International Comparisons of Levels of Capital Input and Multi-factor Productivity

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*Views expressed in the paper are those of the author and not necessarily those of the OECD or its member countries.

Abstract

The paper uses a method by Christensen et al. (1981) to construct cross-country comparisons of the levels of capital input, capital and labour productivity and multi-factor productivity. These results are used to de-compose international differences in GDP per capita into differences in labour utilization, ICT and non-ICT capital intensity and multi-factor productivity for seven OECD countries. We provide Monte Carlo estimates to examine the effects of measurement errors in the base data and these simulations showed that boundaries for the resulting indicators can be important.

1. Introduction

International comparisons of levels of labour and capital inputs, outputs and productivity tend to receive a great deal of attention because they respond directly to policy-makers' and analysts' interest in measuring competitiveness, economic well-being of countries' inhabitants and the intensity by which resources are used. Generally, such level comparisons are more difficult to put in place than comparisons of growth rates: data sources are more susceptible to problems of international comparability (Ahmad et al. 2004), and spatial price indices are required to account for differences in the levels of input or output prices.

While the OECD has a long tradition of measuring comparative levels of GDP and labour productivity by way of its purchasing power parity programme (PPP) (see OECD 2004), there has been much less work to compare levels of capital input, levels of capital productivity and capital intensity. Some recent developments have changed this picture: (i) the OECD Productivity Database[1] now features a set of capital service measures for 18 OECD countries that are as comparable internationally as possible; (ii) in some countries, measures of capital input and capital intensity are followed closely in the policy debate. This is, for example, the case for New Zealand where questions have been posed about the 'hollowing-out' of the New Zealand economy (Black et al 2003) and where comparative measures of capital input are of significant interest to analysts to make an informed statement about the capital intensity of the New Zealand economy; (iii) additional methodological work has been undertaken on comparisons of productivity levels in a number of places, including at the OECD with a forthcoming handbook on the subject (van Ark forthcoming); (iv) several studies with level comparisons of productivity and capital have been published in recent years, in particular Inklaar et al. (2006), Jorgenson (2003), O'Mahony and de Boer (2002) and more results will be forthcoming by way of the EU-KLEMS project[2].

The present paper is a contribution to these efforts. It pursues several objectives: (i) deriving point estimates of relative productivity and capital services, based on the

[1] See data and descriptions of the *OECD Productivity Database* under http://www.oecd.org/statistics/productivity.

[2] http://www.euklems.net/

OECD Productivity Database. As a first step, the comparison relates to seven countries from all OECD regions; (ii) decomposing GDP per capita differences into productivity differences and differences in labour utilisation and identifying the contribution of ICT capital to labour productivity differences; (iii) discussing the statistical uncertainties surrounding level comparisons and determination of likely error margins by way of a simple Monte-Carlo simulation. Overall, the paper is statistical in nature and focuses on the measurement issues rather than on the economic analysis of productivity differences.

2. Bilateral and multilateral comparisons: concepts for comparisons

There is a large body of literature on the international comparison of volumes and prices of output and GDP. The international comparison of the levels of capital input has been less prominent in the methodological literature and partly this is because the principles that apply to the output side are directly transferable to the input side, so there seemed to be little need for extra elaboration. Also, data availability often forces the analyst to use highly simplified assumptions by which conceptual questions about international comparisons are more or less defined away. For example, when labour inputs are measured as undifferentiated hours worked, it is straight forward to compare them across countries. Such an easy comparison is, however, only possible because it is assumed that every hour worked has exactly the same productive properties, independent of the experience, the educational attainment or the skill of workers, and independent of the country or the industry where it is delivered. O'Mahony and de Boer (2002), Jorgenson (2003), Inklaar et al. (2006) are exceptions to this rule – they derive international comparisons of labour input measures that take account of the compositional change of the labour force.

Comparisons of capital input suffer sometimes from a deficiency similar to comparisons of labour input when no account is taken of the composition of capital inputs. The following section describes how such compositional effects can be incorporated into level comparisons of capital input.

2.1 A quantity index of capital services

We start by re-stating the measurement of capital services over time within a country or within an industry. Capital services are the flow of services by which capital goods contribute to production. It is typically assumed that, for each type of capital goods, the flow of capital services is proportional to the productive stock of the same type of capital good. The productive stock reflects the productive capacity embodied in the available stock. Proportionality between the productive stock and the flow of capital services implies that the rate of change of capital services equals the rate of change of the productive stock of each asset. An overall index of capital services is derived by weighting the flow of each asset's capital services by its marginal productivity. Marginal productivity cannot be observed directly, but the theory of production tell us that the marginal productivity of an asset relative to the overall marginal productivity of capital equals each asset's share in the overall user costs of capital. The latter can be measured as the price that the owner of a capital good would charge for renting it out during one period. This provides a handle for the derivation of conceptually correct weights in a capital services index. The theoretical foundations of capital services measures are largely due to Jorgenson (1963, 1965, 1967) and Jorgenson and Griliches (1967). The necessary theory of index numbers and aggregation has been developed by Diewert (1978, 1980) and this literature forms the basis for most empirical studies in capital measurement.

Capital measures in the OECD Productivity Database are also based on these theoretical foundations and time series of capital input between period t and period t-1 in country j are derived as a Törnqvist index:

$$\ln\left(\frac{K_t^j}{K_{t-1}^j}\right)=\sum_s^M \overline{w}_s \ln\left(\frac{K_{s,t}^j}{K_{s,t-1}^j}\right)$$

(1)
$$\overline{w}_{s,t}=\tfrac{1}{2}\left(w_{s,t}^j+w_{s,t-1}^j\right)$$

$$w_{s,t}^j\equiv\frac{u_{s,t}^j K_{s,t}^j}{\sum_s^M u_{s,t}^j K_{s,t}^j};$$

In (1), $K_{s,t}^j$ stands for the productive stock of asset type s=1,2,...M in country j=1,2,...N at the beginning of period t, $u_{s,t}^j$ is period t user cost per unit of the productive stock of type s. $K_{s,t}^j$ is itself constructed with the perpetual inventory method, i.e., by aggregating across volumes of investment in past periods and by weighting each of these investment flows with a factor that reflects productive efficiency and retirements. A full description of data and concepts can be found in Schreyer et al. (2003).

2.2 Bilateral comparisons

The temporal Törnqvist index of capital input above has a strong theoretical basis[3] and one can directly build on these properties to develop a similar index for spatial comparisons of capital input. In principle, all that needs to be done is to substitute the time periods t and t-1 with country indices A and B in expression (1). This is the ***translog bilateral input index*** γ_t^{AB} as derived by Christensen et al. (1981) and by Caves et al. (1982):

[3] The Törnqvist index is a superlative index number formula (Diewert 1976), i.e., an exact representation of a flexible aggregator function. In the present case, the underlying aggregator function is a cost function and the above index of capital input will be exact if we assume that the cost function is of the translog form, that capital markets are competitive and that producers minimise costs.

$$\ln \gamma_t^{AB} = \sum_s^M \overline{w}_{s,t}^{AB} \ln\left(\frac{K_{s,t}^A}{K_{s,t}^B}\right)$$

(2) $$\overline{w}_{s,t}^{AB} = \tfrac{1}{2}\left(w_{s,t}^A + w_{s,t}^B\right)$$

$$w_{s,t}^j \equiv \frac{u_{s,t}^j K_{s,t}^j}{\sum_s^M u_{s,t}^j K_{s,t}^j};\ j = A, B.$$

The theoretical formulation in (2) implicitly assumes that at the level of individual assets, inputs are measured in physical units and that they can therefore be directly compared across countries. In practice, this is not the case and stocks of asset groups are expressed in national currency units of some base year such as 'constant 1995 dollars', reflecting the fact that individual asset types are aggregations across similar sub-types of assets rather than truly homogenous investment goods that could be expressed in physical units. Thus, country A's productive stock of asset type s $K_{s,t}^A$ is measured in currency units of country A and consequently not comparable to $K_{s,t}^B$, expressed in currency units of country B. More specifically, the underlying valuation is in terms of investment goods prices of a base period. This base period for the underlying investment goods price index may or may not coincide with the year of the spatial comparison. We use the asset-specific price index and express each asset's productive stock at replacement costs of the comparison period. Finally, to make the productive stocks of countries A and B comparable, the purchasing power parity for investment good of type s, $q_{s,t}^A / q_{s,t}^B$ has to be applied to (2) to obtain:

(3) $$\ln \gamma_t^{AB} = \sum_s^M \overline{w}_{s,t}^{AB} \ln\left(\frac{K_{s,t}^A}{K_{s,t}^B} \frac{q_{s,t}^B}{q_{s,t}^A}\right).$$

The extension to an index of capital productivity is straightforward. We define a ***bilateral Törnqvist index of capital productivity***[4] as

[4] The time subscript t has been dropped here to facilitate notation.

(4) $\ln \theta^{AB} = \ln \lambda^{AB} - \ln \gamma^{AB}$

where λ^{AB} is the volume of output in country A relative to country B. We skip the presentation of a theoretical Törnqvist quantity index of output here because in our applications we use a readily-available indirect quantity index of GDP, obtained by dividing money values of GDP in the various countries by the OECD/Eurostat PPPs, i.e., by a spatial price index. This spatial deflation yields comparable volume indices of GDP.

The index of capital productivity in (4) can be compared with an index of labour productivity. In principle, labour input should be gauged with a method that is exactly parallel to the measure of capital input, i.e., by aggregating across different types of labour taking into account the relative skills, qualifications and educational attainment of the labour force. Presently, the necessary data for such a differentiation is, however, not available and we have to content ourselves with a measure of labour input that reflects total but undifferentiated hours worked. Letting H_t^A be the number of total hours in country A and period t and letting H_t^B be the number of total hours in country B and period t, a ***bilateral index of labour input*** and a ***bilateral index of labour productivity*** are defined as:

(5) $\ln h^{AB} = \ln\left(\frac{H^A}{H^B}\right)$

(6) $\ln \pi^{AB} = \ln \lambda^{AB} - \ln h^{AB}$.

It is now a small step towards deriving an index of multifactor productivity (MFP). A bilateral index of MFP shows the difference in output between two countries that cannot be attributed to differences in the number of hours worked or to differences in capital input. Akin to the computation over time, MFP is a residual, obtained by weighting relative labour and capital inputs and adjusting relative outputs for relative inputs. Alternatively, MFP can be described as a weighted average of labour and capital productivity, where each of the two partial productivity measures are weighted by the respective share of labour and capital in total costs. For the purpose at hand, we shall choose the latter avenue and define a ***bilateral index of multifactor productivity*** μ^{AB} as:

$$
\begin{aligned}
&\ln\mu^{AB} = \bar{v}^{AB}\ln\pi^{AB} + (1-\bar{v}^{AB})\ln\theta^{AB} \\
(7)\qquad &\bar{v}^{AB} = \tfrac{1}{2}\left(v^{A} + v^{B}\right) \qquad . \\
&v^{j} = p_{w}^{j}H^{j} \Big/ \left(p_{w}^{j}H^{j} + \textstyle\sum_{s=1}^{M} u_{s}^{j}K_{s}^{j}\right) \quad j = A, B.
\end{aligned}
$$

In (7), v^{A} is the share of labour compensation $p_{w}^{A}H^{A}$ in the total compensation of labour and capital $p_{w}^{A}H^{A} + \sum_{s=1}^{M} u_{s}^{A}K_{s}^{A}$. Similarly, v^{B} is country B's labour share and $\bar{v}^{AB}$ is the average share between the two countries.

An alternative way of presenting equation (7) is as a de-composition of the labour productivity difference between the two countries. With a few transformations, one obtains

(8) $\ln\pi^{AB} = (1-\bar{v}^{AB})(\ln\gamma^{AB} - \ln h^{AB}) + \ln\mu^{AB}$.

Expression (8) breaks the bilateral index of labour productivity into two parts: an index of relative capital intensity (the ratio between the index of capital services and the index of hours worked), weighted by the share of capital in total costs and the index of multi-factor productivity. This presentation is well known from the temporal equivalent to (8) in growth accounting exercises. The above de-composition can be carried further to identify the contribution of different asset types to labour productivity differences. In particular, we can distinguish between information and communication technology (ICT) assets and non-ICT assets. This is readily achieved by breaking the computation of the index of capital services (see equation (3) into an ICT and a non-ICT part:

$$\ln \gamma^{AB} = \ln \gamma^{AB}_{ICT} + \ln \gamma^{AB}_{non-ICT}$$

(9)

$$\text{with } \ln \gamma^{AB}_{ICT} = \sum_{s \in ICT} \overline{w}^{AB}_{s,} \ln\left(\frac{K^A_s}{K^B_s} \frac{q^B_s}{q^A_s} \right), \; \ln \gamma^{AB}_{non-ICT} = \sum_{s \in non-ICT} \overline{w}^{AB}_{s,} \ln\left(\frac{K^A_s}{K^B_s} \frac{q^B_s}{q^A_s} \right)$$

To put down the full bilateral de-composition of the index of labour productivity it remains to define ***the bilateral indices of total capital intensity,*** ς^{AB}***, of ICT capital intensity*** ς^{AB}_{ICT} ***and of non-ICT capital intensity,*** $\varsigma^{AB}_{non-ICT}$***:***

$$\ln \varsigma^{AB}_{ICT} = \sum_{s \in ICT} \overline{w}^{AB}_{s,} \left[\ln\left(\frac{K^A_s}{K^B_s} \frac{q^B_s}{q^A_s} \right) - \ln h^{AB} \right]$$

(10)

$$\ln \varsigma^{AB}_{non-ICT} = \sum_{s \in non-ICT} \overline{w}^{AB}_{s,} \left[\ln\left(\frac{K^A_s}{K^B_s} \frac{q^B_s}{q^A_s} \right) - \ln h^{AB} \right]$$

$$\ln \varsigma^{AB} = \ln \varsigma^{AB}_{ICT} + \ln \varsigma^{AB}_{non-ICT}$$

The ***de-composition of the bi-lateral labour productivity index*** with regards to the two asset groups and to multi-factor productivity is

(11) $$\ln \pi^{AB} = (1 - \overline{v}^{AB})(\ln \varsigma^{AB}_{ICT} + \ln \varsigma^{AB}_{non-ICT}) + \ln \mu^{AB} .$$

2.3 Multilateral comparisons

Bilateral comparisons, when applied to more than two countries, have the disadvantage of intransitivity, i.e., in general $\gamma^{AB} * \gamma^{BC} \neq \gamma^{AC}$. A number of techniques exist to obtain transitivity. For the purpose at hand, we apply the Caves et al. (1982) method: transitivity in a multilateral context is achieved by defining the capital input of country i relative to the capital input of all N countries as the geometric mean of the bilateral input comparisons between i and each of the countries:

(12) $\ln \bar{\gamma}^{i} = \frac{1}{N}\sum_{k=1}^{N} \ln \gamma^{ik}$

The ***multilateral Törnqvist index of capital inputs*** $\tilde{\gamma}^{ij}$ is defined as

(13) $\ln \tilde{\gamma}^{ij} = \ln \bar{\gamma}^{i} - \ln \bar{\gamma}^{j}$.

It is not difficult to verify that this index is transitive. If a spatial index of outputs had been constructed in the present exercise, the same method would have been applied to achieve transitivity. There is no need for a particular adjustment here, however, because the OECD/Eurostat PPPs that enter the calculations have already been made transitive by a similar procedure[5] to the one described in (12) and (13)

The ***multilateral Törnqvist index of capital productivity*** $\tilde{\theta}^{ij}$ is defined as

(14) $\ln \tilde{\theta}^{ij} = \ln \lambda^{ij} - \ln \tilde{\gamma}^{ij}$.

Because the index of labour input is one-dimensional (the only unit are hours worked), no issue of transitivity arises and we can immediately define the ***multilateral index of labour productivity*** as:

(15) $\ln \pi^{ij} = \ln \lambda^{ij} - \ln h^{ij}$.

[5] The OECD/Eurostat Purchasing Power Parities Programme uses the Eltetö and Köves (1964) and Szulc (1964) "EKS" method to derive their spatial deflators. The EKS method reaches transitivity by a transformation that is identical to the one in equation (12), the only difference being that the EKS method uses a Fisher Ideal index number formula whereas we have used a Törnqvist formula.

Finally, to compute a multilateral Törnqvist index of multi-factor productivity $\tilde{\mu}^{ij}$ we construct the geometric mean of the bilateral MFP comparisons between i and each of the N countries:

(16) $\ln \bar{\mu}^{i} = \frac{1}{N}\sum_{k=1}^{N} \ln \mu^{ik}$

The ***multilateral Törnqvist index of multi-factor productivity*** $\tilde{\mu}^{ij}$ is defined as

(17) $\ln \tilde{\mu}^{ij} = \ln \bar{\mu}^{i} - \ln \bar{\mu}^{j}$.

The ***multilateral decomposition of the labour productivity index*** follows the same logic and is given by

$$\ln \tilde{\pi}^{ij} = \ln \tilde{c}^{ij}_{ICT} + \ln \tilde{c}^{ij}_{non-ICT} + \ln \tilde{\mu}^{ij}$$

where

(18)
$$\begin{aligned}
&\ln c^{ik}_{s} = (1-\bar{v}^{ik})\varsigma^{ik}_{s} && s = ICT, non-ICT \\
&\ln \bar{c}^{i}_{s} = \sum_{k=1}^{N} \ln c^{ik}_{s} && i = 1,2,....N \\
&\ln \bar{c}^{j}_{s} = \sum_{k=1}^{N} \ln c^{jk}_{s} && i = 1,2,....N \\
&\ln \tilde{c}^{ij}_{s} = \ln \bar{c}^{i}_{s} - \ln \bar{c}^{j}_{s}
\end{aligned}.$$

3. Results

The empirical productivity measures developed in the present paper all relate to the total economy. This reflects data constraints more than a choice. Preferably, computations would also single out the corporate or business sector as well as individual industries. However, measures of capital input and hours worked are not easily available in such a sectoral breakdown and calculations remain at the aggregate level, in line with the *OECD Productivity Database*.

We start by reproducing the set of data on output and hours worked for 2002 that forms the basis for the measurement of relative labour productivity levels. Of the seven countries under consideration, only France exceeds the labour productivity level of the

United States. Labour composition may actually be one of the explanatory factors behind this. OECD (2005) shows that the employment rates for young and older workers are particularly low in France compared to other OECD countries. High minimum labour cost relative to average labour cost has tended to lower demand for labour, especially certain groups such as young and low-skilled workers. By implication, employment is concentrated in the most productive segment of the population (Bourlès and Cette 2005), an effect that is not controlled for in our undifferentiated measure of labour input and which has to be taken into account when interpreting productivity figures.

Table 1: Levels of GDP, hours worked and labour productivity in 2002
USA = 100

Multilateral index of:	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
GDP at 2002 PPPs	5.5	8.9	16.6	21.5	0.8	16.5	100.0
Hours worked	6.8	10.9	15.3	22.4	1.4	18.7	100.0
Labour productivity	80.1	82.1	109.0	95.7	60.8	88.0	100.0

Source: *OECD Productivity Database* .

Table 2 below shows multilateral indices of capital services, capital intensity and capital productivity. As outlined in the methodological section, indices of capital services differ from indices based on net or gross capital stocks insofar as different assets are weighted with their share in total user costs. User costs are designed to capture the marginal productivity of assets so that high productivity assets receive larger weights. Typically, short-lived assets such as information and communication products fall under this category because short service lives and rapid price declines require high marginal productivity while such assets are in operation. Consequently, indices of capital services will tend to be higher for those countries whose investment and capital stock structure is biased towards high-productivity, short-lived capital goods relative to other countries. While the indices of capital services reflect also each country's size, indices of capital intensity and capital productivity are normalised by labour input and output. One notes considerable differences in capital intensity (i.e., capital services per hour worked) between countries.

Table 2: Levels of capital input, capital intensity and capital productivity in 2002
USA=100

Multilateral index of:	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
Capital services	6.1	8.4	14.1	23.0	0.7	12.1	100.0
Capital intensity	89.5	77.8	92.6	102.3	50.8	64.5	100.0
Capital productivity	89.5	105.5	117.7	93.5	119.7	136.5	100.0

Source: *OECD Productivity Database and author's calculations* .

Checking the results against similar studies, we find that our results are in the same order of magnitude as O'Mahony and de Boer (2002) as far as the relative capital intensities between the United Kingdom and the United States are concerned[6] and considering that O'Mahony and de Boer use a measure of net capital stock. It should also be expected that they differ from capital input measures based on a concept of capital services. However, the gap with their results for France seems wide – they find a much higher relative capital intensity than we do.

The bilateral results for Canada and the United States seem to be roughly[7] in line with the relative capital intensity computed by Rao et al. (2003). We were, however, unable to match our bilateral measures of capital intensity with those available from the Database of ICT Investment and Capital Stock Trends of the *Centre for the Study of*

[6] With the UK=100, our capital per hour ratios are 155 for the USA, and 158 for Germany in the year 2002. This compares with O'Mahony's and de Boer (2002) values of 146 for the USA and 147 for Germany in the year 1999.

[7] Rao et al. (2003) compute relative a capital intensity of 95% for the year 2000 between Canada and the United States. However, their calculation relates to the business sector, and not to the total economy as in our study. Furthermore, the authors use a measure of the net stock in 1997 dollars, and so differ from the capital services concept used in the present study. If the USA has a relatively larger share in short-lived ICT capital, this would explain why our measure of capital intensity shows a relatively higher value for the USA than the measure obtained by Rao et al. (2003).

Living Standards[8] although there are also a number of differences in concept and scope. Some further investigation will be necessary to account for these differences.

Table 3 exhibits multilateral indices of labour, capital and multifactor productivity for the year 2002. There are only limited possibilities to compare the result with other studies: Rao et al. (2003) find a similar MFP ratio for Canada vis-à-vis the United States but use a different concept of capital input. Jorgenson (2003) uses a constant quality measure of labour input whereas we use a simple measure of hours worked, which makes the comparison of the productivity residual difficult. O'Mahony and de Boer (2002) make a similar adjustment for labour composition as Jorgenson but do not adjust for capital composition. They find a larger productivity gap between the UK and the United States than we do and a smaller difference between the UK and France.

Table 3 Capital, labour and multifactor productivity in 2002

Multilateral index of:	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
Multifactor productivity	81.5	86.6	110.5	94.4	70.7	97.0	100.0
Labour productivity	80.1	82.1	109.0	95.7	60.8	88.0	100.0
Capital productivity	89.5	105.5	117.7	93.5	119.7	136.5	100.0

Source: *OECD Productivity Database and author's calculation* .

Finally, we show the decomposition of labour productivity ratios into the effects of capital intensity and MFP, where capital measures are broken down into ICT and non-ICT capital goods. The outcome is presented in Table 4 below. Several observations are in place.

First, the table starts with a measure of GDP per capita before moving to the labour productivity index. The index of GDP per capita can be broken down into labour-utilisation and labour productivity gaps of the countries relative to the United States. It is immediately apparent that lower working hours per capita account for the main part in

[8] Available from http://www.csls.ca/. In Table S32 of the database, the non-residential capital stock per worker in the Canadian business sector shows up with a 131% value over the corresponding U.S. figure.

the GDP per capita gap in the two European countries (this holds for many European countries as well, see OECD 2005, 2006). This is due to low participation of people of working age in the labour market and high unemployment. The effect is typically reinforced by fewer hours worked per employee, as part-time work is more prevalent and annual working hours for full-time workers are lower. Labour productivity differences account for the bulk of differences in GDP per capita vis-à-vis the United States for the other countries in the sample, as can be seen from an index of labour utilisation that is close to 100 for Australia, Canada, New Zealand but also relatively high for the United Kingdom. Note, however, that the simple accounting of the difference in the GDP per capita gap may give a distorted picture of countries' relative strengths and weaknesses because aggregate labour utilisation and productivity can be interdependent. Countries with low labour utilisation may not employ many low productivity workers, thereby artificially boosting measured labour productivity relative to that in countries with high employment rates.

Second, the decomposition of the labour productivity index shows that, of the countries in the sample, only New Zealand and the United Kingdom have markedly different indices of labour productivity and MFP. In Australia, France and Germany, the effect of capital intensity does not play an outstanding role. All countries show however an index of ICT capital intensity that is less than 100, indicating a lower ICT capital intensity than the United States. This is consistent with other studies and has been the source of much discussion about the growth effects of ICT investment.

Third, the present calculations make no allowance for differences in the composition of the labour force in the various countries. One working hour is counted as one hour, independent of the level of skills and human capital of the person providing labour input. Thus, the differentiation of different types of assets that turns out to be important for a conceptually correct measure of capital input, has not been applied for labour input, mainly because data limitations have not allowed to implement the relevant calculations. This has consequences for the interpretation of the MFP measure: if a country's labour force is relatively more qualified or skilled than another country's labour force, this will have a positive effect on measured labour productivity. This labour productivity enhancing effect should be explicitly identified (see, for example Jorgenson 2003) rather than buried in the MFP residual as is the case in the calculations at hand[9].

4. Robustness of results

Many uncertainties prevail in the measurement of capital input, in the measurement of output and in the measurement of PPPs and the results shown above should be interpreted with a good deal of caution. For example, Ahmad et al. (2003) have estimated that level comparisons of GDP may well be subject to an error margin of several percentage points. OECD/Eurostat PPPs for GDP, while based on several thousand price observations, are nonetheless subject to statistical noise and a rule of thumb sets a 5 percentage point margin within which it may be difficult to make reliable statements about significant differences between countries' volume GDP per capita. Capital services measures, in particular when constructed at the international level, are also subject to error margins, partly because some of the underlying investment series may have been estimated, in particular for early periods. A particular issue in this context is the choice of an initial productive stock for non-residential structures: an assumed service life of 40 years would require investment series for structures from the 1940s to obtain an estimate of the productive stock in the mid-1980s. Such data are not available at the international level, and some rather simplifying assumptions have been made to establish a starting value for the stock of non-residential structures. Overall, then, there are good reasons to believe that level comparisons of capital and labour input are subject to measurement error and this part of the paper aims at establishing some bounds for such errors.

[9] To get a sense for the relative importance of labour composition in our MFP estimates, an approach proposed by Bourlès and Cette (2005) can be applied. The idea is that when employment rates are low, the average skill of employed workers is higher than when employment rates are high. The fact that high-skilled workers are hired before low-skilled workers or, alternatively, that unemployment is concentrated among low-skilled workers seems to be a well-established empirical observation. Consequently, by regressing productivity level differences against differences in employment rates, it is possible to get a handle on differences in the skill composition of employment. A simple version of the Bourlès and Cette (2005) method applied to the data at hand shows remarkable differences in results for France whose relative MFP level drops from over 110% as initially measured to just over 101% and 98% when relative employment rates and the position in the business cycle are controlled for. The figures for Germany also show a relatively important drop (about four percentage points) when based on total employment rates. For all other countries in the sample the effects are much smaller.

Table 4 Decomposition of labour productivity ratios in 2002
Multiplicative decomposition

Multilateral index of:	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
GDP at 2002 PPPs	5.5	8.9	16.6	21.5	0.8	16.5	100.0
Population	6.9	10.9	21.3	28.6	1.4	20.6	100.0
GDP per capita	79.6	81.8	77.9	75.1	61.2	80.1	100.0
=Effects of labour utilisation (hour worked per capita)	99.4	99.7	71.4	78.4	100.6	91.0	100.0
Labour productivity	80.1	82.1	109.0	95.7	60.8	88.0	100.0
Labour productivity	80.1	82.1	109.0	95.7	60.8	88.0	100.0
=Effects of capital intensity	98.2	94.8	98.6	101.4	86.0	90.7	100.0
of which:							
ICT capital	97.6	96.6	95.6	96.4	94.6	96.0	100.0
Non-ICT capital	100.7	98.1	103.2	105.2	90.9	94.5	100.0
MFP	81.5	86.6	110.5	94.4	70.7	97.0	100.0

Table 5 Decomposition of labour productivity ratios in 2002
Additive decomposition*

Multilateral index of:	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
GDP per capita	-20.4%	-18.2%	-22.1%	-24.9%	-38.8%	-19.9%	0.0%
Effects of labour utilisation (population per hour worked)	0.5%	0.2%	31.1%	20.6%	-0.4%	7.9%	0.0%
Labour productivity	-19.9%	-17.9%	9.0%	-4.3%	-39.2%	-12.0%	0.0%
Effects of capital intensity	-1.8%	-5.2%	-1.4%	1.4%	-14.0%	-9.3%	0.0%
of which:							
ICT capital	-2.4%	-3.4%	-4.4%	-3.6%	-5.4%	-4.0%	0.0%
Non-ICT capital	0.7%	-1.9%	3.2%	5.2%	-9.1%	-5.5%	0.0%
Interaction term	0.0%	0.1%	-0.1%	-0.2%	0.5%	0.2%	0.0%
MFP	-18.5%	-13.4%	10.5%	-5.6%	-29.3%	-3.0%	0.0%
Interaction term*	0.3%	0.7%	-0.2%	-0.1%	4.1%	0.3%	0.0%

*The product of two index numbers cannot be easily de-composed into the sum of two simple discrete percentage differences – there remains an interaction term unless one chooses an additive de-composition based on continuous (i.e., logarithmic) percentage differences or based on a more complex discrete de-composition.

We proceed with a very simple Monte-Carlo simulation. Starting point is the assumption that the following variables are subject to measurement error: GDP, PPPs, hours actually worked, and capital services. More specifically, we assume that the observations of each of these variables are randomly distributed around their true value. Based on our point estimates for each variable, we generate a set of observations that enter the productivity level computations. For example, we generate GDP_s^i, i.e., an observation s for country i's GDP by the relationship $GDP_s^i = GDP^i(1+\varepsilon)$ where GDP^i is the value for country i's GDP from the national accounts and ε is an independently and normally distributed error variable with mean zero and a standard deviation of 0.02. In other words, we generate a set of data with the property that the GDP estimate from the national accounts is the most probable realisation and that there is a near 99% probability that the randomly generated observation for GDP lies within a range of 5% below and 5% above their mean, the observed value from the national accounts. A plus/minus 5% margin is generous and probably overstates the true likelihood of measurement errors. But we prefer to err on the high side than to evoke too optimistic a picture of precision in economic measurement.

Similar assumptions as for GDP levels are made for the other variables and a set of 100 artificial observations of GDP, PPPs, hours worked and productive stock for every asset and every country is generated for the year 2002.

For each of the 100 observations, we compute multilateral indices of capital services, labour and capital productivity, capital intensity and MFP. We compute the average and standard deviation of all observations to obtain statistical bounds[10] for the estimates at hand. Upper and lower bounds confine the area that contains 99% of all outcomes given the error structure that underlies the Monte Carlo experiment. They are shown in the following tables and graph.

[10] Given the various transformations that are necessary to obtain multilateral indices, it is not possible to demonstrate that, as a consequence of assuming normal distribution of the errors for the base data, the multilateral indices are also normally distributed. However, we apply a Jarque-Bera test to check for normality of the results generated by the Monte Carlo simulation and find that for virtually all variables the null hypothesis of a normal distribution cannot be rejected. This permits the construction of confidence intervals on the basis of normal distributions.

Upper and lower bounds provide an order of magnitude for the uncertainties involved in the estimation of international indicators. The bracket for MFP estimates, for example, comprises up to 10 percentage points around the point estimate. In the case of the United Kingdom this means that on the basis of our data with their assumed observation error of +/-5%, there is a 99% probability that MFP relative to the United States may be situated somewhere between 89.4% and 103.9% (Table 9). Or labour productivity for France can be located somewhere between 101% and 116% of the U.S. level – a particularly large range. These boundaries once more show that precise rankings of countries may be difficult to obtain and in general should not be undertaken when countries are clustered around similar values of indices of productivity or per capita income – a point that has also been made in the context of the OECD/Eurostat PPP programme (OECD 2004).

Table 6: Upper and lower bounds for labour productivity in 2002
USA=100

	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
Upper bound	85.7	87.2	115.7	102.0	64.8	94.0	100.0
Point estimate	80.1	82.1	109.0	95.7	60.8	88.0	100.0
Lower bound	73.8	76.4	101.1	88.7	56.5	81.4	100.0

Source: *OECD Productivity Database and author's calculation* .

Table 7: Upper and lower bounds for capital intensity in 2002
USA=100

	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
Upper bound	97.0	87.2	100.2	110.8	54.8	69.4	100.0
Point estimate	89.5	77.8	92.6	102.3	50.8	64.5	100.0
Lower bound	82.4	76.4	85.1	93.7	46.9	59.5	100.0

Source: *OECD Productivity Database and author's calculation* .

Table 8: Upper and lower bounds for capital productivity in 2002
USA=100

	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
Upper bound	98.2	116.3	129.7	101.9	131.6	150.9	100.0
Point estimate	89.5	105.5	117.7	93.5	119.7	136.5	100.0
Lower bound	79.8	94.0	104.6	84.8	107.1	121.4	100.0

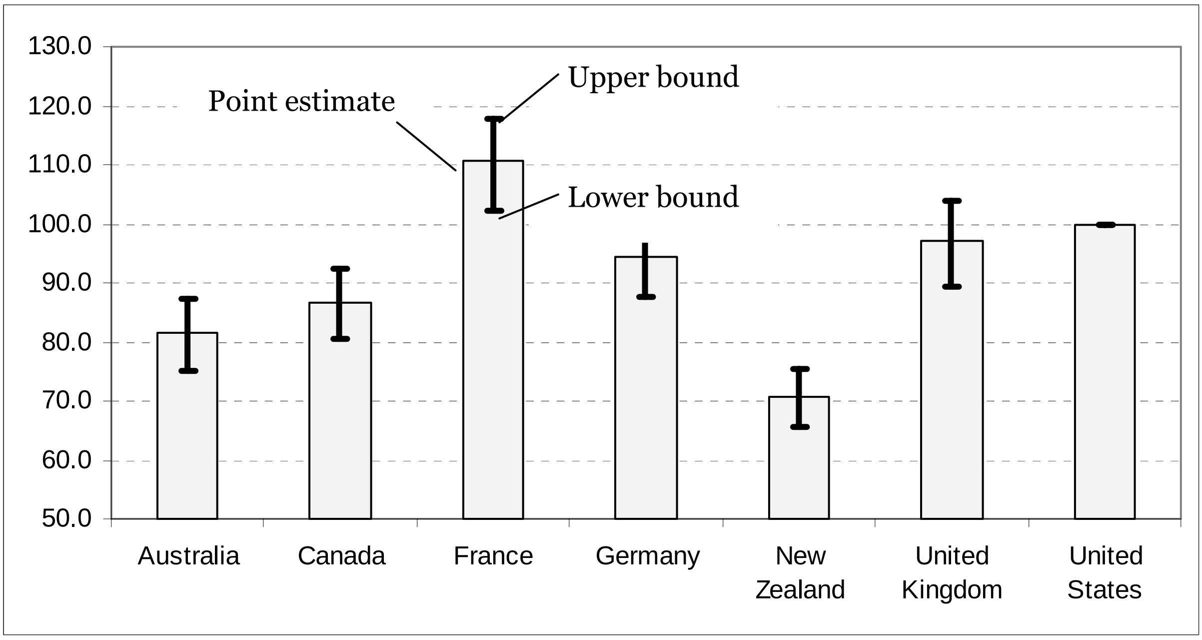
Source: *OECD Productivity Database and author's calculation* .

Table 9: Upper and lower bounds for multi-factor productivity in 2002
USA=100

	Australia	Canada	France	Germany	New Zealand	United Kingdom	United States
Upper bound	87.2	92.3	117.6	100.3	75.4	103.9	100.0
Point estimate	81.5	86.6	110.5	94.4	70.7	97.0	100.0
Lower bound	75.1	80.4	102.2	87.8	65.5	89.4	100.0

Source: *OECD Productivity Database and author's calculation* .

Figure 1 Upper and lower bounds for multi-factor productivity in 2002
USA=100



5. Conclusions

The present study provides a set of partial and multi-factor productivity levels for seven OECD countries and shows how GDP per capita differences can be broken down into differences in labour utilisation, ICT and non-ICT capital intensity and MFP. The paper focuses on the statistical aspects of these indicators and refers to determinants and analysis of productivity only at the margin. Three main conclusions arise from this work:

- Level estimates of capital and multi-factor productivity are feasible and provide a useful complement to the labour productivity estimates that have been an integral part of the OECD productivity estimates for several years.
- Methodology matters – the choice of the conceptually correct measure of capital input shapes results as does the choice of index number formulae when comparisons along both the time and spatial dimension are undertaken.
- Statistical uncertainties remain and results have to be interpreted with a good deal of caution. We provide Monte Carlo estimates to examine the effects of measurement errors in the base data and these simulations showed that boundaries for the resulting indicators can be important.

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