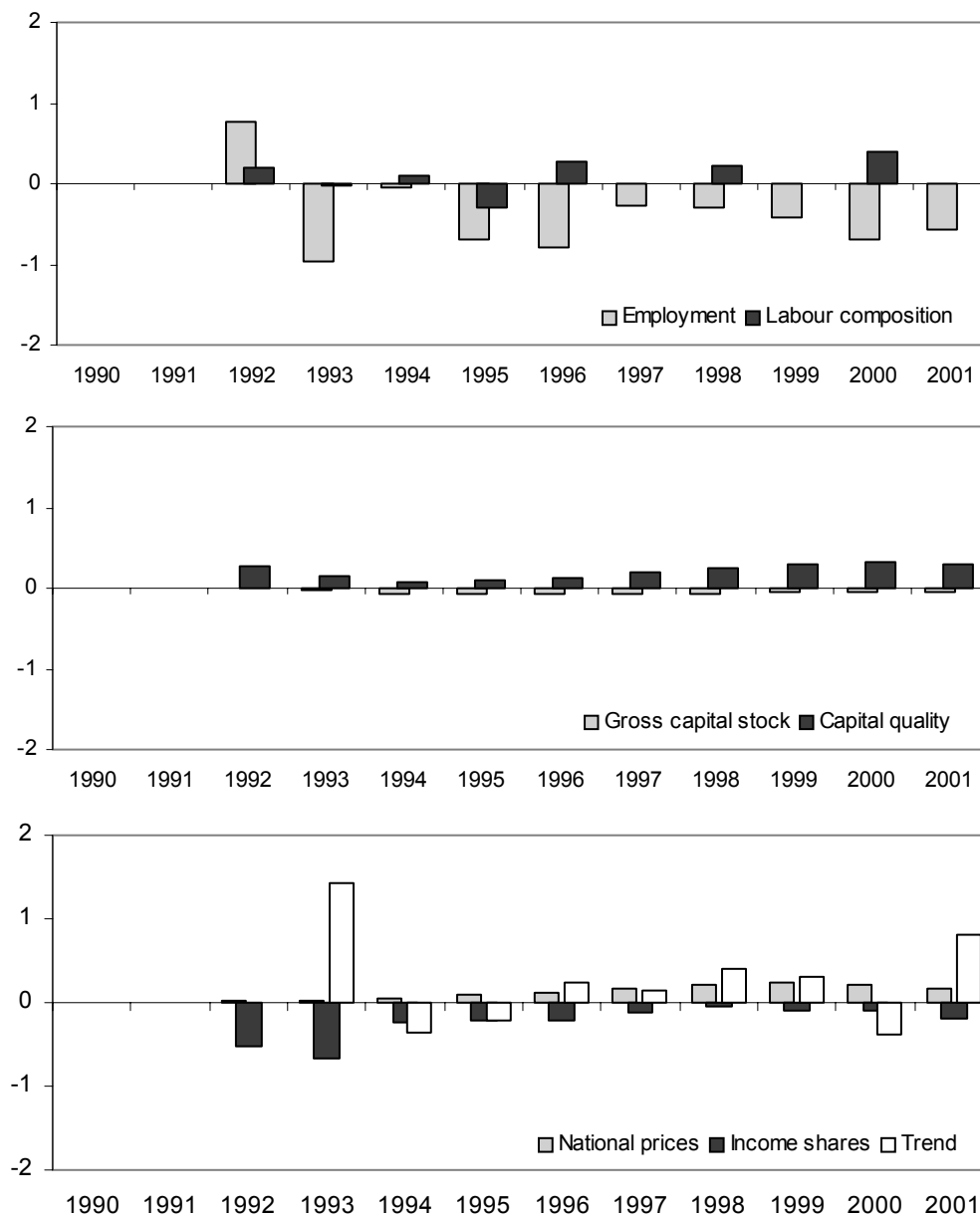
France, 1990-2001, deviations of annual growth in percentage points

Source : OECD Productivity Database, 2003.

Figure 8d. **Deviations of MFP growth from reference values under different scenarios of measurement of capital and labour**
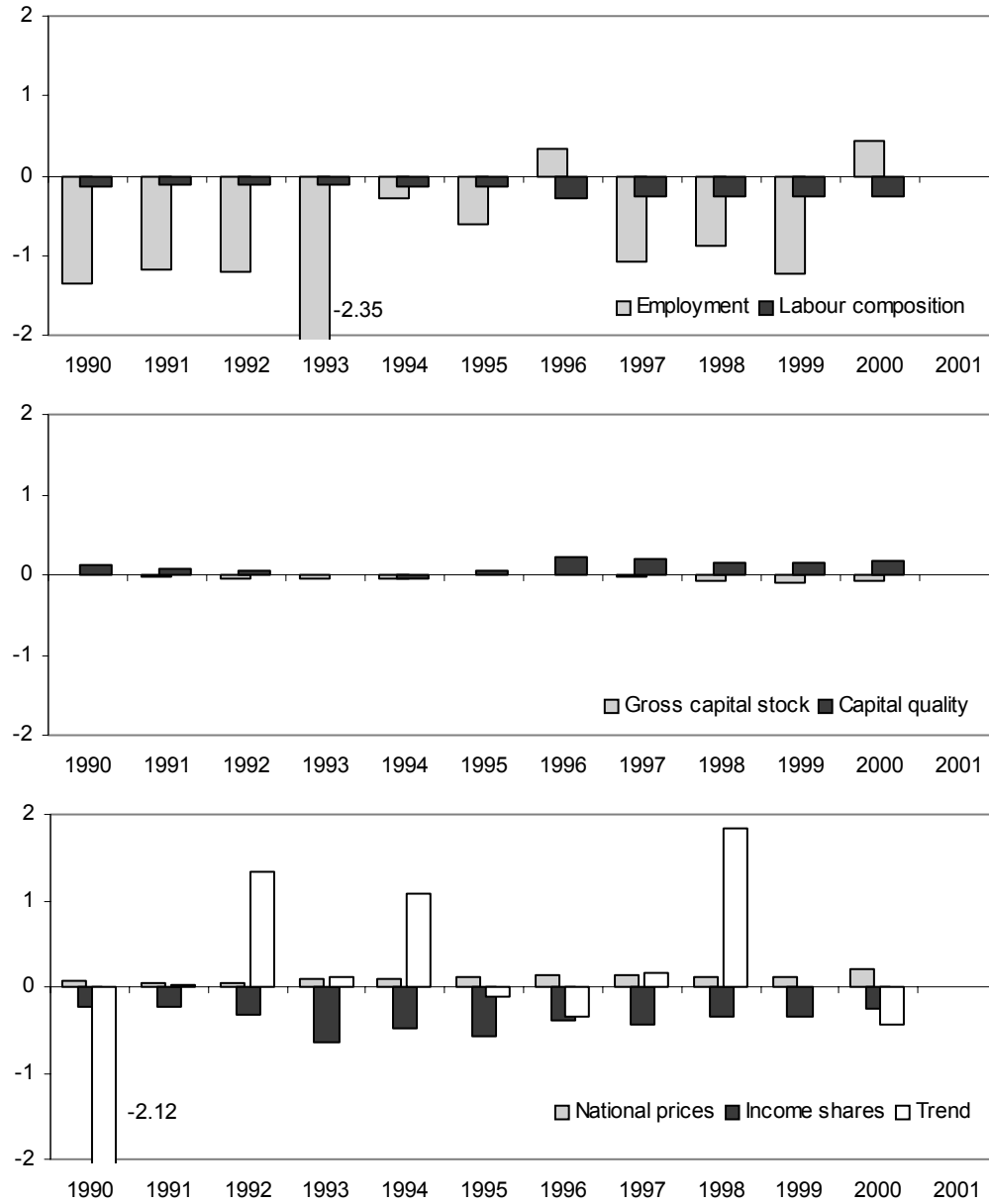
Germany, 1990-2001, deviations of annual growth in percentage points

Figure 8e.   **Deviations of MFP growth from reference values under different scenarios
of measurement of capital and labour**

Japan, 1990-2001, deviations of annual growth in percentage points

Figure 8f.   **Deviations of MFP growth from reference values under different scenarios
of measurement of capital and labour**

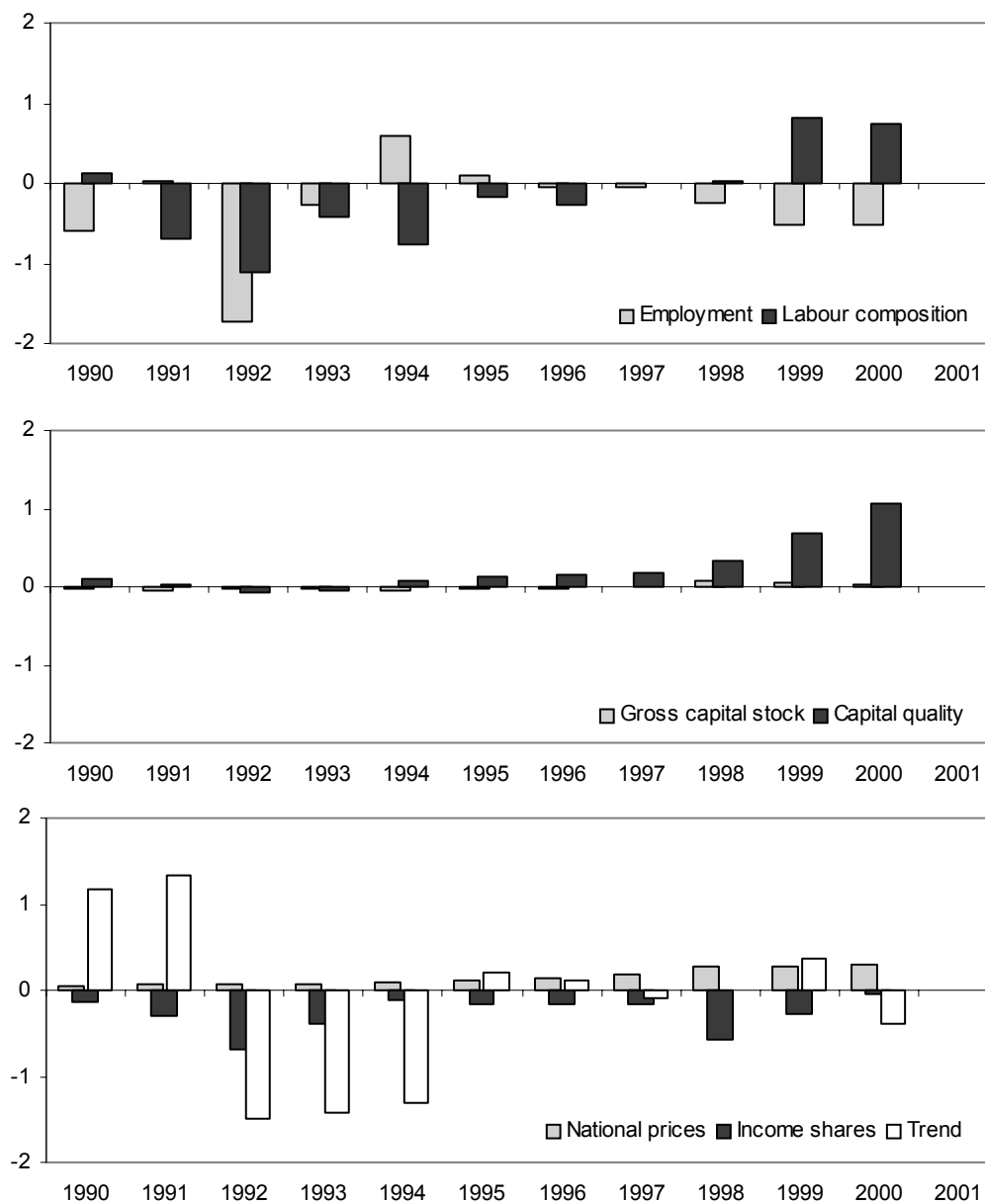The United Kingdom, 1990-2001, deviations of annual growth in percentage points

Figure 8g. **Deviations of MFP growth from reference values under different scenarios of measurement of capital and labour**

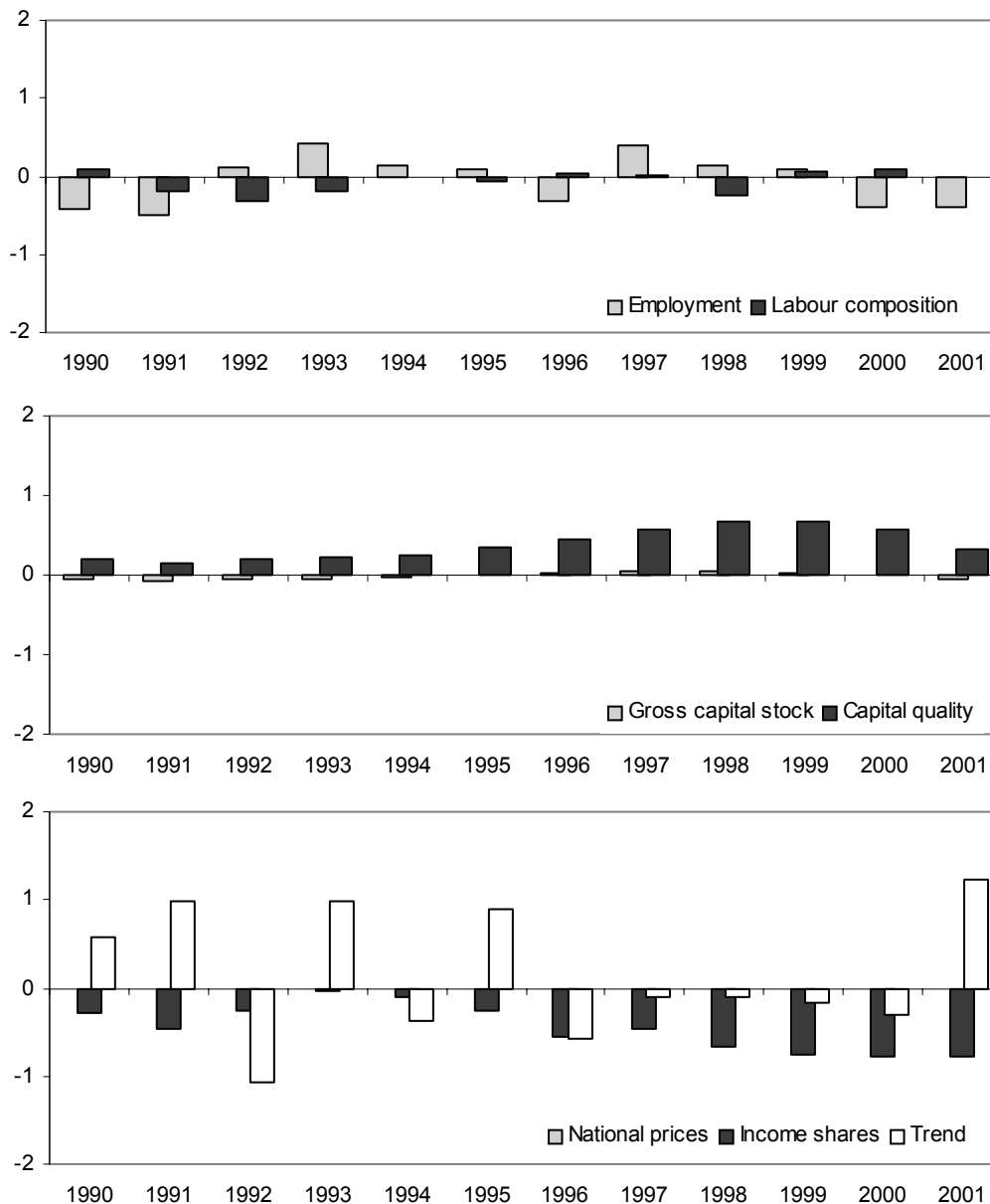The United States, 1990-2001, deviations of annual growth in percentage points

Note: The effect of the choice of ICT-goods price index is nil for the United States, as the hedonic national price of United States served as the reference for the harmonized hedonic price indices of the other countries.

Source : OECD Productivity Database, 2003.

4.   Conclusion

The analysis presented in this paper provides an initial picture of the contribution of capital, labour and multifactor productivity (MFP) to GDP growth and analysed some basic measurement problems related to MFP. The growth accounting exercise shows that for most OECD countries, the strongest contributions to GDP growth over the past decade have come from growth in total capital input and MFP. Information and communication technologies (ICT) play an increasing role in economic growth, particularly over the 1995-2003 period. This was caused by capital deepening, *i.e.* strong investment in ICT capital, which also resulted in a shift in the composition of capital input towards ICT capital assets in some OECD countries. In addition, the acceleration of MFP in some countries in the 1995-2003 period may partly reflect positive effects from increased investment and use of ICT in the form of spillover effects; however, this can not be examined through a growth accounting exercise (see also OECD, 2003*a*; OECD, 2004).

It was shown that measurement plays a relatively important role in calculating MFP. With few exceptions, the results of the sensitivity analysis for 8 OECD countries suggest that changes in measurement typically affect the level of MFP growth depending on different assumptions; the growth pattern over time is altered less, though. The impact varies also substantially depending on which type of measurement issue is examined. Substantial differences in MFP growth can be observed when employment-based MFP growth rates are compared with MFP growth rates that are computed on the basis of total hours worked. Also the share with which capital and labour enter the growth accounting equation, and thus, the assumptions concerning the production function, matters substantially for the MFP estimate. Finally, policy conclusions on the basis of different empirical studies should be made very carefully. This relates mainly to the question which time period and for which countries the respective studies have been undertaken, as well as whether actual or trended time series are used.

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APPENDIX

Table A1. **MFP growth rates of the reference scenario used in the paper
and those of the most recent data of the OECD Productivity Database**

Annual average percentage growth[1]

	Reference scenario December 2003			OECD Productivity Database June 2006		
	1985-90	1990-95	1995-01	1985-90	1990-95	1995-01
Australia	0.5	1.9	2.2	0.3	1.4	1.7
Canada	-0.4	0.5	1.0	-0.5	0.6	1.2
Denmark	0.0	1.0	0.1	0.3	1.8	0.0
Finland	2.2	1.4	2.6	2.1	1.4	2.4
France	1.9	0.9	1.5	1.7	1.2	1.5
Germany			0.8			1.2
Ireland	3.2	3.3	4.4	3.3	3.2	4.4
Italy	1.4	2.1	0.2	1.2	1.5	0.3
Japan	3.0	0.9	0.8	3.0	0.9	0.6
Netherlands	0.6	0.7	0.9	0.5	1.7	0.3
Portugal			1.6			1.6
Sweden	0.2	0.6	0.8	0.3	0.9	1.3
United Kingdom	0.7	1.8	1.0	0.5	1.9	1.4
United States	0.8	0.7	1.0	0.6	0.7	1.3

1) or nearest year available.

Source : OECD Productivity Database, December 2003 and June 2006.

Table A2. **Average annual share of total capital in total costs, average share of ICT capital assets in total capital income, and annual growth rates of total capital and ICT capital assets**

1980-1990, 1990-1995, 1995-2001[1)], in percent

| | Average share of total capital income in total costs, in per cent | | | Average share in total capital income, in per cent | | | | | | | | | | | |
| | | | | Non-ICT capital assets | | | Hardware | | | Communications Equipment | | | Software | | |
	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001
Australia	33.9	40.0	34.4	93.5	91.7	87.5	1.9	2.6	4.5	3.4	3.1	4.0	1.3	2.6	4.1
Canada	25.6	25.2	23.8	91.4	88.8	84.4	3.5	3.8	5.3	2.8	3.1	4.2	2.4	4.2	6.2
Denmark	n.a.	29.2	32.9	93.6	92.0	91.0	2.8	2.6	2.2	1.4	1.4	1.2	2.2	3.9	5.6
Finland	26.3	28.7	33.5	95.5	93.6	94.2	1.0	1.2	1.1	0.4	0.4	0.6	3.0	4.8	4.1
France	23.1	27.9	29.4	94.1	94.3	93.5	1.8	1.7	1.6	2.7	2.4	2.5	1.4	1.7	2.5
Germany	n.a.	28.5	34.9	92.3	90.1	91.8	2.6	3.6	2.7	3.2	3.7	3.3	1.9	2.6	2.3
Ireland	16.6	18.7	21.5	86.7	91.6	90.3	7.6	3.7	4.9	2.7	3.0	3.4	3.0	1.6	1.4
Italy	18.3	25.6	27.4	79.5	88.2	88.5	7.9	3.4	2.6	9.4	5.2	5.6	3.2	3.1	3.3
Japan	22.3	23.4	26.6	92.7	91.6	91.5	4.1	4.7	4.5	1.8	2.0	2.4	1.3	1.7	1.6
Netherlands	28.7	35.8	32.0	89.9	91.1	89.4	4.5	3.5	3.9	3.1	2.7	3.0	2.4	2.7	3.7
Portugal	n.a.	n.a.	20.2	90.6	90.3	89.1	2.9	2.7	2.6	4.8	4.6	5.2	1.7	2.4	3.2
Sweden	29.4	31.0	29.9	95.2	93.0	90.6	1.4	1.7	1.8	1.1	1.0	1.3	2.3	4.3	6.3
United Kingdom	26.0	25.7	26.7	94.6	92.9	90.6	3.5	4.3	5.1	1.3	1.3	2.1	0.6	1.5	2.2
United States	26.9	25.5	23.6	88.9	83.4	79.2	3.1	4.7	5.7	5.1	6.2	6.4	2.9	5.6	8.7

Average annual growth rate, in per cent

| | Total Capital | | | Non-ICT capital assets | | | Hardware | | | Communications Equipment | | | Software | | |
	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001	1980-1990	1990-1995	1995-2001
Australia	2.9	1.6	2.3	2.1	0.8	0.6	29.3	19.9	28.9	4.1	2.3	5.6	19.3	11.0	6.8
Canada	6.6	4.0	5.6	5.5	3.0	3.0	27.1	16.8	34.7	9.2	6.5	8.1	15.0	11.3	14.1
Denmark	3.3	2.8	4.1	2.2	1.9	2.6	26.5	16.7	29.0	7.1	3.6	4.5	17.5	14.0	18.2
Finland	3.2	0.8	2.0	2.6	0.3	1.0	30.4	16.4	31.7	5.4	9.6	22.8	14.2	5.5	12.4
France	3.5	2.8	2.8	2.8	2.5	1.8	27.9	14.7	32.6	5.6	4.5	6.6	15.2	6.5	18.5
Germany	2.8	2.8	2.6	2.1	2.1	1.6	24.1	15.4	28.6	3.9	4.4	4.0	6.5	7.9	9.3
Ireland	3.1	2.4	7.0	1.8	1.4	4.6	15.2	22.3	40.2	12.2	7.3	15.5	2.9	2.1	18.6
Italy	6.2	2.6	3.6	4.1	2.3	2.5	23.6	8.3	28.5	4.9	3.7	6.3	18.1	0.7	11.5
Japan	5.6	4.6	4.0	4.5	3.8	2.3	28.0	18.4	30.1	9.1	7.5	10.6	10.4	7.2	15.2
Netherlands	3.5	2.5	4.0	2.1	1.9	2.1	23.6	15.7	31.1	4.9	3.4	7.9	13.6	6.8	18.9
Portugal	2.6	3.6	5.9	1.3	2.7	4.7	29.6	19.2	30.5	5.6	7.3	9.3	18.5	13.2	15.2
Sweden	3.4	2.4	4.0	2.6	1.7	2.3	29.4	17.7	30.3	5.0	6.1	14.8	18.7	11.1	18.2
United Kingdom	3.5	2.6	4.7	2.2	1.6	2.7	32.4	19.6	32.2	9.1	7.6	13.6	25.8	13.5	13.1
United States	3.6	3.1	5.4	2.1	1.5	2.5	31.1	18.1	29.8	6.6	4.3	7.8	15.1	12.3	14.1

Note 1: or nearest year available

Source: OECD Capital Services, OECD Productivity Database, 2003

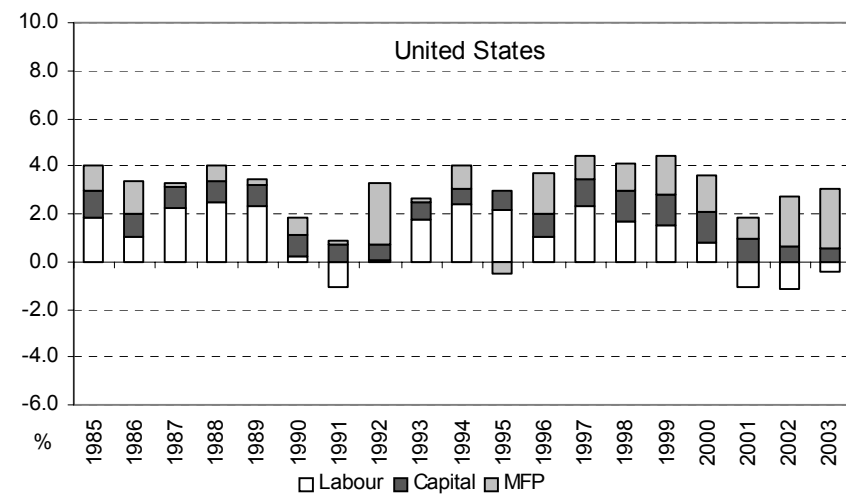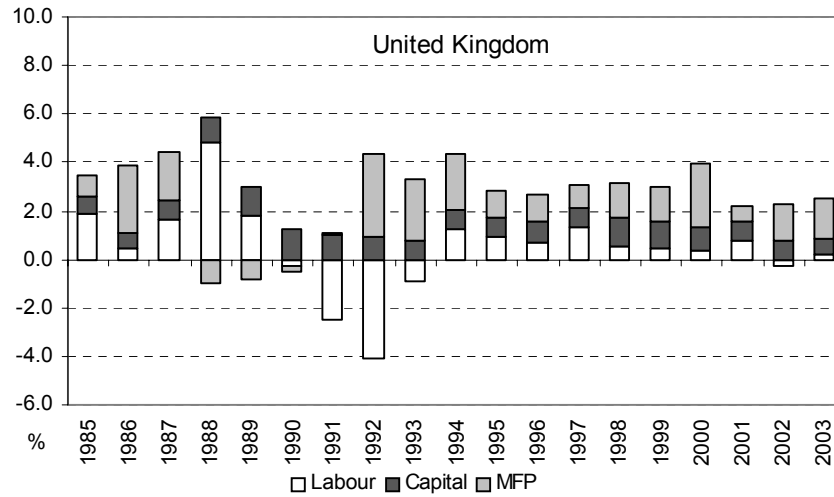Figure A1. **Growth accounting over time for selected countries**
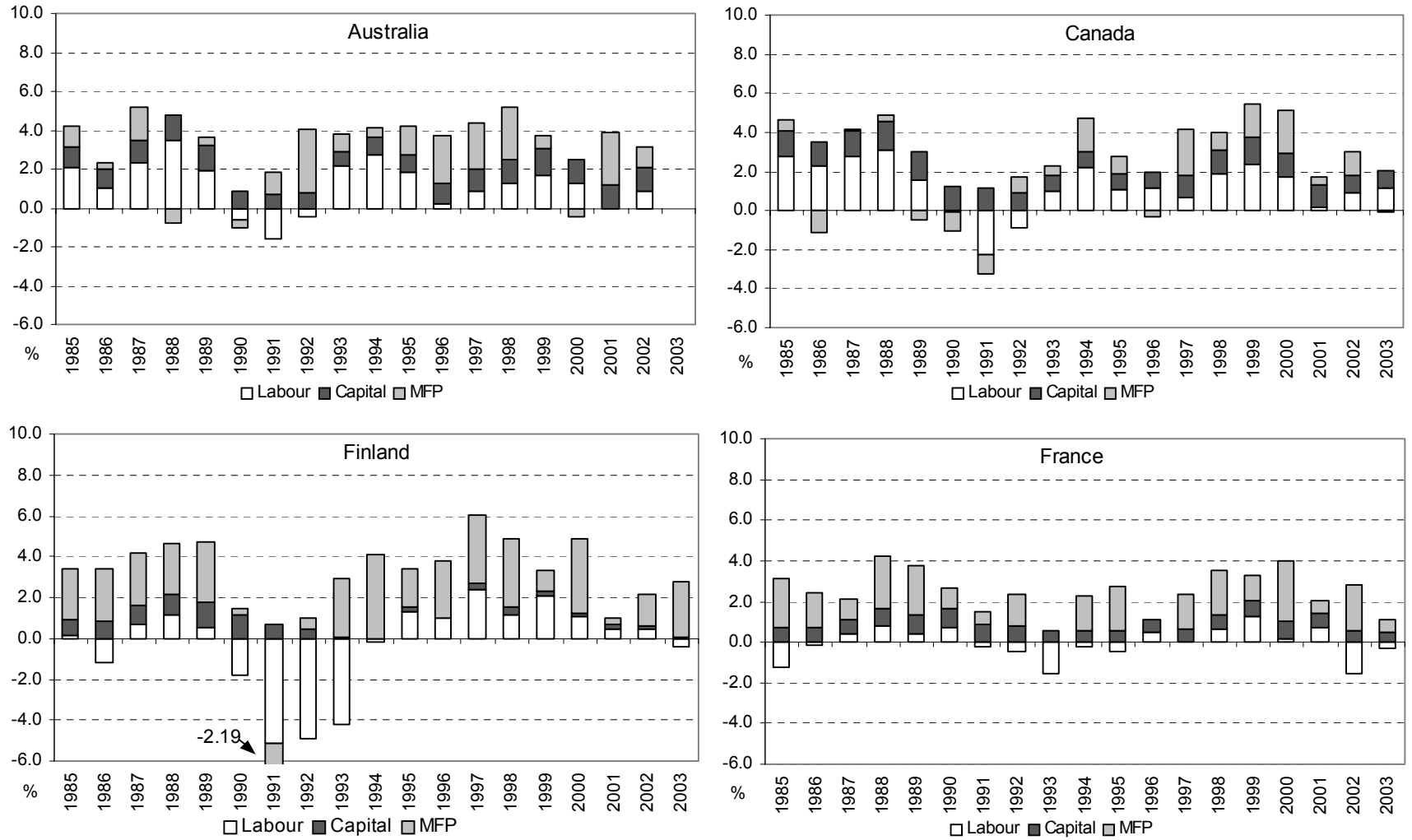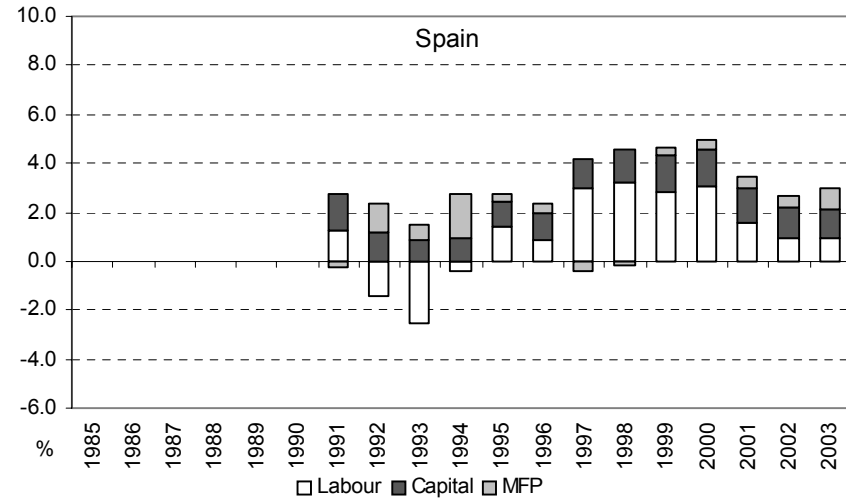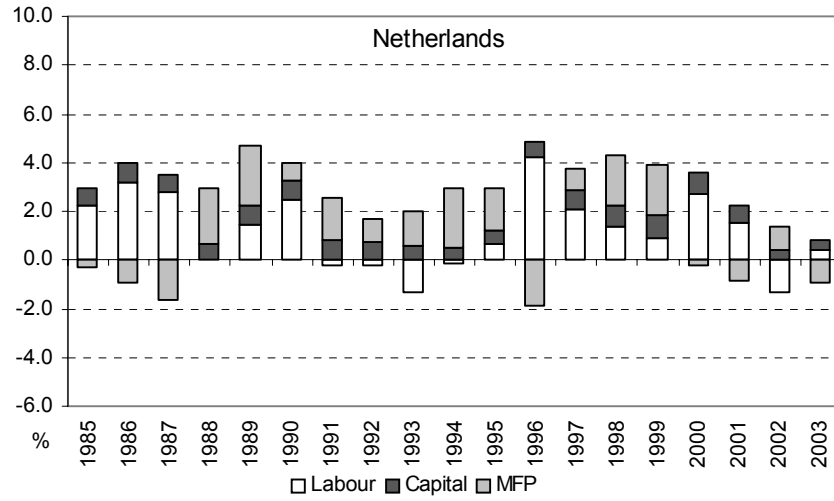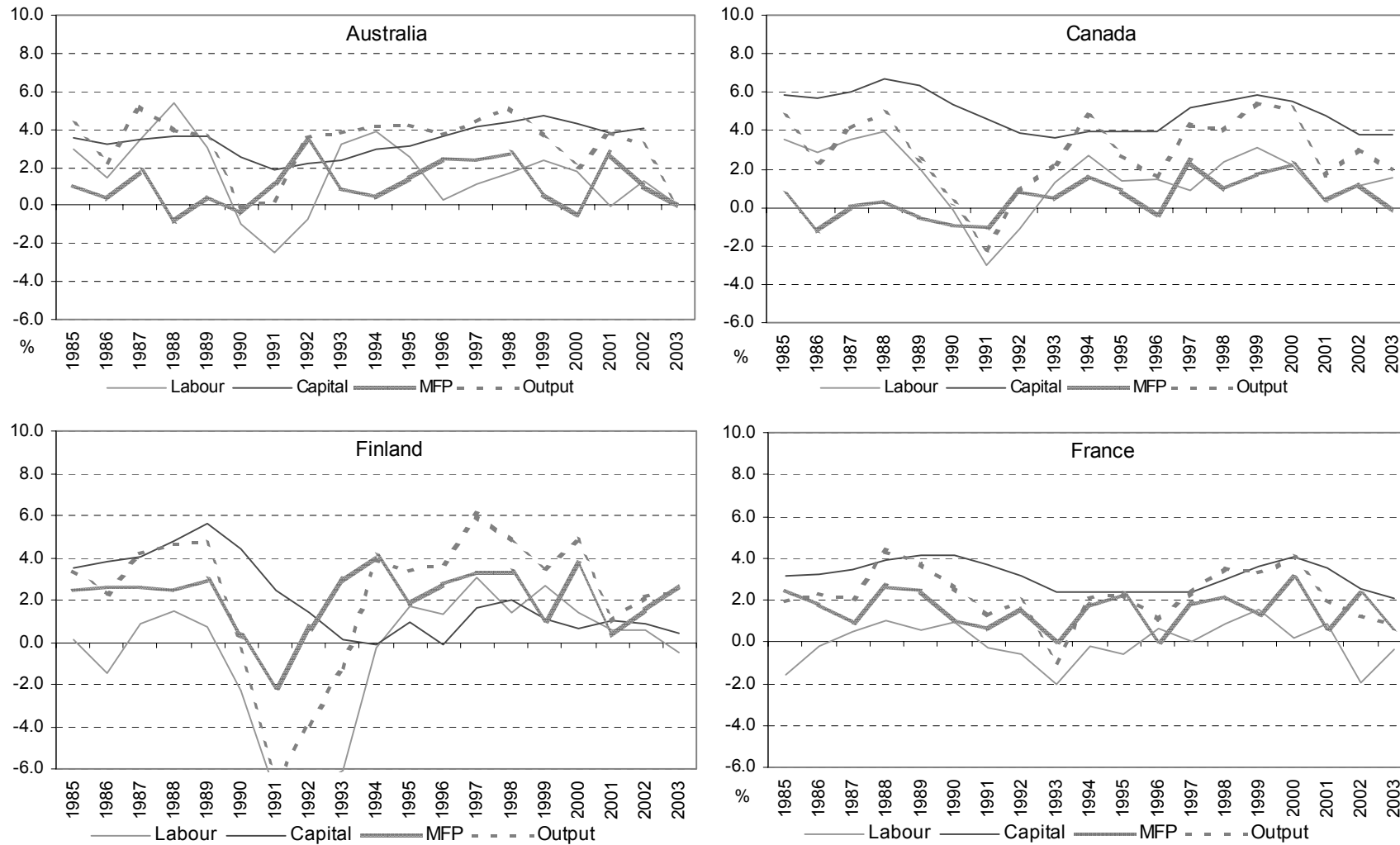

Source : OECD Productivity Database, 2006.

Figure A1. **Growth accounting over time for selected countries – continued**
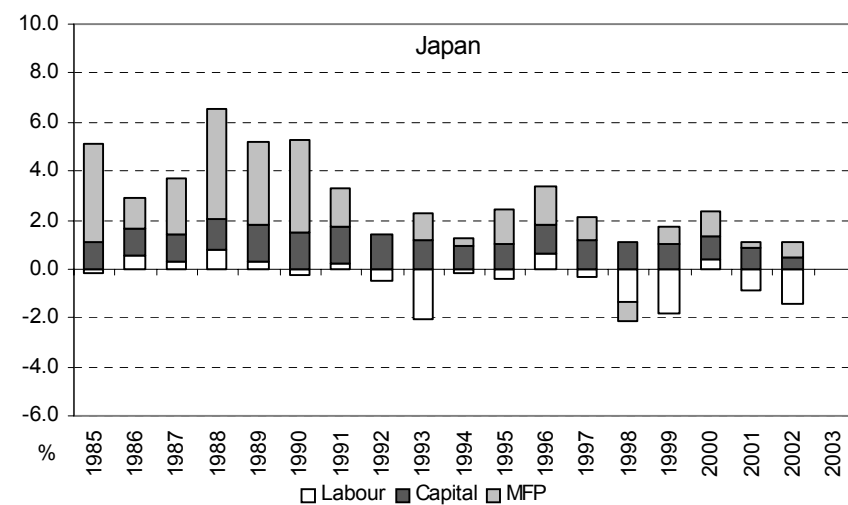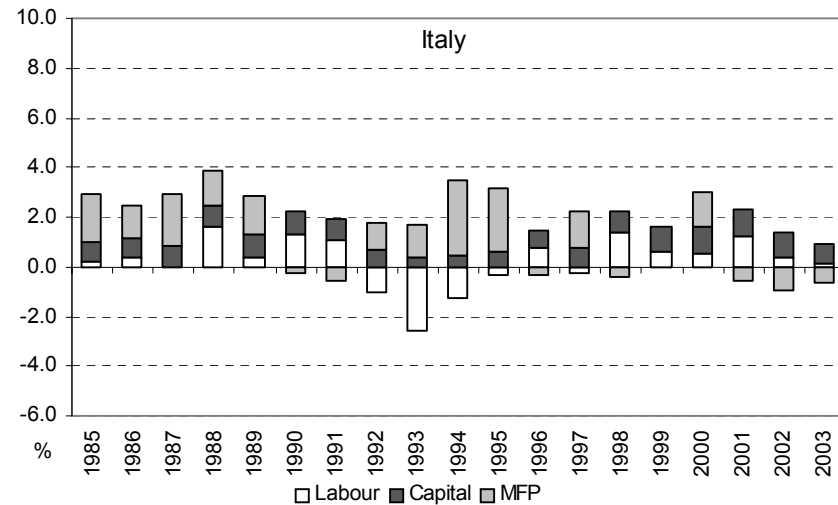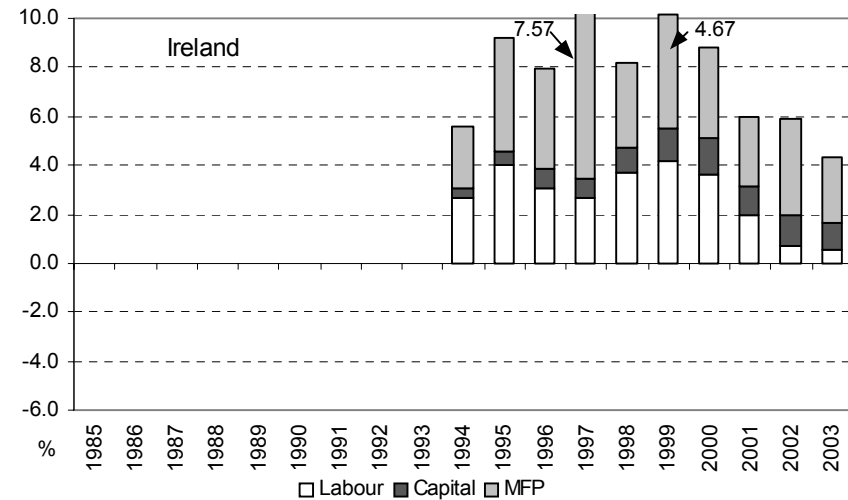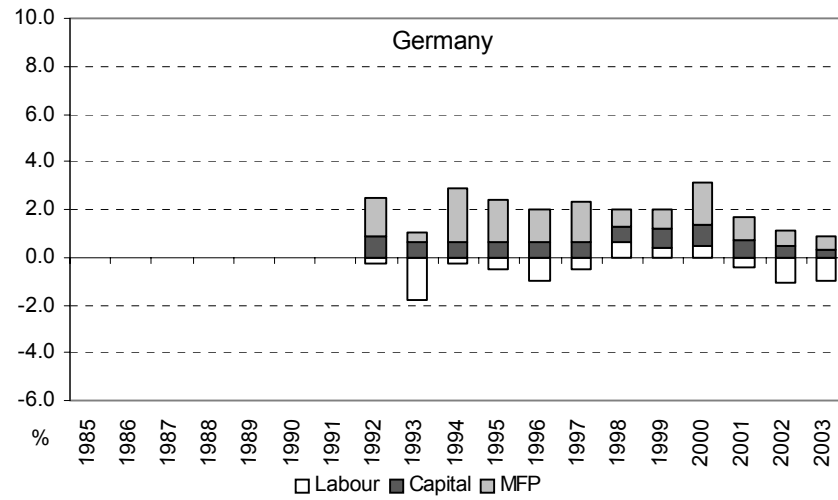
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Figure A1. **Growth accounting over time for selected countries – continued**
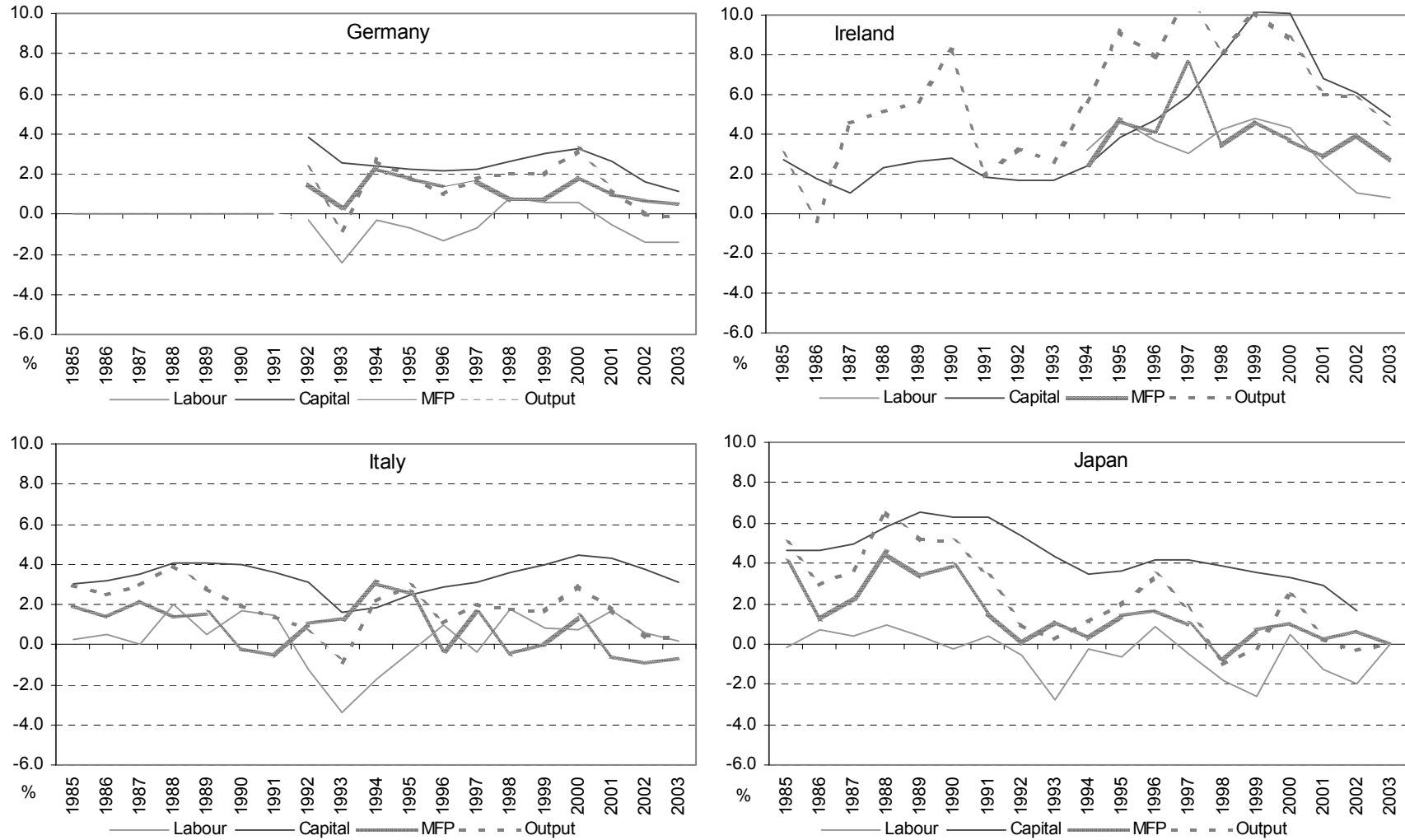

Source : OECD Productivity Database, 2006.

Figure A2.   **Annual growth of GDP, labour, capital and MFP over time, in percent**
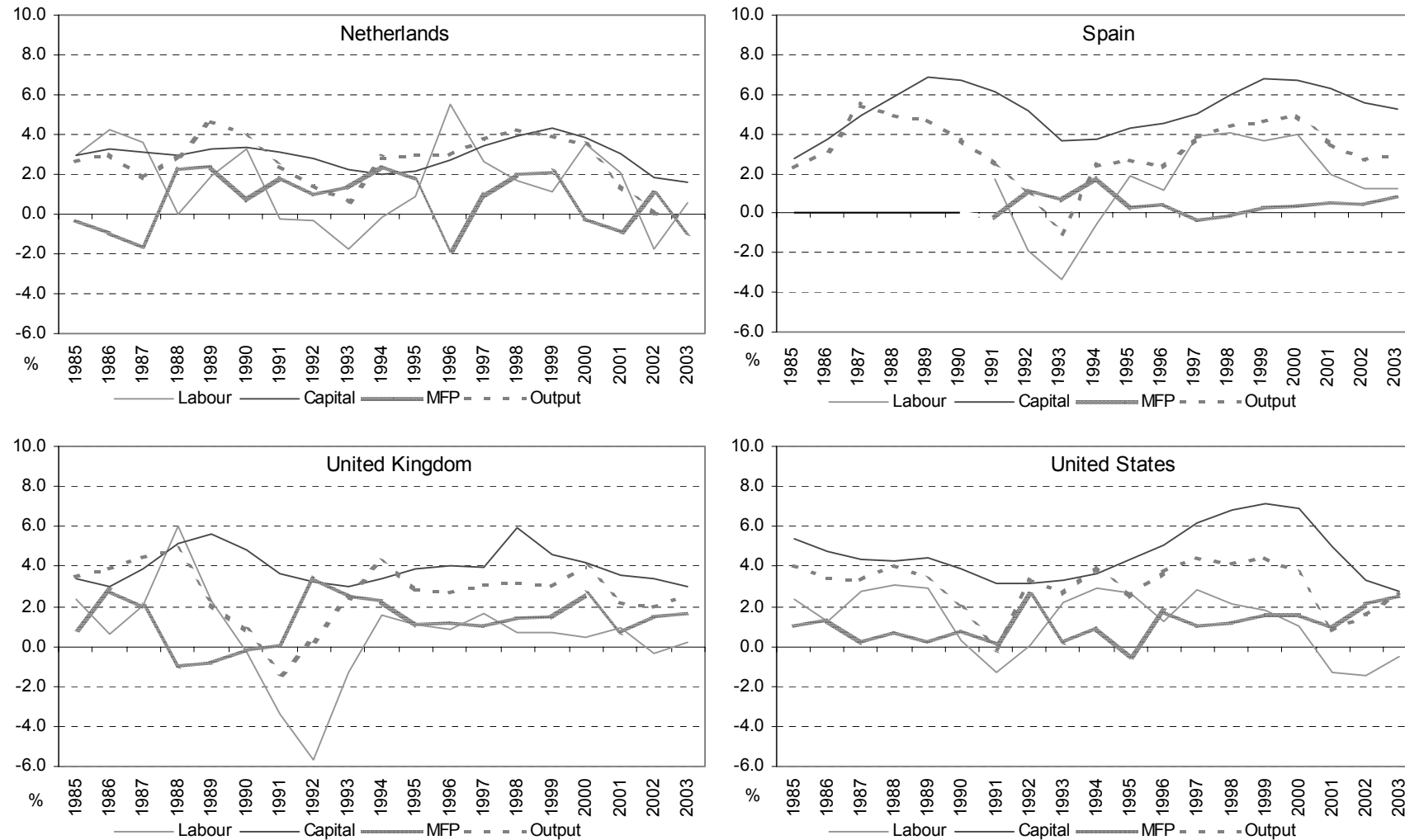

Source : OECD Productivity Database, 2006.

Figure A2. **Annual growth of GDP, labour, capital and MFP over time, in percent, continued**

Source : OECD Productivity Database, 2006.

44

Figure A2.   **Annual growth of GDP, labour, capital and MFP over time, in percent, continued**

Source : OECD Productivity Database, 2006.

45