International Comparisons of Industry Output, Inputs and Productivity Levels: Methodology and New Results

by

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Abstract

In this paper we provide new evidence on relative levels of output, inputs and productivity at a detailed industry level for a set of seven countries. These comparisons are based on sectoral output measures that exclude intra-industry flows. We argue that this improves international comparability and the insightfulness of the analysis. Productivity levels are relatively similar in the European and Anglo-Saxon countries we analyze, but we do find large differences in production structures. U.S. industries use more skilled labour, more ICT capital more services input and more energy, but less materials, per unit of output than the other countries. This pattern is found for both goods-producing and services-producing industries.

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1. Introduction

New technology, such as information and communication technologies (ICT) and globalization are having a large impact on production and trade patterns. Production of ICT goods and services is increasing, and productivity growth in this sector is high. Investment has been moving rapidly toward ICT assets, substituting away from non-ICT capital and due to the skill-biased nature of ICT, the demand for higher educated workers is rising. Higher levels of ICT capital deployed in the economy have led to an increased demand for business services and, outsourcing of activities in general, has led to shifts in the production and consumption of intermediate materials, energy and services input, both within and between countries. So far, these trends have been documented for national economies but international comparisons of output, input and productivity levels are lacking. This study aims to fill this gap by analyzing these comparative levels for seven countries: Australia, Canada, France, Germany, the Netherlands, the UK and the US. The comparisons are made at a detailed industry-level, looking at the relative levels of various inputs used in the production process, and the efficiency with which inputs are used in generating output. Inputs are grouped into seven major groups: two types of labour (university degree and below), two types of capital (ICT capital and non-ICT capital), and energy, materials and services inputs.

Comparisons of output and productivity across countries, using a growth accounting methodology, have a long history and date back at least to Denison (1967). The methodology for level comparisons has been firmly based in the neo-classical theory of production by Jorgenson and associates (Jorgenson, 1995). Instead of comparing output and input combinations of one country at two different points in time as in growth accounting, one compares input-output combinations of two different countries at a similar point of time. Hence the term "level comparison" is used to contrast it with growth comparisons. Level comparisons have been scarce, especially those involving more than two countries and those that are based on gross output rather than value added. The seminal multilateral study of this type is by Conrad and Jorgenson (1985) which provided a comparison of Germany, Japan and the U.S. However, there have been no subsequent studies of this scope. The main reason has been a lack of comparable data on inter-industry transactions, capital service flows and purchasing power parities. Based on new data sources, this study aims to fill the gap by providing new multilateral comparisons of output, inputs and productivity for 26 detailed industries for 1997. Along the way, we stress the empirical relevance of so-called sectoral output and input measures in which intra-industry deliveries are netted out (Gollop, 1979). We show that these sectoral measures do not suffer from possible biases due to differences in the degree of integration of firms across countries.

Level comparisons of inputs and productivity can be useful for various purposes, for example, in the light of the debate on sources of growth. In recent years there has been an intense interest in the effects of ICT on economic growth. Much of this was sparked by research showing that ICT played an important role in the acceleration in U.S. labour productivity growth after 1995. Comparative studies tried to explain Europe's lagging behind and showed that differences in ICT investment played a major role in the transatlantic divergence process, and TFP growth lagged mainly in market services.[1] The results from these growth accounting studies can be put in perspective by linking them to the level comparisons provided in this paper. The interpretation of comparative growth patterns will depend on the initial starting position in terms of levels. For example, if growth is fastest in the country with the lowest initial level, this can be seen as catch-up growth in which follower countries converge to more advanced countries through imitation and spillover of technologies (Griffith, Redding and van Reenen 2004). In addition, level estimates can shed new light on issues such as the relative ICT capital intensity of various economies. It measures the differences in the penetration of new technology in the production process. Relative levels of energy, materials and services inputs can be important measures in debates on outsourcing of service activities, international differences in production structures and energy use and reduction strategies (see for example Motohashi, 1998; Bohwmik, 2003). Finally, productivity comparisons capture international differences in the efficiency with which inputs are used in the production process and provide new evidence for theories of international trade (Harrigan 1997).

The remainder of the paper is organised as follows. In Section 2, we discuss the importance of "sectoral" measures of input and output for international comparisons. Although the concept of sectoral output and input has been around for some time, it has mainly been used for deriving consistent measures of total factor productivity at various levels of aggregation. We stress its usefulness not only for comparisons of productivity, but also for meaningful comparisons of output and intermediate inputs. We show that comparisons based on data which includes intra-industry trade will be biased due to differences in the degree of integration of firms across countries. This is illustrated with data for a manufacturing industry. Basically, our level comparisons are based on deflating inputs and output as given in national input-output tables by a set of relative prices. We use a new set of relative prices which is specifically developed for making cross-country, industry-level productivity comparisons. These are complemented by relative prices for capital and labour inputs, as described in Section 3. In Section 4, we discuss our approach for multilateral comparisons, following the standard methodology as developed by Jorgenson and associates.[2] Relative output, input and productivity levels for the benchmark year 1997 are presented in Section 5. We find that per unit of output U.S. industries use more skilled labour, more ICT capital, more services input and energy than comparable industries in other countries. In contrast, they use less non-ICT capital and material inputs. This pattern can be found for most industries. Section 6 concludes.

[1] See for example, Jorgenson *et al.* (2003, 2005), Timmer and van Ark (2005), Inklaar, O'Mahony and Timmer (2005) and Inklaar, Timmer and van Ark (2006).
[2] See contributions in Jorgenson (1995).

2. Sectoral output and input measures

2.1 Sectoral output and input concept

An important consideration when making cross-country comparisons is the effect of differences in the degree of integration of firms within an economy. In some countries, an industry may be made up of many small firms that only handle part of the production process, while in other countries, firms may be more integrated. In the former case, there will be a lot of intra-industry trade of intermediate products, and the industry uses more of its own production. In this study we make use of the so-called "sectoral" output and input concepts as introduced by Domar (1961) in which intra-industry deliveries are netted out. Essentially, all industries are considered to be completely integrated, i.e. all individual units in an industry are combined into a single unit. This assumption is made at all levels of aggregation. Sectoral output measures will be identical to gross output at the firm level, but as one moves up the hierarchy of industries, it moves closer and closer to value added. Similarly, sectoral intermediate input measures approach total imports at higher aggregation levels. Indeed, at the level of the total economy sectoral output is equal to GDP plus imports and sectoral intermediate input is equal to imports, as all domestic inter-industry deliveries have been netted out.[3] Using the terminology of Durand (1996), this approach can be called aggregation with integration, as opposed to aggregation without integration. The main advantage of the aggregation with integration approach is that differences in integration across countries will not distort relative measures of inputs and productivity. A simple example can illustrate this point.

Suppose that we want to compare output, input and productivity in motor car manufacturing in two countries, A and B. Assume for simplicity that in both countries 10 cars are being produced, using 10 units of labour. The countries only differ in the number of firms: two in country A and only one in country B. The first firm in country A produces car components (engines, bodies, wheels etc.) using 5 units of labour. The second firm does the final assembly and produces 10 final cars, using 5 labour units to put together the car components produced by the other firm. In country B the two activities (car part production and assembly) are integrated in just one firm. So, by construction, the sectoral output (10 cars) and inputs (10 labour units) are the same in both countries, as the intra-industry trade of components between the two firms in country A is netted out. Similarly, productivity levels are identical by definition. However, when one is to aggregate outputs and inputs in country A without integration, differences will appear. Suppose that the output of car components of firm 1 is 5 units.[4] Then total output in country A of firms 1 and 2 will be 15 (=10+5), and total intermediate inputs will be 5. This would suggest that car manufacturing in country A uses more intermediates than in country B. Similarly, standard

[3] To be more precise, sectoral output at the aggregate equals GDP at basic prices plus imports at purchasers' prices, see Aulin-Ahmavaara and Pakarinen (2005) for a discussion. The term "sectoral" was suggested by Gollop (1978). This name is somewhat unfortunate, as the concept "sector" is used by statisticians to indicate institutional sectors. Nevertheless, we stick to the use of sectoral output and input concepts to indicate the outputs and inputs of a fully integrated sector.

[4] For simplicity I abstract from incorporating prices in the example and assume unit prices for all goods.

total factor productivity (TFP) measures in A will be lower than in B as the input/output ratio of the aggregated sector is higher than the input/output ratio of the integrated sector.[5] In the extreme case of infinite fragmentation, TFP would tend to zero, intermediate input-output ratios to unity and labour- and capital-output ratios to zero. Hence comparisons of input and productivity across countries will be sensitive to differences in the degree of integration. This is clearly an undesirable characteristic.

In addition, there is a statistical reason for using sectoral measures. National statistical offices are known to differ in their recording of intra-firm deliveries. This will partly depend on the unit of activity which is being surveyed (establishments or enterprises) and the treatment of sub-contracting transactions. Therefore we prefer to use sectoral measures in international comparisons. In section 2.3 an empirical example will be given which shows that the use of sectoral output measures is also empirically relevant, besides being conceptually preferable.

Measures of sectoral output and input require industry by industry input-output tables (IOTs) with separate information on domestic and imported supplies of commodities. IOTs are not available for all countries in a common benchmark year and we used supply and use tables (see data description below) to construct comparable IOTs in the following way. Let *S* be the supply matrix of a particular country (product*industry) of dimension n*m+1 with n products and m industries and a separate column for imports, and *q* the vector of total supply by product (n*1). Further, define *U*, the intermediate part of the Use table (product*industry) of dimension n*m, and *II* the intermediate part of the input-output table (industry*industry) with an additional row for imports, so dimensions m+1*m. There are various ways to transform supply and use-tables into input-output tables depending on the assumptions made (see e.g. Chapter 11 in Eurostat 2002). We use the so-called fixed product-sales structure assumption where each product has its own specific sales structure, irrespective of the industry where it is produced. This assumption is much more plausible than its alternative (fixed industry-sales structure). Under this assumption, the intermediate part of the input-output table (II) is derived as follows:

$$II = S'(diag\, q)^{-1}U \qquad (1)$$

where *diag q* is the matrix with q on the diagonal. Using this matrix, intermediate input can be defined as follows. Let II_{ij} be elements of II, that is, intermediate inputs from industry i used by industry j, then total sectoral intermediate input used by j (II_j) is given by:

$$II_j = \sum_i II_{ij} - II_{jj} \qquad (2)$$

[5] This follows from the identity that nominal output is equal to the value of intermediate inputs and value added. With integration, output and intermediate input are reduced by the same amount, while value added remains the same. Hence, the ratio of intermediates over output will be lower. See section 4 for a formal definition of TFP.

In this study, intermediates are subdivided into three groups: use of energy (E), materials (M) and services (S). Furthermore, we distinguish four primary inputs, namely hours worked by workers with a university degree or above (H^U), hours worked by other workers (H^O), capital services from ICT assets (K^{ICT}) and non-ICT assets (K^N). Let *p* denote prices, and uppercase letters denote quantities, then nominal value of sectoral output of industry j ($p_j^Y Y_j$) is given by

$$p_j^Y Y_j = p_j^E E_j + p_j^M M_j + p_j^S S_j + p_j^{ICT} K_j^{ICT} + p_j^N K_j^N + p_j^U H_j^U + p_j^O H_j^O \qquad (3)$$

where output, energy input, material input and services input are all sectoral measures, excluding intra-industry deliveries. This basic identity is the basis of the level comparisons of output, input and productivity made in the remainder of this paper.

2.2 Nominal Supply and Use Tables

For making level comparisons we need nominal output and input values for each country and relative input and output prices to derive relative quantities as described above. The nominal SUTs are transformed into input-output tables to derive sectoral output and inputs by industry and the value added block is further disaggregated to distinguish various labour and capital types. The starting point of our analysis is the national Supply and Use table for each country, valued in national currency for 1997.[6] For Canada, the U.S. and Australia these tables are obtained from the national statistical offices. Eurostat makes these tables available for the European countries on a common industry classification and at a sufficient level of industry detail for the purpose of this study. For Canada, the U.S. and Australia the classification for these tables had to be adjusted to the European industry classification.[7] For all countries, except the U.S. and Canada, the Supply table has a column for imported commodities. In the latter two cases, the Use table has a column (with negative entries) instead which is used to supplement the Supply table and make them comparable to the other countries.

An important decision to make is whether or not to treat trade and transport margins as separate inputs or not. As we are also interested in the output and productivity performance of trade and transportation industries, productivity analysis ideally should be based on intermediate inputs valued at basic prices plus net taxes on products, rather than at purchasers' prices, which

[6] Only for Australia do we have to rely on a set of tables for 1998 (more precisely, the tables are for fiscal year 1998-1999, but following OECD convention, the data for that fiscal year are allocated to 1998). We use data on value added at current prices from the GGDC 60-industry database to adjust the 1998 table to 1997. This adjustment leaves all input proportions unaffected and only changes the overall sum of inputs and outputs by the difference between value added from the 1998 table and the 1997 data from the 60-industry database.

[7] For Canada we had access to the worksheet level tables, which cover 713 commodities and 284 industries, and for the U.S. we used the benchmark level of detail, which covers 508 commodities and industries. In both cases, the detail is fine-grained enough to make a fairly good concordance to the European classification. The Australian tables 'only' cover 106 commodities and industries, so in some cases data from industrial surveys had to be used to distinguish the necessary industries.

include trade and transportation margins.[8] Net taxes on products include taxes less subsidies determined on the basis of the quantity purchased such as non-deductible value added taxes, sales taxes, taxes and duties on imports and other taxes. Therefore we compiled a set of comparable input-output tables at basic prices plus net taxes.

The Australian and the U.S. Use tables are at the required price concept. But the original European and Canadian Use tables are at purchasers' prices and needed to be converted into basic prices plus net taxes. To do this, we estimated a margin matrix for the intermediate block in the Use table using total margins from the supply table and additional information from wholesale and retail trade survey material on margin rates by product. In addition, we assumed that all retail margins are generated in the delivery of goods to final demand.[9] We divide the wholesale margin between intermediate and final use by assuming that the wholesale margin rate is equal for each type of use, leaving us with an estimate of wholesale margins by commodity. For each industry, we assume an identical wholesale margin rate and attribute the resulting wholesale margins to the wholesale commodity use of each industry. After this conversion of the Use table, all SUTs are turned into an industry-by-industry input-output tables as described in section 2.1.

The value added block of the Use table only distinguishes two primary factors, namely capital and labour, so further disaggregation of these factor inputs is required.[10] The value of labour input should include all costs incurred by the producers in employment of labour such as taxes levied, health and other types of insurance and contributions to retirement paid by the employer, and the value of payments in kind and allowances (such as housing and rent). The value of capital input should include all taxes levied on the ownership and the utilisation of capital. The SUTs do not readily conform to these definitions and divide gross value added into gross operating surplus, net taxes on production and compensation of employees. We assume that compensation for employees only includes all direct and indirect costs in hiring employees. This means it is necessary to estimate the labour compensation of self-employed workers. We imputed an estimate of compensation of self-employed workers by assuming that the average self-employed worker has an average compensation of 70% of the level employees.[11] Capital compensation is defined as gross value added at basic prices minus labour compensation. To avoid negative capital compensation, a minimum total capital compensation share in value added is set at 5 percent.

The next step is splitting capital compensation of each industry into compensation of six capital assets. These are three ICT assets (computers, communication equipment and software)

[8] See e.g. Jorgenson, Gollop and Fraumeni (1987); Aulin-Ahmavaara (2003); Aulin-Ahmavaara and Pakarinen, (2005).

[9] This is confirmed by data for Australia, where margins are split by commodity, type of margin and type of use as only a small fraction of retail margins is attributed to intermediate use.

[10] Capital compensation includes operating surplus and taxes less subsidies on production. Hence the output valuation concept is basic prices. In the case of the U.S., the distinction between taxes on products and taxes on production can only be made at the aggregate level, so here the valuation concept is factor cost. At the aggregate level, net taxes on products and net taxes on production accounted for around three percent of GDP each.

[11] This figure is taken from total economy data of Jorgenson, Ho and Stiroh (2005) and is applied to all countries and industries.

and three non-ICT assets (non-residential structures, transport equipment and other non-ICT equipment).[12] The shares of each asset in total compensation are calculated based on capital rental prices using the ex-post approach (Jorgenson and Griliches 1967). In the absence of taxation the familiar cost-of-capital equation for asset type k is given by:

$$p_{k,t}^{K} = p_{k,t-1}^{I} r_t + \delta_k p_{k,t}^{I} - [p_{k,t}^{I} - p_{k,t-1}^{I}] \qquad (4)$$

This formula shows that the rental price is determined by the nominal rate of return (r) , the rate of economic depreciation (δ) and the asset specific capital gains ($p_{k,t}^{I} - p_{k,t-1}^{I}$) . The asset revaluation term can be derived from investment price indices. The rate of depreciation are the geometric rates which vary across asset, but assumed identical across countries. The nominal rate of return is the same for all assets in an industry, but ideally is allowed to vary across industries, and derived as a residual as follows:

$$r_{j,t} = \frac{p_{j,t}^{K} K_{j,t} + \sum_k [p_{k,j,t}^{I} - p_{k,j,t-1}^{I}] K_{k,j,t} - \sum_k p_{k,j,t}^{I} \delta_k K_{k,j,t}}{\sum_k p_{k,j,t-1}^{I} K_{k,j,t}} \qquad (5)$$

where the first term $p_{j,t}^{K} K_{j,t}$ is the capital compensation in industry j, which under constant returns to scale can be derived as value added minus the compensation of labour for each industry j. However, we found high variances in industry-level rates of return for some industries and instead opted to use the total economy rate of return. All data is described in Inklaar et al. (2005).[13]

Our data on labour input consists of two parts. Total hours worked by all persons is taken from the GGDC 60-industry database (GGDC 2006) and are consistent with employment data from the National Accounts. We split up total hours worked and total labour compensation using data on worker characteristics from national labour force surveys. Since matching the educational system at a finer level is a more complicated exercise, which goes beyond the scope of this study, the only distinction we make is between workers with a university degree (bachelor's degree and higher) and those without. The sources of our data on educational attainment of workers are described in more detail in Inklaar *et al.* (2005) for all countries except Australia and Canada. In the case of Canada, we relied on relative Canada-U.S. labour quality estimates from Lee and

[12] Note that residential buildings are not taken into account, as these are only used in the real estate sector which is excluded in this study due to its problematic output measure, as it partly includes imputed rents for owner-occupied dwellings, see e.g. Inklaar et al. (2005).
[13] Capital compensation by asset was normalised to industry level capital compensation to maintain consistency.

Tang (2002) for 1995. In the case of Australia, the data on educational attainment of workers by industry are from the ABS, *Survey of Education and Training 2001*. This source also contains information about relative wages. The relative wage of university-educated workers is only available at the level of the total economy, so the average industry variation from the other countries is used to estimate this data at the industry level.

2.3 Sectoral output and input measures

In Table 1, we provide input shares in output for one of our 26 industries: transport equipment manufacturing. The main purpose of this table is to illustrate the differences between sectoral measures of inputs, assuming full integration hence excluding intra-industry deliveries, and measures based on aggregation without integration, which do include intra-deliveries. In the last row, it can be seen that gross output is higher than sectoral output, as it should by definition. Importantly, this ratio varies highly across countries from a low 1.1 in the Netherlands, to over 1.3 in France and the U.S. This shows that the use of sectoral output measures is also empirically relevant, besides being conceptually attractive. This is further illustrated by comparing the input shares based on the two alternative approaches. For example, based on gross output, shares of materials and services input in the Netherlands and the U.S. look almost similar. However, when netting out intra-industry deliveries, it appears that Dutch transport equipment manufacturing uses much more material inputs than the Americans, and much less services. This is because the Dutch transport equipment sector is much more integrated than its U.S. counterpart.

The numbers in Table 1 are nominal shares in output, while one is ultimately interested in comparisons of input quantities and productivity. For this, we need relative prices to convert local currencies into a common denominator. This is discussed in the next section.

3. Relative output and input prices

Levels of outputs and inputs between countries can be compared by using relative prices to express these outputs and inputs in a common currency. It is well known that the use of exchange rates may be highly inaccurate, since relative prices and exchange rates may differ considerably. For a long time, international comparisons of output have been based on expenditure PPPs from the International Comparisons Project which provide relative prices for a range of final demand products (Kravis, Summers and Heston 1982). However, comparisons of productivity also require PPPs for (intermediate) inputs. Nishimizu and Jorgenson (1978) introduced the methodology to derive PPPs for labour and capital input, based on relative wages and investment prices. This system was extended by Jorgenson, Kuroda and Nishimizu (1987) to include PPPs for intermediate inputs. They were also the first to adjust expenditure PPPs, which are based on a purchasers' price concept, into basic prices, eliminating trade and transportation margins and net indirect taxes. This is required as industry output in the National Accounts is measured at basic prices, not purchasers' prices. However, it is well known that this procedure has several drawbacks. First, the adjustment factors for expenditure PPPs are often not available. Second, expenditure PPPs are not always a feasible option for all industries because no price data are available for products which are typically used as intermediates rather than for final consumption.

Recently, Timmer, Ypma and van Ark (2006) presented a new and comprehensive dataset of industry output PPPs, which addresses these weaknesses. Output PPPs are defined from the producer's point of view and are at basic prices. These PPPs have partly been constructed using unit value ratios for agricultural, mining, and manufacturing products and transport and communication services. For the other industries, PPPs are based on specified expenditure prices from Eurostat and the OECD, which were adjusted to industry level by using relative transport and distribution margins and adjusting for differences in relative tax rates. PPPs have been made transitive by applying the multilateral EKS-procedure for the set of 26 countries.[14] This set of gross output PPPs for 1997 covering 45 industries at (roughly) 2-digit industry level is the basic starting point for our current study. The gross output PPPs are allocated to the industries in the input-output tables.

Intermediate input PPPs should reflect the costs of acquiring intermediate deliveries and match the price concept used in the input-output tables, hence at basic prices plus net taxes. We assume that the basic price of a good is independent of its use.[15] That is, we use the same gross output PPP, of an industry to deflate all intermediate delivers from this industry to other industries. Unfortunately, (net) tax matrices are not available for most countries, so gross output PPPs could not be adjusted for differences in tax rates across countries. As net taxes on products are minor for most market industries, this will probably not greatly affect our level estimates, but further investigation is needed to substantiate this claim, especially for comparisons at a detailed level. The aggregate intermediate input PPP for a particular industry can be derived by weighting intermediate inputs at the output PPP from the delivering industries. Imports are separately identified and exchange rates are used as conversion factors.

To obtain relative PPPs for capital and labour input, we follow Nishimizu and Jorgenson (1978). Under the assumption that the relative efficiency of new capital goods is the same in both countries, the relative capital rental price is calculated as (the asset subscript k is dropped for convenience): **Formatted:** English (U.S.)

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$$\frac{p^K_{t,C}}{p^K_{t,US}} = \frac{p^I_{t,C}}{p^I_{t,US}} \frac{\left(\frac{p^I_{t-1,C}}{p^I_{t,C}}\tilde{r}_{t,C}+\delta\right)}{\left(\frac{p^I_{t-1,US}}{p^I_{t,US}}\tilde{r}_{t,US}+\delta\right)} \qquad (6)$$

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with $\tilde{r}$ the real rate of return. This can be simplified to

[14] One is referred to Timmer, Ypma and van Ark (2006) for further details about the construction and data sources underlying these PPPs.

[15] We assume net taxes on intermediates to be zero. Aulin-Ahmavaara and Pakarinen (2005) provide a discussion of sectoral measures which explicitly account for differences in net tax rates of intermediates.

$$PPP_t^K = PPP_t^I \frac{u_{t,C}^K}{u_{t,US}^K} \quad (7)$$

where u indicates the user cost of one currency unit's worth of capital stock, PPP^I is purchasing power parity for investment, and PPP^K the PPP for capital services. Capital PPPs represent the price of a unit of domestic currency's worth of capital input in terms of a common currency.Capital service input depends on the investment made in the past and hence the capital input PPP will differ from the new investment good PPP. The user cost of capital input depends on the rate of return to capital, the depreciation rate and the investment price change, as in equation (4). Investment PPPs are available for 35 capital assets from OECD (2002) for 1999. The PPPs for the 35 assets are aggregated to the six assets in this study using an EKS aggregation procedure. Investment deflators by asset and industry are used to move these PPP to the benchmark year, which is 1997. The required rate of return is set equal to the aggregate internal rate of return.

The PPP for labour represents the price of one unit of domestic currency's worth of labour input in terms of a common currency. The procedure for labour is more straightforward than for capital as it simply involves aggregating relative wages across different labour types using labour compensation for each type as weights. As explained above, the only distinction we make is between workers with a university degree or higher, and those without.

Table 2 gives an overview of the input and output PPPs for one industry, transport equipment manufacturing, for 1997 to give a flavour of the type of results from this exercise. We show relative price levels, which are defined as the PPP over the exchange rate, with the U.S. as the base country. When comparing Germany with the U.S., one can see that transport equipment manufacturing output prices are relatively high, compared to the exchange rate. All inputs, especially labour and energy inputs are much more expensive in Germany than in the U.S. In Canada, an opposite pattern is found with both output and inputs cheaper than in the U.S. High energy prices are found for all countries compared to the U.S., except for Canada. The price of labour services is much higher in Europe than elsewhere, as might be expected and capital inputs are particularly expensive in France and the UK, both for ICT- and non-ICT capital.

4. Methodology for output, input and productivity comparisons

In this section we present our methodology for comparing levels of output, input and productivity for our set of countries. Our index number approach is the multilateral one advocated by Caves, Christensen and Diewert (CCD, 1982) based on a translog production function. Importantly, in the CCD methodology, the indices of relative input and output are transitive. This means that the indices are base-country invariant.[16] This methodology has first been used by Christensen, Cummings and Jorgenson (1981) in comparing productivity at the level of the total economy for a set of 9 countries, and was first used at the industry level by Conrad and Jorgenson (1985) in a comparison of Germany, Japan and the U.S.[17] It is based on a constant returns to scale translog production function for each industry which differs across countries. In addition we assume the necessary conditions for producer equilibrium. The translog functional form places relatively few restrictions on the production technology and is given by (industry index is omitted for clearity):

$$\ln Y = \alpha_0 + \sum_c \alpha_c D_c + \sum_j \alpha_j \ln X_j + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln X_i \ln X_j + \sum_j \beta_{jc} \ln X_j D_c + \frac{1}{2}\sum_c \beta_{cc} D_c^{\,2} \quad (8)$$

where Y is the output quantity, X_j is a quantity index of input j, and the α's and β's are parameters. A dummy variable D is included for each country c, which captures differences in technology across countries. Since D_c is interacted with inputs X, differences in technology are permitted to be non-neutral. We will omit the dummy variable for the U.S. from the production function as we find it convenient to express levels relative to the U.S.

In addition we specify aggregate output and inputs as constant returns to scale translog functions of its components. Using the CCD approach translog multilateral indices of output relative to the U.S. can be derived as follows:

$$\ln Y_c - \ln Y_{US} = \sum_i \hat{v}_{i,c}\left[\ln Y_{i,c} - \ln \overline{Y}_i\right] - \sum_i \hat{v}_{i,US}\left[\ln Y_{i,US} - \ln \overline{Y}_i\right] \quad (9)$$

with $\hat{v}_{i,c} = \frac{1}{2}\left[v_{i,c} + \frac{1}{n}\sum_C v_{i,c}\right]$, $v_{i,c} = \frac{p^Y_{i,c} Y_{i,c}}{\sum_I p^Y_{i,c} Y_{i,c}}$ and $\ln \overline{Y}_i = \frac{1}{n}\sum_C \ln Y_{i,c}$

$v_{i,c}$ is the share of product i in total output of industry j, with i the components of Y and n the number of countries. Effectively, one creates an artificial country by averaging over all countries in the data set, and use this constructed country as a star in binary comparisons with each other country.[18]

[16] All binary pairs of comparisons pass the following test: $I_{ik}=I_{ij}\ I_{jk}$ where I_{ij} is an index comparing countries i and j.

[17] However, the Japan-US study by Jorgenson, Kuroda and Nishimizu (1987) is better known and normally seen as the seminal study of this type. See Lee and Tang (2002) for a recent application.

[18] In practice, this involves applying an EKS procedure to a matrix of all possible binary Törnqvist indices.

Similarly, we can express differences in input levels for any country relative to the US. Analogously to output, translog multilateral indices of inputs, used in country c relative to the U.S. can be derived as follows:

$$\ln X_c - \ln X_{US} = \sum_i \hat{v}_{i,c}\left[\ln X_{i,c} - \ln \overline{X}_i\right] - \sum_i \hat{v}_{i,US}\left[\ln X_{i,US} - \ln \overline{X}_i\right] \quad (11)$$

Now we can define the translog multilateral productivity indices relative to the U.S. (A_c) as follows :

$$\ln \frac{A_c}{A_{US}} = \ln \frac{Y_c}{Y_{US}} - \ln \frac{X_c}{X_{US}} \quad (12)$$

As indicated above, we will divide our inputs into a number of groups: two types of labour, two types of capital, and intermediate inputs, which is further subdivided into energy (*E*), materials (*M*) and services (*S*). Aggregation across the different inputs in each group follows along the lines of equation (11). Relative input per unit of output is defined as the ratio of the relative input level over the relative output level in a country compared to the U.S. So, for example, the relative energy intensity (E_{INT}) of industry *j* is given by:

$$\ln E_{INT} = \ln \frac{E_c}{Y_c} - \ln \frac{E_{US}}{Y_{US}} \quad (13)$$

In practice, several index-number problems have to be dealt which will be briefly discussed here. First and most importantly, the indices in equations (9)-(11) are discrete approximations to the underlying (continuous) translog production functions. In a time-series context, this approximation generally does not pose any practical problems, since the shares in adjacent years are usually very similar. However, this is not guaranteed in a cross-country context and as a result, the approximation may be quite poor. These problems are less for the price comparisons.[19] Hence, we calculate relative quantities implicitly by the ratio of the nominal values and the relevant price indices.

Second, CCD-aggregation is not consistent in aggregation: the value of the index calculated in two stages does not necessarily coincide with the value of the index calculated in a single stage. For example, one can derive the total intermediate input PPP by aggregating directly from the most detailed level available, or in two steps: first to the groups of E, M and S and in a second

[19] This is because the relative prices generally vary less than the relative quantities, so price aggregation is more reliable; see Allen and Diewert (1981). See also the appendix of Inklaar *et al.* (2006) for further discussion.

stage to total. Fortunately, the differences are quantitatively minor as superlative index numbers are approximately consistent in aggregation (Diewert 1978).

5. Comparative levels of output, input and productivity

By applying the input and output PPPs to the nominal input-output tables, we derive relative input levels, expressed per unit of output, as given in equation (13). These levels are used to calculate relative TFP levels, using equation (12). In Table 3, the relative input per unit of output levels in transport equipment manufacturing are given for each country, compared to the U.S. One can see that the adjustment for differences in prices across countries has important implications. For example, the nominal share of labour in output in Germany is higher than in the U.S. as shown in Table 1. However, when correcting for the higher price of labour in Germany (see Table 2), the labour input quantity per unit of output is almost equal in both countries for both types of labour. Similarly, the share of energy in nominal output is similar in the Netherlands and the U.S., but after correcting for relative price differences, Dutch production of transport equipment is less energy-intensive. This indicates that price adjustments are important and necessary for meaningful evaluations of production structures across countries.

Our analysis is done at the lowest level for which comparable data on inputs and outputs can be constructed. Capital inputs is the limiting factor as data on investment cross-classified by both asset type and industry (so-called capital formation matrices) is scarce. It was possible to make consistent and comparable accounts for 26 industries, based on the ISIC revision 3 industrial classification. These industries together cover the total economy. For expositional reasons we limit our discussion of the results to two major sectors: goods-production, which includes agriculture, mining and manufacturing industries, and market services, which includes all service industries except real estate, education, health and government.[20] We choose these two sectors as they will be different in their production structures, and previous research on productivity growth has shown that Europe lags behind the U.S. especially in market services. [21] The results for individual industries are used to validate the empirical patterns found for these two broad groups. In the Appendix table, a complete list of the 26 industries is given.

The upper panel of Table 4 shows the results for goods-producing industry and the lower panel for market services. One has to bear in mind that the levels shown in the table are levels for the integrated sectors, in which intra-industry flows have been netted out. So for example material inputs in goods production will come exclusively from imports, as domestic deliveries have been

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[20] Real estate is removed because output of this industry mostly consists of residential rents, while the other three industries are removed because measuring output for those services industries is particularly challenging. Much of the output in this sector is measured by input indicators, and hence productivity growth is zero by construction which is not very meaningful.
[21] Note that we do not include utilities in either of the groups to highlight the role of energy inputs in the economy.

excluded. This explains the high levels of material input use in most countries compared to the U.S., as imports are generally much higher.

On the basis of Table 4 a number of general observations can be made. First, with respect to total factor productivity (TFP) levels, it is clear that production processes in Europe are at least as efficient as in the U.S. This is especially true for goods production as all four European countries show TFP levels which are at least 5 per cent higher than in the U.S. In market services comparable levels are closer. Only productivity levels in Australia seriously lag behind the U.S., both in goods production and in market services. This finding for the two broad groups is pretty robust when looking at the detailed industry results. In Figure 1, we provide TFP levels in both sectors, based on unweighted averages of the industries belonging to each group. For goods production it is the average of 13 industries and for market services 8 industries are included.[22] Error bars in the graph indicate plus and minus one standard deviation within each group based on the detailed industry scores. Unweighted averages are different from the group TFP levels but are generally close. The spread around the group means indicate that only Australia seems to clearly lag the U.S. in productivity levels. Europe is, if anything, ahead, especially in goods production. Even at this relatively broad level of aggregation, caution is in order as there are many measurement and statistical uncertainties surrounding these estimates. The error bars are included mainly to give an idea of the within-group variability, not as a statistical decision criterion.[23]

Second, there are clear patterns in the use of primary inputs, labour and capital, for both groups. A clear distinction can be made between the Anglo-Saxon countries where production is relatively labour intensive, and continental Europe where labour input is lower, especially the use of labour with university degrees in market services, see Table 4. Most salient, however, are the high levels of ICT capital in the U.S. Per unit of output, ICT use in the U.S. is typically twice the level in any other country, both in goods production and in market services. This confirms earlier findings by Timmer and van Ark (2005) which stressed the transatlantic gap in ICT investment. In contrast, relative input levels of non-ICT capital are not radically different across countries. If anything, non-ICT use in market services seems to be higher outside the U.S. This might indicate that a substitution process is taking place of new ICT capital for older non-ICT capital assets, and that this process has progressed much faster in the U.S. than elsewhere. These patterns of capital input use are also evident from the detailed industry comparisons, as shown in Figure 2. The high ICT levels in the U.S. compared to the other countries are found in all industries, suggesting that there are economy-wide forces which stimulate ICT investment in this country. Another point to

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[22] The average for goods production excludes mining and petroleum manufacturing which, due to their small size and volatile price behaviour, often have outlying levels of productivity which would distort the unweighted averages.

[23] Some of the uncertainties include index number problems, sampling error, the relative prices and various types of non-sampling errors in the measurement of current output and employment by statistical offices as well as relative prices. See also Schreyer (2006) for a discussion of the uncertainty surrounding productivity level estimates.

note is that the spread around the group means is relatively large for capital inputs. This might be partly due to the quality of data on investment by industry and asset, as well as the investment PPPs. For example, the recording of assets by industry of ownership, or by industry of use, still differs across countries. And the measurement of ICT assets, especially of own-account software, is still far from internationally harmonised. As a result, differences in leasing propensity or own-account software production across countries might muddle the picture. These are clearly areas for data improvement. But even with these caveats, it seems save to say that the use of ICT inputs in the U.S. has progressed much further than in Europe.

Third, the use of various intermediate inputs (energy, materials and services) varies greatly across countries. European countries use much less energy in production, often less than half the energy use of the U.S. Especially Canadian production seems to be very energy-intensive. A similar pattern is found at the detailed industry level, see Figure 3.[24] When looking at material inputs, the picture is reversed: U.S., and to a lesser extent Canadian, production processes consume relatively fewer material products. In market services, European countries typically use 40 per cent or more materials than the U.S. However, the spread around the means is high as indicated in Figure 3. Consumption of services inputs is clearly the highest in the U.S. and in Australia. In goods production, U.S. levels of services inputs are almost double the levels in Europe and these findings are robust at the detailed industry level. One potential explanation for these differences is that the 'services content' of purchased materials is higher outside the U.S. This would mean that manufacturing firms that provide materials also provide some of the services, such as perhaps transportation, while in the U.S., separate firms supply those services. If the 'services content' argument holds, it would explain both higher materials and lower services input levels in Europe compared to the U.S. While much of this derives from anecdotal evidence, Pilat and Wölfl (2005) have investigated this issue in more detail, but find comparatively little evidence that can help resolve this issue. Furthermore, if supply tables are constructed properly and based on complete data, then services provision by manufacturing firms would be recorded as secondary production. Alternatively, instead of the purchased inputs being different, the degree and nature of outsourcing could also be different. This would mean that non-U.S. firms have more aggressively outsourced their materials provision but have kept many services in-house. Obviously, more research is needed to explain these international differences in material and services consumption in production.

6. Concluding remarks

In this paper, we outlined a new methodology to make multilateral comparisons of industry output, inputs and productivity. Based on the CCD index number approach (Caves, Christensen and Diewert, 1982), new estimates of relative output, inputs and productivity levels are made for

[24] Energy use as measured here only includes the direct use of energy. Indirect energy use, through the consumption of other intermediates, is not taken into account.

a set of 7 countries. These estimates have two important characteristics. First, they are based on sectoral measures of output and input, in which intra-industry trade is netted out. We have shown that sectoral measures are not only superior in theory, but also empirically relevant. Second, the level comparisons are made with a new set of relative output and input PPPs based on producer prices, rather than the more common expenditure prices.

The results indicate that productivity levels do not differ much between the European and Anglo-Saxon countries, but we do find large differences in the structures of production. U.S. industries use more skilled labour and more ICT capital than others. In addition, they use more services input and more energy, but less materials, per unit of output. This pattern is found for both the goods-producing and services-producing sectors and seems robust for detailed industries as well. These findings suggest new hypotheses about differences in production structures in various economies related to energy use, ICT capital diffusion, use of materials and services and outsourcing. They can be tested when a larger set of countries and benchmark years becomes available. This set is currently under preparation in the EU KLEMS project for a much larger set of European countries[25].

In addition, the paper raises a series of methodological and data issues. These include improvements in the treatment and measurement of net taxes and of capital-asset matrices. In addition, multilateral comparisons of countries with differing production structures emphasized a weakness of the CCD-methodology which is based on discrete approximations to the underlying (continuous) translog production functions. In a time series context, this approximation generally does not pose any practical problems, since the shares in adjacent years are usually very similar. However, in a cross-country context the approximation may be quite poor and alternative measures, such as based on minimum-spanning trees need to be considered.

[25] See www.euklems.net for more details.

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Table 1 Comparison of input shares in output, with and without integration, transport equipment manufacturing, 1997

	France	Germany	Nether-lands	U.K.	U.S.	Australia	Canada
as % of sectoral output							
Sectoral Energy input	0.9%	1.1%	0.8%	1.3%	0.8%	1.2%	0.7%
Sectoral Material input	48.4%	44.7%	52.6%	47.7%	40.7%	41.6%	42.2%
Sectoral Services input	20.0%	15.1%	21.1%	15.2%	24.8%	21.0%	18.7%
ICT capital input	0.4%	0.8%	0.5%	0.6%	1.8%	1.7%	0.9%
Non-ICT capital input	10.3%	6.7%	7.2%	7.4%	6.7%	14.6%	15.1%
Labour input	20.1%	31.7%	17.9%	27.8%	25.1%	19.9%	22.4%
Sectoral output	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
as % of gross output							
Energy input	0.7%	0.9%	0.7%	1.2%	0.6%	1.0%	0.6%
Material input	63.6%	57.8%	60.1%	58.9%	55.2%	50.7%	56.7%
Services input	12.6%	9.9%	16.1%	9.1%	18.8%	17.7%	12.4%
ICT capital input	0.3%	0.6%	0.4%	0.5%	1.4%	1.4%	0.7%
Non-ICT capital input	7.7%	5.4%	6.5%	6.4%	5.1%	12.3%	11.9%
Labour input	15.1%	25.4%	16.2%	24.0%	19.0%	16.8%	17.7%
Gross output	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Gross output as % of sectoral output	133.8%	125.3%	110.5%	116.7%	132.4%	118.4%	126.2%

Sources: National Supply and Use tables, see main text.

Table 2 Relative price levels of sectoral output and inputs, transport equipment manufacturing (PPPs / exchange rate, US$=1), 1997

	France	Germany	Nether-lands	U.K.	U.S.	Australia	Canada
Sectoral output	1.52	1.49	1.64	1.64	1.00	1.46	0.86
Energy input	1.67	1.86	2.05	2.64	1.00	1.40	0.56
Material input	1.09	1.09	1.07	1.11	1.00	1.15	0.92
Services input	1.33	1.17	1.04	1.15	1.00	1.10	0.92
ICT capital input	1.35	1.06	1.16	1.39	1.00	1.11	0.89
Non-ICT capital input	1.40	1.05	1.24	1.56	1.00	0.87	0.84
Labour input	1.56	2.03	1.01	1.25	1.00	0.70	0.92

Source: Output and intermediate input PPPs based on Timmer, Ypma and van Ark (2006). Labour and capital PPP, see main text.

Table 3 Relative input per unit of output, transport equipment manufacturing, 1997, U.S.=1

	France	Germany	Nether-lands	U.K.	U.S.	Australia	Canada
Transport equipment							
Energy input	1.09	1.11	0.79	1.09	1.00	1.67	1.46
Material input	1.65	1.50	1.97	1.74	1.00	1.29	0.96
Services input	0.92	0.78	1.33	0.88	1.00	1.11	0.70
ICT capital input	0.23	0.62	0.38	0.38	1.00	1.16	0.44
Non-ICT capital input	1.66	1.42	1.40	1.15	1.00	3.62	2.28
Labour input below degree	0.84	1.03	1.21	1.55	1.00	1.76	0.83
Labour input university degree	0.78	0.93	1.15	1.45	1.00	1.65	0.83
Total factor productivity	0.83	0.88	0.66	0.73	1.00	0.68	1.06

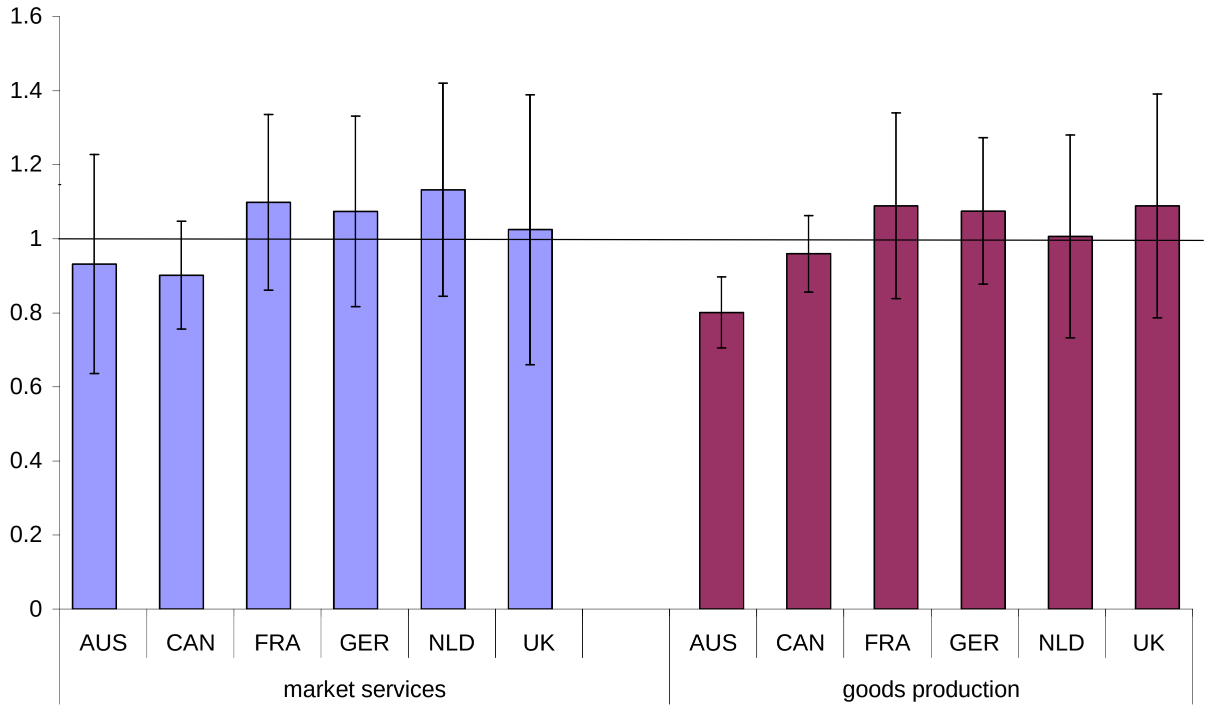
Source: based on Tables 1 and 2.

Table 4 Relative input per unit of output, 1997, U.S.=1, goods producing industries and market services

	France	Germany	Nether-lands	U.K.	U.S.	Australia	Canada
Goods-producing industries							
Energy input	0.83	0.62	0.52	0.48	1.00	1.14	1.86
Material input	2.39	2.20	3.32	2.21	1.00	1.62	1.79
Services input	0.72	0.71	0.71	0.68	1.00	0.95	0.72
ICT capital input	0.15	0.41	0.44	0.43	1.00	0.67	0.32
Non-ICT capital input	0.97	0.72	0.99	0.74	1.00	1.64	1.34
Labour input below degree	0.97	1.00	0.73	1.19	1.00	1.39	0.99
Labour input university degree	0.88	0.89	0.70	1.11	1.00	1.30	0.98
Total factor productivity	1.05	1.13	1.03	1.08	1.00	0.80	0.97
Market services							
Energy input	0.67	0.42	0.47	0.29	1.00	1.03	1.61
Material input	1.48	1.31	1.34	1.51	1.00	1.49	1.07
Services input	0.99	1.27	1.57	1.41	1.00	0.98	1.08
ICT capital input	0.34	0.58	0.50	0.40	1.00	0.44	0.51
Non-ICT capital input	1.37	1.68	1.03	1.10	1.00	1.34	1.12
Labour input below degree	1.00	0.87	0.84	1.28	1.00	1.24	1.33
Labour input university degree	0.91	0.77	0.83	1.20	1.00	1.16	1.30
Total factor productivity	0.98	0.98	1.06	0.89	1.00	0.86	0.88

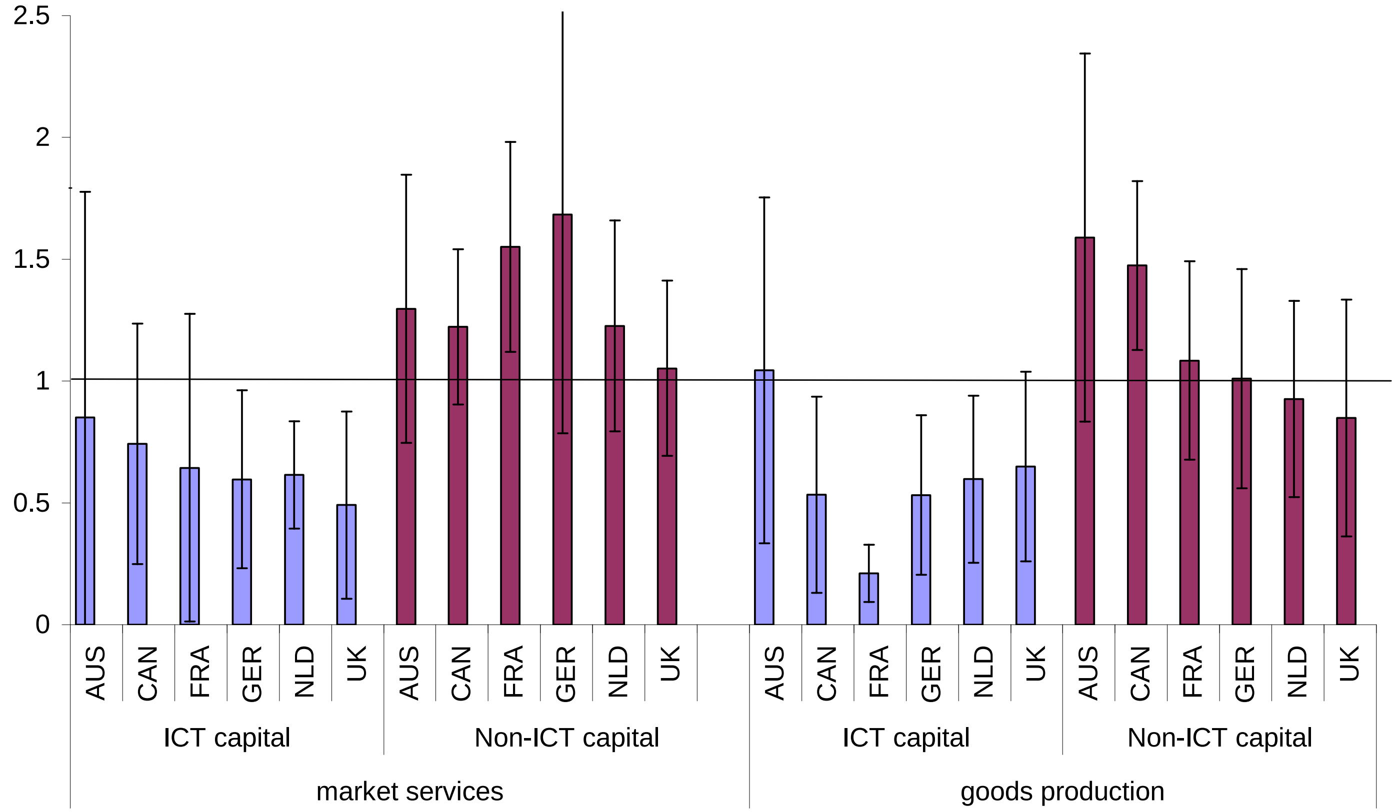
Sources: National Supply and Use tables converted with relative input and output prices, see main text.

Figure 1, Relative TFP levels by industry group in the Netherlands, France, Germany, UK, Canada and Australia in 1997, U.S.=1



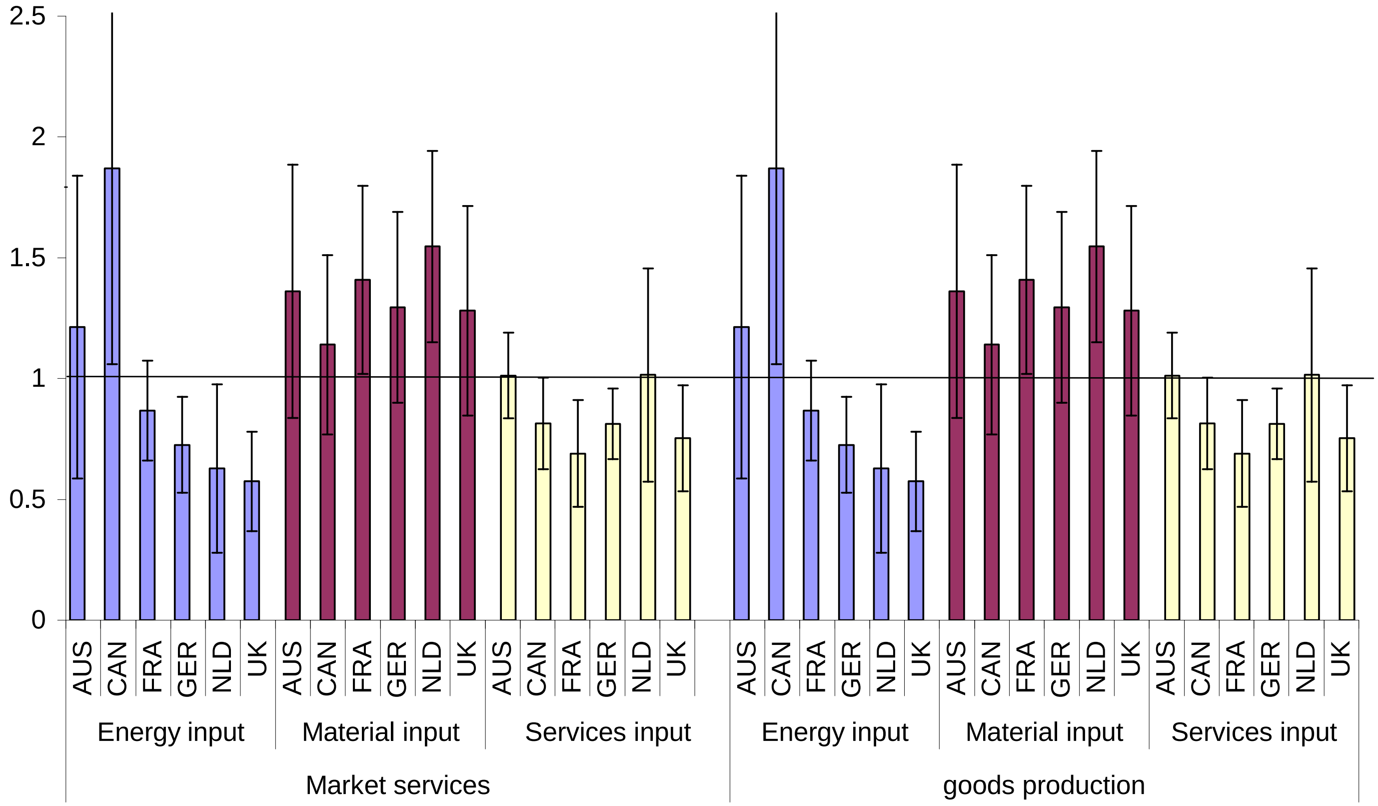
Note: The solid bars denote unweighted averages of levels in industries within goods production (13 industries, excluding mining, petroleum manufacturing and construction) and market services (8 industries). The errors bars indicate one plus/minus one standard deviation within the group. See appendix for list of industries. See main text for sources.

Figure 2, Relative capital input levels in 1997 in the Netherlands, France, Germany, UK, Canada and Australia, U.S.=1



Note: see Figure 1.

Figure 3, Intermediate input levels for industry groups in 1997 in the Netherlands, France, Germany, UK, Canada and Australia, U.S.=1



Note: see Figure 1.

Appendix Table Industry classifications

Industry	ISIC rev.3
Agriculture, forestry and fishing	01-05
Mining and quarrying	10-14
Food products	15-16
Textiles, clothing and leather	17-19
Wood products	20
Paper, printing and publishing	21-22
Petroleum and coal products	23
Chemical products	24
Rubber and plastics	25
Non-metalic mineral products	26
Metal products	27-28
Machinery	29
Electrical and optical equipment	30-33
Transport equipment	34-35
Furniture and miscellaneous manufacturing	36-37
Electricity, gas and water	40-41
Construction	45
Wholesale trade	50-51
Retail trade	52
Hotels and restaurants	55
Transport & storage	60-63
Communications	64
Financial intermediation	65-67
Business services	71-74
Social and personal services	90-99
Non-market services	75-85