Productivity Convergence Across Industries and Countries

Inklaar, R.; Timmer, M.P.

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Inklaar, R., & Timmer, M. P. (2009). Productivity Convergence Across Industries and Countries: The Importance of Theory-based Measurement. (GGDC Working Papers; Vol. GD-109). Groningen: GGDC.
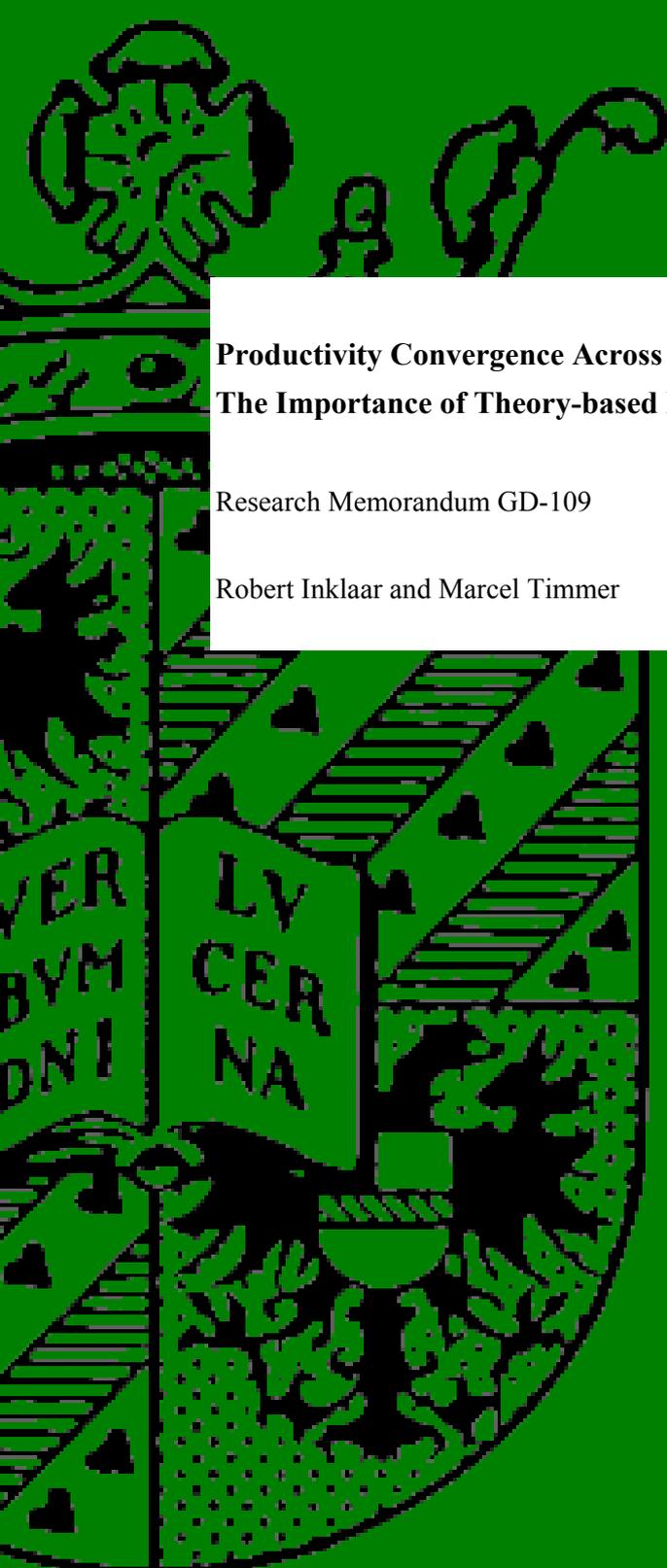
Productivity Convergence Across Industries and Countries: The Importance of Theory-based Measurement

Robert Inklaar and Marcel Timmer

Productivity Convergence Across Industries and Countries:

The Importance of Theory-based Measurement[*]

Robert Inklaar and Marcel P. Timmer

University of Groningen

March 2009

Abstract

Cross-country studies of economic growth have been hampered by the scarcity of reliable data on productivity at the sector level, see Bernard and Jones (AER, 2001) and Rogerson (JPE, 2008). We bring together literature on industry prices, human capital and capital assets to construct industry-level productivity measures that are well-grounded in neo-classical production theory. These theory-based measures differ widely from the crude measures commonly used in the literature. We use these to confirm and strengthen the finding of Bernard and Jones (AER, 1996) that for advanced OECD countries, patterns of convergence across sectors have differed since 1970: while productivity in market services converged, there is no convergence in manufacturing. More detailed analysis confirms that patterns of convergence are highly industry-specific. There is no dominant convergence trend in sectoral productivity growth across advanced countries.

Keywords:

Convergence; Economic Growth; Productivity measurement; Sectoral trends

1. Introduction

Comparative productivity levels are an important ingredient in cross-country studies of economic growth. Initially, this research was mainly focused on explaining patterns of convergence and divergence at the aggregate level.[1] More recently, studies on the differences in performance at the sectoral level (agriculture, manufacturing and services) have appeared, motivated by the influential study by Bernard and Jones (1996), henceforth BJ. They found that across a set of selected OECD countries, convergence at the aggregate does not necessarily imply convergence at the industry level. In particular they found that during the period 1970-1987 manufacturing showed little evidence of productivity convergence, in contrast to the services sector in which convergence was strong.

These findings have not been undisputed. Sørenson (2001) showed that the finding of non-convergence in manufacturing heavily depended on the choice of a set of purchasing-power parities (PPPs) to convert national currencies into comparable units. BJ used one set of aggregate GDP PPPs to convert all sectoral variables. However, as sectoral prices do not move in tandem over time, the sectoral findings of BJ became highly sensitive to the choice of the base year for the aggregate PPPs. Typically manufacturing prices grow much slower than prices of services and a common PPP would not capture this difference. In their reply, BJ conclude that: ".. future research is needed to construct conversion factors appropriate to each sector and that research relying on international comparisons of sectoral productivity and income should proceed with caution until these conversion factors are available" (Bernard and Jones, 2001, p. 1169).

Since then research relying on sectoral productivity comparisons has boomed. Productivity levels figure prominently in cross-country studies of technology spillovers, multi-sector growth and dynamic models of trade.[2] However, the warning by Sørenson still lingers as evidenced by the following remark in Rogerson (2008) that: "…systematic sectoral accounts that permit cross-country comparisons of sectoral productivity have not yet been developed. Whereas aggregate productivity comparisons such as those provided by the Penn World Tables can be carried out using only prices for final goods and investment, one would also need international prices for all intermediate inputs to compute relative sectoral value-added productivities. Without accounts that explicitly address this issue, the numbers that one obtains from various exercises are not reliable." (p.251).[3]

In this study we develop a new database of comparative productivity levels that directly confronts this criticism, called the *GGDC Productivity Level database*. It is based on a new set of PPPs for both output and intermediate inputs at a detailed industry level. In addition, novel measures of labour and capital inputs are used, that take account of differences in the composition of each input, such as different levels of skills, or types of capital goods such as ICT and other assets. The basic

methodology, grounded in neo-classical production theory, has a long history but has never been comprehensively applied in a large cross-country setting, mainly due to a lack of suitable data.[4] As an alternative many studies relied upon crude measures of input, output and productivity. We show that the theory-based measures from the new database differ widely from the crude measures commonly used in the literature, justifying the warnings mentioned above.

The new database offers plenty of opportunities for new analysis and we illustrate this with a sigma-convergence analysis in the tradition of Bernard and Jones (1996). We find that their main message was basically right: patterns of convergence in a set of advanced OECD countries differ considerably across sectors. Since the 1970s, we find a process of steady convergence in market services. In contrast, there is little evidence for convergence in manufacturing or other goods-producing industries, and even some suggestion of divergence since the mid-1990s. Moreover, when we analyze convergence at a more detailed industry level using a dataset of 24 industries, we find that patterns of convergence and divergence since 1980 are very different and far from homogenous even within industry groups such as market services.

This study work is related to various strands of literature that have highlighted and addressed the problems of crude productivity measurement, albeit only in a piecemeal fashion. It is akin to work by Biesebroeck (2007) and Sørenson and Schjerning (2009) who redo the convergence analysis of Bernard and Jones (1996) by applying sectoral PPPs. However, they do not account for intermediate input prices, and ignore differences in the composition of capital and labour inputs. On the other hand, De la Fuente and Doménech (2006) and Cohen and Soto (2007) provide growth and convergence studies based on detailed measures of labour input, but only for the aggregate economy level. Caselli and Wilson (2004), Jorgenson and Vu (2005) and Timmer and van Ark (2005) provide country-wide comparisons of productivity allowing for different types of capital, in particular ICT-capital, while Hsieh and Klenow (2007) highlight the importance of differences in relative prices of various asset types. All these studies emphasise the empirical importance of using detailed measures of prices and quantities of output and inputs. This study though is the first to bring together these various strands of literature in a unified framework to measure productivity levels. Based on this, we provide the first comprehensive set of comparative productivity levels at the industry level for a large set of OECD countries.

The rest of the paper is organised as follows. In Section 2 we outline the methodology for comparing levels of output, input and productivity across countries. In Section 3 we describe the data sources we use to implement this methodology. Section 4 compares for our benchmark year, 1997, different productivity level estimates and traces these differences to refinements in measurement of inputs and

output. Section 5 then re-examines the evidence for sectoral convergence patterns along the lines of Bernard and Jones (1996) and Section 6 concludes.

2. Methodology

In this section we present our methodology for comparing levels of output, input and productivity across countries, so-called level accounting.[5] This approach has a long history dating back to the seminal article by Griliches and Jorgenson (1967) and extended in a range of studies by Jorgenson and various collaborators (see Jorgenson 1995a,b). It was further grounded in economic theory by Diewert (1976), Caves, Christensen and Diewert (1982a) and Diewert and Morrison (1986). As we are trying to construct a consistent set of productivity measures for a large number of countries and industries at the same time, various choices have to be made not only concerning the use of particular index number formulae, but also their actual implementation. In this section the basic methodology is laid out which basically consists of two steps. In the first step, PPPs for output, capital, labour and intermediate inputs for 29 industries are derived based on data for 45 sub-industries. This is done with the price-variant of the multilateral index number approach advocated by Caves *et al.* (1982b), also known as CCD-method. These PPPs are used to implicitly derive quantities of all inputs (capital, labour and intermediate inputs) and output. In the second step, productivity comparisons are made for each industry on the basis of input and output quantities in a bilateral Törnqvist model following Diewert (1976) and Jorgenson and Nishimizu (1978). This approach is also known as primal level accounting.[6] In this section we first outline our basic methodology for measuring productivity, followed by our approach to deriving PPPs for outputs and inputs. Our general notation is as follows. Variable *V* indicates values in current national prices, *PPP* indicates a relative price index across two countries and *Q* indicates a quantity index. Superscripts indicate the type of output or inputs, and subscripts indicate industry j, country c and time t.

In this paper, we only outline the methodology for measures of MFP based on value added, taking into account both labour and capital services as inputs.[7] We assume that production in industry *j* in a country *c* takes place according to the following production function *F:*

$$Q_{c,j,t}^{VA} = F\left(Q_{c,j,t}^{K}, Q_{c,j,t}^{L}, T\right) \tag{1}$$

with Q^{VA}, Q^{K} and Q^{L} quantity indices of value added, capital services and labour services respectively and T indicating time. Following Jorgenson and Nishimizu (1978), we define a translog index of difference in multi factor productivity. Under the necessary conditions for producer equilibrium in each country, this index is defined for a country *c* in industry *j* as follows:[8]

$$\ln MFP_{c,j} = \ln \frac{Q_{c,j}^{VA}}{Q_{US,j}^{VA}} - \overline{w}_j^K \ln \frac{Q_{c,j}^K}{Q_{US,j}^K} - \overline{w}_j^L \ln \frac{Q_{c,j}^L}{Q_{US,j}^L} \qquad (2)$$

The weights are defined as the share of each factor input in value added averaged over the two countries. $\overline{w}_j^K$ is the share of capital services in value added averaged over the two countries: $\overline{w}_j^K = w_{c,j}^K + w_{US,j}^K$ with $w_{c,j}^K = V_{c,j}^K / V_{c,j}^{VA}$ and V_c^K the nominal value of capital compensation in country c, and similarly for labour. We assume constant returns to scale such that $\overline{w}_j^K + \overline{w}_j^L = 1$.

Our models of production are bilateral and involve comparisons of a country *c* with the US as base. We chose US as the base country as these comparisons generally generate the highest interest, the U.S. being the overall productivity leader. Alternative bilateral comparisons with other countries as the base can be made using the same approach by simply replacing the US by another base country in the formula's given above.[9] The formulas indicate that comparable volume measures of output and inputs for the countries are needed. When a single output or input is being compared, physical measures, such as numbers of cars of hours worked, are possible. However, comparisons at the industry or aggregate level require quantity indices to be calculated implicitly by the ratio of the nominal values and the relevant price indices. This is usual done with a purchasing power parity (PPP) that indicates the relative price of output or input in one country relative to another country. A volume index of labour services is given by:

$$Q_{c,j}^L = \frac{V_{c,j}^L}{PPP_{c,j}^L} \qquad (3)$$

with $V_{c,j}^L$ the nominal value of labour compensation in country *c* (at current national prices) and $PPP_{c,j}^L$ the price of labour services in country *c* relative to the U.S. And similarly for aggregate capital input in country *c*:

$$Q_{c,j}^K = \frac{V_{c,j}^K}{PPP_{c,j}^K} \qquad (4)$$

with $V_{c,j}^K$ the nominal value of capital compensation in country *c* and $PPP_{c,j}^K$ the relative price of capital services in country *c*.[10] Finally, value added volume in country *c* is given by

$$Q_{c,j}^{VA} = \frac{V_{c,j}^{VA}}{PPP_{c,j}^{VA}} \qquad (5)$$

The PPPs for outputs and inputs required in (3)-(5) are derived on the basis of detailed sets of output and input prices.[11] Prices are aggregated using the multilateral translog price indices introduced by Caves, Christensen and Diewert (1982b) (CCD-index). Basically, in this methodology one creates an artificial country by averaging over all countries in the data set, and uses this constructed country as a bridge when making binary comparisons between two countries. This creates so-called transitive PPPs that are base-country independent. As with our MFP indices, the PPPs are normalised with U.S. as 1.

Labour and capital volume indices grounded in production theory should take into account the composition of each factor input, such as different levels of skills or types of capital goods (in particular ICT versus non-ICT assets). For labour, this can be achieved by deflation with an appropriate PPP based on relative wages of each labour type l as follows:

$$\ln PPP_{c,j}^{L} = \sum_{l} \bar{v}_{c,j}^{l} \left[\ln PPP_{c,j}^{l} - \overline{\ln PPP_{j}^{l}} \right] \qquad (6)$$

where the bar in the last term indicates a geometric average over all countries indexed by $c=1,..,N$ and N is the number of countries such that $\overline{\ln PPP_{j}^{l}} = 1/N \sum_{c} \ln PPP_{c,j}^{l}$. And $\bar{v}_{c,j}^{l}$ is the average weight of labour type l defined as $\bar{v}_{c,j}^{l} = \frac{1}{2} [v_{c,j}^{l} + \Sigma_{c} (v_{c,j}^{l} / N)]$ with $v_{c,j}^{l}$ the share of labour type l in total labour compensation in country c: $v_{c,j}^{l} = V_{c,j}^{l} / V_{c,j}^{L}$. The PPP for each labour type is derived on the basis of relative wages as described in Section 3.

The derivation of an appropriate capital PPP is basically similar to that of a labour PPP. Suppose one has a PPP for each capital asset type k, then the aggregate capital PPP is given by:

$$\ln PPP_{c,j}^{K} = \sum_{k} \bar{v}_{c,j}^{k} \left[\ln PPP_{c,j}^{k} - \overline{\ln PPP_{j}^{k}} \right] \qquad (7)$$

For the deflation of value added, a double deflation procedure is used based on separate PPPs for gross output and intermediate inputs as required (Jorgenson, Kuroda and Nishimizu, 1987). We follow a CCD-like approach by taking a geometric mean of all possible binary Törnqvist indices for a particular country c. First, we calculate the binary value added PPP for each country pair (c,d) as follows:

$$\left[\ln PPP_{c,j}^{VA} - \ln PPP_{d,j}^{VA} \right] =$$

$$\frac{1}{1 - \bar{v}_{c,d,j}^{II}} \left[\left(\ln PPP_{c,j}^{Y} - \ln PPP_{d,j}^{Y} \right) - \bar{v}_{c,d,j}^{II} \left(\ln PPP_{c,j}^{II} - \ln PPP_{d,j}^{II} \right) \right] \qquad (8)$$

The weight $\bar{v}_{c,d,j}^{II}$ is the share of intermediate inputs in gross output, averaged over the two countries. $PPP_{c,j}^{Y}$ is the multilateral index for output and derived analogous to the derivation of labour PPPs, but now using shares of output types in total output value as weights, and similarly for $PPP_{c,j}^{II}$ which is the multilateral index for intermediate input. Finally, a G-EKS procedure is applied to multilateralize the set of value added binaries given in (8), as in Caves, Christensen and Diewert (1982b).

Equations (2) to (8) provide the system of equations used to derive MFP measures consistent with neo-classical production theory. In Section 4 a comparison will be made with cruder measures of MFP which do not take into account detailed measures of various labour and capital types, and neglect differences in sectoral output and input prices. In particular, many studies use GDP PPPs to deflate industry-level outputs and inputs:

$$PPP_{c,j}^{VA} = PPP_{c}^{GDP} \qquad (9)$$

As noted in the literature, this approach ignores the difference in prices across various industries, and the differences in prices of intermediate inputs and outputs (Sørenson, 2001; Rogerson, 2008). This can be easily seen when comparing our data-intensive measure given in (8) with (9).

When it comes to measuring labour input volumes, some studies only measure the relative number of persons engaged while others also account for differences in average hours worked across countries. Implicitly, these studies use the following PPP for labour:

$$PPP_{c,j}^{L} = \left(\frac{V_{c,j}^{L}}{\tilde{Q}_{c,j}^{L}} \right) \Bigg/ \left(\frac{V_{US,j}^{L}}{\tilde{Q}_{US,j}^{L}} \right) \qquad (10)$$

with $\tilde{Q}_{c,j}^{L}$ the quantity of aggregate labour input in industry j and country c, directly measured as total number of workers, or total hours worked. In contrast to our data-intensive measure given in (6), this measure does not account for differences in the composition of the workforce in different countries.

Finally, as a measure of capital input volumes, most studies use a measure of the relative capital stock. Typically, as data on capital stocks is given in national prices, a GDP PPP is used to make them comparable across countries, as follows:

$$PPP_{c,j}^{K} = PPP_{c}^{GDP} \left(\frac{V_{c,j}^{K}}{\tilde{Q}_{c,j}^{K}} \right) \Big/ \left(\frac{V_{US,j}^{K}}{\tilde{Q}_{US,j}^{K}} \right) \tag{11}$$

with $\tilde{Q}_{c,j}^{K}$ the quantity of aggregate capital in industry j and country c, directly measured as the capital stock summed over all asset types. Consequently, this crude measure of capital does not take into account differences in investment prices, nor differences in the composition of capital. Our detailed measure is given in (7) above is based on a comparison of capital service levels, accounting for asset heterogeneity and investment PPPs.

In our empirical analysis, both the data-intensive and the crude measures of MFP-levels are extrapolated over time. The level comparisons are made for the year 1997. Growth rates of MFP are applied to generate series of MFP levels over the period 1970-2005. For the data-intensive measure, MFP growth rates (value added based) are taken from the *EU KLEMS database*, March 2008 which includes adjustments for changes in the composition of labour and capital over time. The time series of MFP growth used to extrapolate the crude measure of MFP do not take this into account. They are calculated by subtracting the weighted growth in persons engaged and growth of the capital stock from growth in value added volumes. The weights are the same as for the data-intensive measure. These series are also taken from *EU KLEMS database*, March 2008.

3. Data

In this study we use a combination of the *GGDC Productivity Level database* and the *EU KLEMS Growth accounting database*. The first database provides productivity level comparisons for 20 OECD countries at a detailed industry level using the methodology outlined in section 2. These comparisons are only made for one particular benchmark year, 1997. The *EU KLEMS database* is used to extrapolate this benchmark through time from 1970 to 2005. This is done at a detailed industry level. The list of industries is given in Appendix Table 1. The *EU KLEMS database* has been extensively described elsewhere (see O'Mahony and Timmer, 2009). Here we provide a short discussion of the underlying sources of the *GGDC Productivity Level database*.[12] All databases are available at www.ggdc.net.

This database is based on two main sets of data: a set of national input-output tables for the nominal values of output and inputs, and a set of PPPs for deflation. Input-output tables are not available for all countries in a common benchmark year

and we used supply and use tables to construct these. The starting point of our analysis is the national Supply and Use table for each country, valued in national currency for 1997. 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 non-European countries these tables are obtained from the national statistical offices. They had to be adjusted to the European industry classification.

The value added block of the tables only distinguishes two primary factors, namely capital and labour, so further disaggregation of these factor inputs is required. We use the labour and capital compensation as given in the *EU KLEMS database* in which a correction is made for the labour income of self-employed. Total hours worked and wages for each of the 18 labour types is taken from the *EU KLEMS database* and extended to 30 types by incorporating more detailed educational attainment data. Capital compensation is split into three ICT assets (computers, communication equipment and software) and five non-ICT assets (residential structures, non-residential structures, transport equipment, other non-ICT equipment and other assets). The share of each asset in total compensation is based on capital rental prices using the ex-ante approach. We multiply the asset- and industry-specific rental prices with the capital stock taken from the capital input files from the *EU KLEMS database* to derive the ex-ante capital compensation by asset.[13]

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 market 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.[14] PPPs have been made transitive by applying the multilateral EKS-procedure for a set of 30 countries.[15] Intermediate input PPPs 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. The data problems to obtain input PPPs for individual industries are larger than for output. There is often no input price parallel to the output PPPs. Business statistics surveys and productivity censuses provide little, or no, information on quantities and values of inputs in manufacturing, and for non-manufacturing industries the information is largely absent. Moreover, PPPs from the expenditure side by definition do not reflect prices of intermediate inputs as they cover only final expenditure categories. In this study we use output PPPs as a proxy for relative intermediate input prices under the assumption that the basic price of a good is independent of its use. That is, we use the same gross output PPP of an industry to deflate all intermediate delivers from this industry to other industries. The aggregate intermediate input PPP for a particular industry can be derived by

weighting intermediate inputs at the output PPP from the delivering industries. Imported goods are separately identified and exchange rates are used as conversion factors for imports.

PPPs for labour inputs are derived by dividing a country's wage rate by the corresponding US wage rate. This must be done at a detailed level of aggregation as characteristics of workers vary greatly across countries, see e.g. de la Fuente and Domenech (2006). For example, the share of college-educated workers in the U.S. is typically (much) higher than in the European countries. By having a detailed breakdown into various labour types, we try to minimise problems of composition in the determination of relative wages. Labour input is cross classified by type of education (5 types), age (3 types) and gender, into 30 groups. For each group in each industry, wages per hour worked are taken from the *EU KLEMS database*. They include all costs incurred by the producers in employment of labour including taxes levied, health cost payments, other types of insurance and contributions to retirement paid by the employer and financial benefits.

Capital PPPs give the relative price of the use of a unit of capital in two countries from the purchasers' perspective. To obtain relative prices for capital input, we follow Jorgenson and Nishimizu (1978). Under the assumption that the relative efficiency of new capital goods is the same in both countries, the relative rental price of an asset k between country c and the base country US (PPP_t^K) is calculated as:

$$PPP_t^K = PPP_t^I \ \frac{p_{t,c}^K / p_{t,c}^I}{p_{t,US}^K / p_{t,US}^I} \tag{12}$$

with lower-case p indicating prices, PPP_t^I the relative current investment price of asset k between country c and the US, and p_t^K the cost of capital as defined below. This definition indicates that the relative rental price of a unit of capital between two countries depends on the relative investment price and the user cost of capital input. In the absence of taxation the familiar cost-of-capital equation for asset type k is given by:

$$p_{t,c}^K = p_{t-1}^I r_t + \delta \ p_t^I - [p_t^I - p_{t-1}^I] \tag{13}$$

This formula shows that the user cost is determined by the nominal rate of return (r) , the rate of economic depreciation (δ) and the asset specific capital gains. This is done for each asset type k in each industry j, using asset-industry specific depreciation rates and investment prices.[16]

4. Productivity levels: crude versus data-intensive

The preceding discussion has demonstrated that a great deal of data is required to get close to the theoretical concept of productivity as based on neo-classical production theory. Detailed information about the composition and relative prices of labour and capital are needed to get an accurate comparison of input across countries and industry-specific output prices are needed for an accurate comparison of output. But an important question is whether all these refinements matter in practice or whether a cruder measure that is easier to implement would give qualitatively similar results. To examine this, we first look at comparative measures of inputs and outputs in detail in Tables 1 to 3, and next compare a number of alternative productivity level estimates based on varying data-intensity in Table 4.

In Table 1 we present value added PPPs for various sectors in the economy as a ratio of the overall GDP PPP. The ratios are given for three sectors: Manufacturing, Other goods and Market services.[17] Most studies rely on GDP PPPs for conversion of sectoral output and as discussed in the introduction, this has generally been seen as a major weakness of current convergence studies. The value added PPPs have been derived by separate deflation of output and intermediate inputs as in equation (8). As shown in the table, the ratio of sectoral value added to GDP PPP can vary between 75% and more than 200%.[18] Importantly, the table shows that the ratio is not stable across sectors indicating large differences in relative sectoral prices, confirming the findings by Biesebroeck (2007) and Sørenson and Schjerning (2009). For example, the relative production price of Other goods in Japan is much higher than the relative price for Manufacturing. This is mainly due to the high output prices in the agricultural sector which is famous for its weak competitiveness and strong import protection (van Ark and Pilat, 1993). The use of an overall GDP PPP would greatly overestimate productivity levels in this sector. On balance, the VA PPPs for manufacturing differ about 16% from the GDP PPP across our set of countries.[19] This directly translates into a 16 percent difference in measures of productivity levels. For Market Services the difference is comparable (15%), while for Other goods it is even bigger (32%).

[Table 1 about here]

Next we look at data-intensive measures of labour and capital input. To ease exposition, we only present results for the aggregate market economy, though a similar comparison could be made for each of the detailed industries in our dataset. Table 2 presents our measures of labour services input per worker compared to the U.S. The most straightforward measure of labour input compares the number of persons engaged, but this popular measure neglects variation in the average number of hours worked and the composition of the workforce, as is discussed in Section 2, equations (3), (6) and (10). As shown in the first column, average annual hours

worked vary considerably across countries, between 1,474 hours in Belgium and 2,111 hours in Hungary.[20] Our measure of labour services also adjusts for differences in educational attainment of the labour force. The difference in skill levels across OECD countries is illustrated in the second column, which provides the share of high-skilled workers in employment.[21] Apart from Finland, the US appears to have the largest share of high-skilled workers, as also found by de la Fuente and Domenech (2006) and Cohen and Soto (2007). However, focusing only on workers with university education is potentially misleading as one ignores differences in lower levels of education. For example, Germany has a comparatively large share of workers in vocational education categories, whose skills are highly valued in the labour market as reflected in relatively high skill premia. Such a category of workers is not to be found in the U.S. Furthermore, labour force characteristics such as age and gender are also relevant as indicators of work experience. Our detailed measures correct for this as well. The final column of Table 2 shows the amount of labour services per worker which combines the effects of both differences in hours worked and compositional differences across countries. Except for Hungary, all countries have lower inputs of labour services per worker than the US. For countries like Belgium, Denmark and the Netherlands, this is mainly due to lower working hours, while for countries like Czech Republic, Portugal and Slovenia differences in labour composition are most important.

[Table 2 about here]

Table 3 looks at a crude and our data-intensive measure of capital input. The first column is based on comparisons of aggregate capital stock as in equation (11), discussed in section 2. The drawback of this measure is that it does not take into account differences in investment prices nor the composition of the capital stock. Both issues are empirically important as indicated by Caselli and Wilson (2004) and Hsieh and Klenow (2007). Whereas in the past capital stocks provided a good proxy for capital input levels, this is no longer the case in the ICT-era. Jorgenson and Vu (2005) and Timmer and van Ark (2005) highlighted the diverging trends in the use of ICT-capital and its impact on comparative productivity levels. This is illustrated in Column 2 which presents the share of ICT-assets in total capital compensation. This share is more than 20 per cent in Denmark, Sweden, UK and the U.S., but less than 11 per cent in Czech Republic, Ireland, Italy and Portugal. Comparisons based on detailed measures of capital according to equation (7) are given in the final column. As almost all countries use less ICT than the US, relative capital input services are lower than relative levels of stocks. In general the lower the share of ICT, the bigger the difference between the crude and data-intensive measure.

In addition, relative prices between equipment and other capital assets such as buildings and structures are known to differ as the former are mostly imported, while the latter are domestically constructed. The latter depend largely on local wages and its PPP is usually close to the GDP PPP (Hsieh and Klenow, 2007). In contrast, PPPs for equipment are closely related to exchange rates. For countries in which exchange rates are much higher than the overall GDP PPP, the crude capital input measures as given in equation (11) will be overestimated. This is the case for example for the Czech Republic, Hungary and Slovenia. All in all, for these countries data-intensive measures of capital input can be as low as only halve of the crude measures. But also for other countries differences can be sizeable. For example for France we find a 25 percentage point difference.

So far we only discussed measures for the market economy as a whole. As shown by Stiroh (2002), there is wide dispersion of ICT-intensity across sectors in an economy with generally high levels of ICT-investment in market services sectors such as finance and business services, communication and transportation. This cross-industry pattern is also found in our dataset: the cross-country level differences found for the market economy are generally also reflected at lower industry levels (see Inklaar and Timmer, 2008).

Each adjustment to output and input volumes discussed above has a direct impact on the measurement of MFP. Table 4 brings the previous tables together by comparing four alternative productivity level estimates using increasingly data-intensive methods when moving from left to right. So the first column shows a crude measure, where GDP PPPs are used to convert output to a common currency, the number of persons engaged is used as the labour measure and capital stocks are the capital measure. This measure (MFP1) is comparable to the one used by BJ. MFP2 then adjusts MFP1 for differences in the average number of hours worked and for the composition of the labour force, as in Table 2. Average hours worked are lower than in the US in many countries. In addition, the labour composition effect is smaller than one in all countries compared to the US. As a result, MFP2 is lower than MFP1 for all countries, but Hungary. Differences in labour input measures do not translate one to one to MFP, since they are weighted with the labour costs in value added, which is about two-thirds. Still this can have a great impact: while Belgium has a productivity level of 87 percent of the US according to MFP1, the level is 105 percent according to MFP2.

Instead of a GDP PPP, MFP alternative 3 is based on a value added PPP. MFP3-levels are lower than MFP2-levels in almost all countries because VA PPPs being higher than GDP PPPs (see Appendix Table 1). Although this is true for the market economy as a whole, this will not be the case for all detailed industries as

13

shown in Table 1. The final step towards our preferred MFP alternative is an adjustment for capital PPPs and composition, as shown in Table 3. Differences between capital stock and services input, weighted by the share of capital in value added (about one-third) account for the differences between MFP3 and MFP4. Because of lower levels of capital services per hour worked than capital stocks per hour worked relative to the U.S., MFP4-levels are mostly higher than MFP3-levels.

For some countries, all these adjustments almost cancel out: for Ireland both MFP1 and MFP4 are 99 percent of the U.S. and for Slovenia, MFP1 is 50 and MFP4 is 49 percent of the US. However, for most countries the effect is substantial, between 5 and almost 20 percentage points. For example, Germany would appear to be 18 percentage points less productive than the US according to the crudest productivity measure but only 7 percentage points according to the data-intensive measure. Furthermore, differences at the detailed industry level tend to be even larger, see Inklaar and Timmer (2008).

Irrespective whether the differences are large or small, the main point is that our data-intensive measure does not suffer from the conceptual problems of cruder measures. Because output and input prices are industry-specific and the large heterogeneity in labour and capital inputs is recognized, we can have more faith in the results of studies based on these measures. This will be illustrated by a convergence analysis in the next section.

[Table 4 about here]

5. Convergence analysis

A key issue in modelling economic growth is whether there is a tendency of productivity levels to convergence to a common level or whether differences in levels can continue indefinitely or even increase over time. BJ analyze this issue for a set of OECD countries for the period 1970-1987 and conclude that there are substantial differences in convergence patterns across sectors, with services showing convergence but no convergence in manufacturing. In this section we revisit their analysis using more data-intensive productivity measures and extend their findings from 1987 to 2005. For this we take our 1997 benchmark productivity levels and extrapolate them to 1970 and 2005 using relative MFP growth rates from the EU KLEMS database.[22,23]

As Islam (2003) argues in his survey, a test for productivity convergence should examine the dispersion of productivity levels over time (-convergence). A regression where productivity growth is explained by initial productivity levels can be used (-convergence), but a significant coefficient on initial productivity levels is only a necessary, but not sufficient condition for a smaller dispersion in productivity

levels over time. Although -convergence is useful in many economic models (i.e. Griffith, Redding and van Reenen, 2004) we rely on -convergence in this paper.

Figure 1 shows the result of our industry group analysis for the 1970-2005 period. The figure plots the standard deviation of productivity levels relative to the US for three industry groups, namely manufacturing, market services and other goods-producing industries. This latter group includes agriculture, mining, utilities and construction. Given the long time span, we were forced to reduce our sample to the thirteen countries with sufficient data.[24] Looking at the 1970-1987 period covered by BJ, their qualitative findings are confirmed: convergence in market services and no convergence in manufacturing and other goods-producing industries.[25] This pattern does not change in subsequent years: market services continue to show convergence, while the other two sectors even show some evidence of divergence since the mid-1990s. This contrasting convergence pattern across sectors confirms the key message of BJ that an industry perspective is very important in the convergence debate.

[Figure 1 about here]

This is further confirmed in Table 5 where we look at patterns of convergence in each of our 24 detailed industries. Data limitations require us to restrict the analysis to the 1980-2005 period. Across industries, the evidence for convergence and divergence is also diverse: 13 industries have lower standard deviations in 2005 than in 1980 while 11 have higher standard deviations. The final column of Table 5 shows a test-statistic for the equality of standard deviations from Carree and Klomp (1997).[26] Taking into account that the standard deviations over time are not independent, they formulate a test-statistic that is asymptotically normally distributed. Five of the industries have a significantly positive test statistic, implying significant convergence while two show significant divergence. Interestingly, two of the significantly converging industries are in manufacturing which does not converge in aggregate. Similarly, post and telecommunications, an industry in market services, is one of the industries showing significant divergence, while aggregate market services converges. In summary, the detailed industry perspective further reinforces the message of BJ that convergence patterns differ substantially across industries.[27]

[Table 5 about here]

6. Concluding remarks

Economic growth analysis has been hampered by a lack of data of sufficient quality on industry productivity levels. Neo-classical production theory implies that accurate productivity level estimates require industry-specific relative output and input prices and a thorough accounting for the heterogeneity of inputs.[28] Although each of these problems is widely acknowledged and has been partially addressed in various studies, this is the first study which provides a comprehensive treatment and does so at a detailed industry level.

As we have shown in our empirical results for 20 advanced OECD countries, the differences between crude and data-intensive measures are very important in practice: there are considerable differences across countries in average hours worked; the composition of the workforce in terms of educational attainment and experience; the use of ICT and non-ICT capital; and prices of both industry output, intermediate inputs and investment. Accounting for these differences has a substantial impact on productivity level estimates. The new data-intensive measures provide a more reliable data-set which can be used in a variety of studies on economic growth, structural change and international trade.

In a convergence analysis, we confirm and strengthen the main conclusion from Bernard and Jones (1996) that convergence or divergence is an industry-specific phenomenon. Of the industry groups distinguished by Bernard and Jones (1996), only market services shows convergence, while there is no convergence in manufacturing or other goods-producing industries. These findings hold for the 1970-1987 period as studied by Bernard and Jones (1996) but also extend to the more recent 1987-2005 period for a similar group of 13 advanced countries. At a more detailed industry level using data for 24 industries we show even greater heterogeneity. Between 1980 and 2005, about half the industries show decreasing dispersion of productivity levels and the other half shows *increasing* dispersion. There is no dominant convergence trend in sectoral productivity growth across advanced countries.

Our preferred, data-intensive productivity level estimates take into account many of the criticisms that have been raised against cruder estimates. However, this does not imply that all data issues are resolved. There are a number of areas for further improvement in the basic statistics underlying measurement of productivity growth and levels (Diewert, 2008). Of particular importance is data on capital assets, such as land and inventories which are not included in our set of assets due to missing data. More recently, attempts are made to measure investment in intangible capital.[29] Some of the industry output prices, in particular for services industries like finance and business services are hard to measure, both over time and across countries.[30] More generally, it is true that more detailed measures of labour and capital are less

reliable than more aggregate measures due to limited survey evidence, suggesting a trade-off between precision and measurement error.[31]

Notwithstanding these remaining issues, we would argue that our productivity level estimates provide a fruitful starting point for further research. In our estimation, we have brought together different strands of the literature on topics such as PPPs, physical and human capital measurement; provided internationally comparable measures and combined these in a coherent framework to show the importance of theory-based measurement. This should specifically open the door to examining the robustness of earlier findings in the literature to improvements in measurement practices (Hamermesh, 2007) and in general increase the degree of trust in cross-country growth analyses relying on industry productivity levels.

References

Abraham, Katharine G. (2005) What We Don't Know Could Hurt Us: Some Reflections on the Measurement of Economic Activity. *Journal of Economic Perspectives* 19(3), pp. 3-18.

Aghion, Philippe and Peter Howitt (2006) Joseph Schumpeter Lecture: Appropriate Growth Policy: A Unifying Framework. *Journal of the European Economic Association* 4(2-3), pp. 269-314.

Allen, Robert. C. and W. Erwin Diewert (1981), Direct versus implicit superlative index number formulae. *Review of Economics and Statistics* 63, pp. 430-435.

Ark, Bart van, and Dirk Pilat (1993) Productivity Levels In Germany, Japan And The United States. *Brookings Papers on Economic Activity, Microeconomics*, 2, pp.1-48.

Ark, Bart van and Marcel P. Timmer (2001), PPPs and International Productivity Comparisons: Bottlenecks and New Directions. Paper presented at the Joint World Bank-OECD Seminar on Purchasing Power Parities: Real Advances in Methods and Applications, Washington DC, 30 January-1 February, 2001.

Barro, Robert and Xavier Sala-i-Martin, (2004). *Economic Growth*, Second edition, Cambridge: MIT Press.

Basu, Susanto, John G. Fernald, Nicholas Oulton and Sylaja Srinivasan (2004) The Case of the Missing Productivity Growth: Or, Does Information Technology Explain Why Productivity Accelerated in the United States but not in the United Kingdom? In M. Gertler and K. Rogoff (eds) *NBER Macroeconomics Annual 2003*, MIT Press: Cambridge, pp. 9-63.

Bernard Andrew B. and Charles I. Jones (1996) Comparing Apples to Oranges: Productivity Convergence and Measurement Across Industries and Countries. *American Economic Review* 86(5), pp. 1216-1238.

Bernard Andrew B. and Charles I. Jones (2001) Comparing Apples to Oranges: Productivity Convergence and Measurement Across Industries and Countries: Reply. *American Economic Review* 91(4), pp. 1168-1169.

Biesebroeck, Johannes van (2007) Cross-Country Conversion Factors for Sectoral Productivity Comparisons. Working Paper 290, University of Toronto, Department of Economics

Carree, Martin A. and Luuk Klomp (1997) Testing the convergence hypothesis: a comment. *Review of Economics and Statistics* 79, pp. 683-686.

Caselli, Francesco (2005) Accounting for Cross-Country Income Differences. In Philippe Aghion and Steven Durlauf (eds), *Handbook of Economic Growth*, pp. 679-741 Elsevier.

Caselli, Francesco and Daniël J. Wilson (2004) Importing technology. *Journal of Monetary Economics* 51(1), pp. 1-32.

Caves, Douglas W., Laurits R. Christensen and W. Erwin Diewert (1982a) The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity'. *Econometrica* 50, pp. 1392-1414.

Caves, Douglas W., Laurits R. Christensen and W. Erwin Diewert (1982b) Multilateral comparisons of output, input and productivity using superlative index numbers. *Economic Journal* 92, pp. 73-86.

Cohen, Daniel and Marcelo Soto (2007) Growth and human capital: good data, good results. *Journal of Economic Growth* 12(1), pp. 51-76.

Corrado, Carol A., Charles R. Hulten and Daniel E. Sichel (2005) Measuring Capital and Technology: An Expanded Framework. In Carol A. Corrado, John C. Haltiwanger and Daniel E. Sichel (eds) *Measuring Capital in the New Economy*, University of Chicago Press: Chicago; pp. 11-46.

de la Fuente, Angel and Rafael Doménech (2006) Human capital in growth regressions: how much difference does data quality make? *Journal of the European Economic Association* 4(1), pp. 1-36.

Diewert, W. Erwin (1976) Exact and Superlative Index Numbers. *Journal of Econometrics* 4, pp. 114-145.

Diewert, W. Erwin (2008) What is to be done for better productivity measurement. *International Productivity Monitor* 16, 40-52.

Diewert, W. Erwin. and Catherine J. Morrison Paul (1986) Adjusting Output and Productivity Indexes for Changes in the Terms of Trade. *Economic Journal* 96, 659-679.

Griffith, Rachel, Stephen J. Redding and John Van Reenen (2004) Mapping the two faces of R&D: productivity growth in a panel of OECD industries. *Review of Economics and Statistics* 86, pp. 883-895.

Hamermesh, Daniel S. (2004) Viewpoint: Replication in economics. *Canadian Journal of Economics* 40(3), pp.715-733.

Harrigan, James (1999) Estimation of cross-country differences in industry production functions. *Journal of International Economics* 47(2), pp. 267-293.

Hsieh, Chang-Tai and Peter J. Klenow (2007) Relative Prices and Relative Prosperity. *American Economic Review* 97(3), pp. 562-585.

Inklaar, Robert and Marcel P. Timmer (2007) International Comparisons of Industry Output, Inputs and Productivity Levels: Methodology and New Results. *Economic Systems Research* 19(3), pp. 343-364.

Inklaar, Robert and Marcel P. Timmer (2008) GGDC Productivity Level Database: International Comparisons of Output, Inputs and Productivity at the Industry Level. *GGDC Research Memorandum*, GD-104, Groningen Growth and Development Centre.

Inklaar, Robert and Marcel P. Timmer (2009) Measurement Error in Productivity Levels: Is more Detailed Data Better? *GGDC Research Memorandum*, GD-111, *Groningen: Groningen Growth and Development Centre.*

Islam, Nazrul (2003) What have we learnt from the convergence debate? *Journal of Economic Surveys* 17(3), pp. 309-362.

Jorgenson, Dale W. (1995a) *Productivity, Volume 1: Postwar U.S. Economic Growth.* Cambridge, MA: MIT Press.

Jorgenson, Dale W. (1995b) *Productivity, Volume 2: International Comparisons of Economic Growth.* Cambridge, MA: MIT Press.

Jorgenson, Dale W. and Zvi Griliches (1967) The Explanation of Productivity Change. *Review of Economic Studies* 34, pp. 249–280.

Jorgenson, Dale W. and Mieko Nishmizu (1978) U.S. and Japanese economic growth, 1952-1974: an international comparison. *Economic Journal*, 88, pp. 707-726.

Jorgenson, Dale W. and Khuong Vu (2005) Information Technology and the World Economy. *Scandinavian Journal of Economics* 107(4), pp. 631-650.

Jorgenson, Dale W. and Yip, Eric (2001) Whatever Happened to Productivity Growth? Investment and Growth in the G-7. In Edwin R. Dean, Michael J. Harper, and Charles R. Hulten (eds.), *New developments in productivity analysis*. Chicago, IL: University of Chicago Press, pp. 205-246.

Jorgenson, Dale W., Masahiro Kuroda and Mieko Nishimizu (1987) Japan-U.S. industry-level productivity comparisons, 1960-1979. *Journal of the Japanese and International Economies* 1, pp. 1-30.

Keller, Wolfgang (2002) Trade and the Transmission of Technology. *Journal of Economic Growth* 7(1), pp. 5-24.

Lee, Frank and Jianmin Tang (2000) Productivity Levels and International Competitiveness between Canadian and U.S. Industries. *American Economic Review* 90(2), pp. 176-79.

OECD (2002) *Purchasing Power Parities and Real Expenditures, 1999 Benchmark Year.* Paris: OECD.

O'Mahony, Mary (1999) *Britain's Productivity Performance 1950-1996 – An International Perspective.* London: National Institute of Economic and Social Research.

O'Mahony, Mary and Marcel P. Timmer (in press) Output, Input and Productivity Measures at the Industry Level: the EU KLEMS Database, *Economic Journal*

Oulton, Nicholas (2007) Ex Post Versus Ex Ante Measures Of The User Cost Of Capital. *Review of Income and Wealth* 53(2), pp. 295-317.

Restuccia, Diego, Dennis Tao Yang and Xiaodong Zhu (2008) Agriculture and aggregate productivity: a quantitative cross-country analysis. *Journal of Monetary Economics* 55(2), pp. 234-250.

Rogerson, Richard (2008) Structural Transformation and the Deterioration of European Labor Market Outcomes. *Journal of Political Economy* 116(2), pp. 235-259.

Schreyer, Paul (2008) International Comparisons of Levels of Capital Input and Multi-Factor Productivity. *German Economic Review* 8(2), pp. 237-254.

Sørensen, Anders (2001) Comparing Apples to Oranges: Productivity Convergence and Measurement Across Industries and Countries: Comment. *American Economic Review* 91(4), pp. 1160-1167.

Sørensen, Anders and Bertel Schjerning (2008) Productivity Measurement in Manufacturing and the Expenditure Approach. *Review of International Economics* 16(2), pp. 327-340.

Stiroh, Kevin J. (2002) Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say? *American Economic Review* 92(5), pp.1559-1576.

Timmer, Marcel P., Gerard Ypma, and Bart van Ark (2007) PPPs for industry output: a new dataset for international comparisons. *GGDC Research Memorandum GD-82, Groningen: Groningen Growth and Development Centre*.

Timmer, Marcel P. and Bart van Ark (2005) Does Information And Communication Technology Drive Productivity Growth Differentials? A Comparison Of The European Union Countries And The United States. *Oxford Economic Papers* 57(4), pp. 693-716.

[Appendix Table 1 about here]

Tables and Figures

Table 1, Value added PPPs for various sectors (as ratio of GDP PPP), 1997

	Manu-facturing	Other goods	Market services
Australia	1.42	0.75	1.12
Austria	1.47	1.29	1.32
Belgium	1.03	1.39	1.16
Czech Republic	1.20	1.21	1.42
Denmark	1.32	1.33	0.93
Finland	1.02	0.85	1.08
France	1.10	1.52	1.16
Germany	1.06	1.53	1.02
Hungary	1.06	1.55	1.07
Ireland	1.32	1.38	1.11
Italy	0.86	1.25	1.31
Japan	0.98	2.17	1.37
Luxembourg	1.18	1.85	0.79
Netherlands	1.20	1.58	0.96
Portugal	1.36	1.22	1.02
Slovenia	1.14	1.50	1.34
Spain	1.22	1.30	1.17
Sweden	1.12	1.08	1.09
United Kingdom	1.17	1.34	1.11
United States	1.00	1.00	1.00

Notes: PPPs for value added in various sectors divided by the GDP PPP. See Table 5 for definitions of

the sectors.

Source: see Appendix Table 1.

Table 2, Measures of labour input, 1997, market economy.

	Average hours worked	Share of high-skilled workers (%)	Labour services per worker (US=1)
Australia	1,862	11	0.87
Austria	1,659	6	0.77
Belgium	1,474	11	0.75
Czech Republic	2,049	8	0.96
Denmark	1,537	5	0.68
Finland	1,842	27	0.86
France	1,745	9	0.90
Germany	1,526	6	0.77
Hungary	2,111	10	1.12
Ireland	2,023	9	0.97
Italy	1,968	5	0.91
Japan	1,837	19	0.97
Luxembourg	1,647	12	0.86
Netherlands	1,486	7	0.75
Portugal	1,912	5	0.62
Slovenia	1,897	10	0.85
Spain	1,768	10	0.83
Sweden	1,740	9	0.90
United Kingdom	1,797	11	0.86
United States	1,848	24	1.00

Source: GGDC Productivity Level database (Inklaar and Timmer, 2008).

Table 3, Measures of capital input per hour worked, 1997, market economy.

	Capital stock per hour worked (US=1)	ICT-share in total capital compensation	Capital services per hour worked (US=1)
Australia	1.31	16.3	1.03
Austria	1.44	13.4	1.12
Belgium	1.95	18.0	1.59
Czech Republic	0.93	8.3	0.45
Denmark	1.40	21.8	1.24
Finland	1.23	17.5	1.17
France	1.15	16.6	0.90
Germany	1.18	18.4	1.06
Hungary	0.95	12.9	0.47
Ireland	0.83	10.0	0.58
Italy	1.25	10.7	1.06
Japan	1.18	19.4	1.19
Luxembourg	1.49	21.6	1.32
Netherlands	1.24	17.2	1.03
Portugal	0.49	10.9	0.40
Slovenia	0.78	26.9	0.49
Spain	1.01	17.0	0.69
Sweden	1.18	23.8	1.09
United Kingdom	0.84	22.0	0.75
United States	1.00	26.8	1.00

Notes and sources: Capital stock based on aggregate stocks in national currencies from *EU KLEMS database* (O'Mahony and Timmer, 2008), converted with GDP PPPs from the OECD (2002). Share of ICT in total capital compensation and capital services based on *GGDC Productivity Level database* (Inklaar and Timmer, 2008).

Table 4, Measures of 1997 market economy MFP levels, US=1

	MFP1	MFP2	MFP3	MFP4
Australia	0.75	0.82	0.75	0.81
Austria	0.72	0.86	0.63	0.68
Belgium	0.87	1.05	0.90	0.96
Czech Republic	0.45	0.46	0.37	0.48
Denmark	0.75	0.97	0.90	0.94
Finland	0.76	0.84	0.82	0.84
France	0.88	0.94	0.78	0.84
Germany	0.82	0.98	0.90	0.93
Hungary	0.44	0.41	0.36	0.47
Ireland	0.99	1.01	0.87	0.99
Italy	0.82	0.88	0.74	0.78
Japan	0.69	0.71	0.52	0.52
Luxembourg	1.04	1.14	1.17	1.22
Netherlands	0.79	0.97	0.89	0.94
Portugal	0.56	0.77	0.68	0.74
Slovenia	0.50	0.56	0.43	0.49
Spain	0.79	0.89	0.75	0.85
Sweden	0.84	0.90	0.82	0.84
United Kingdom	0.83	0.92	0.78	0.81
United States	1.00	1.00	1.00	1.00
Measurement alternatives				
PPP	GDP	GDP	VA	VA
Labour	Persons	Hours by type	Hours by type	Hours by type
Capital	Stock	Stock	Stock	Services by type

Source: authors calculations based on *GGDC Productivity Level database* (Inklaar and Timmer, 2008).

Table 5, Standard deviation of industry productivity levels in 1980 and 2005 and

a test for equality

	Group	1980	2005	Difference	T3-test
Agriculture, forestry and fishing	OG	0.22	0.22	0.00	-0.06
Mining and quarrying	OG	1.00	0.58	-0.41	4.04*
Food and beverages	MFG	0.08	0.10	0.02	-0.73
Textiles, wearing apparel and leather products	MFG	0.15	0.13	-0.02	0.81
Wood and wood products	MFG	0.23	0.24	0.02	-0.35
Paper, printing and publishing	MFG	0.10	0.13	0.03	-2.19*
Coke, refined petroleum and nuclear fuel	MFG	0.20	0.21	0.02	-0.33
Chemicals and chemical products	MFG	0.16	0.19	0.03	n.a.
Rubber and plastics	MFG	0.36	0.36	0.00	-0.04
Non-metallic mineral products	MFG	0.21	0.18	-0.03	0.87
Basic metals and fabricated metal products	MFG	0.20	0.15	-0.05	1.90*
Machinery	MFG	0.15	0.12	-0.02	0.80
Electrical and optical equipment	MFG	0.17	0.17	0.00	-0.05
Transport equipment	MFG	0.17	0.15	-0.01	0.78
Manufacturing, nec; recycling	MFG	0.42	0.27	-0.15	3.13*
Electricity, gas and water supply	OG	0.12	0.12	0.00	0.02
Construction	OG	0.14	0.18	0.04	n.a.
Wholesale and retail trade	SER	0.36	0.23	-0.13	3.09*
Hotels and restaurants	SER	0.18	0.15	-0.03	1.16
Transport and storage	SER	0.27	0.27	-0.01	0.31
Post and telecommunications	SER	0.19	0.34	0.14	-2.02*
Financial intermediation	SER	0.19	0.23	0.05	-0.85
Business services	SER	0.14	0.12	-0.02	0.79
Social and personal services	SER	0.20	0.11	-0.09	4.14*

Notes: * Denotes a standard deviation in 2005 that is significantly different from that in 1980 at the 5%-level. T3-test is a test for significant difference between standard deviations from Carree and Klomp (1997). This statistic asymptotically has a standard normal distribution. n.a. denotes that the test statistic could not be calculated due to specific parameter values, see Carree and Klomp (1997). Group denotes the industry group to which that industry belongs: OG: Other goods-producing, MFG: manufacturing and SER: market services.

Figure 1, Standard deviation of productivity levels, 1970-2005
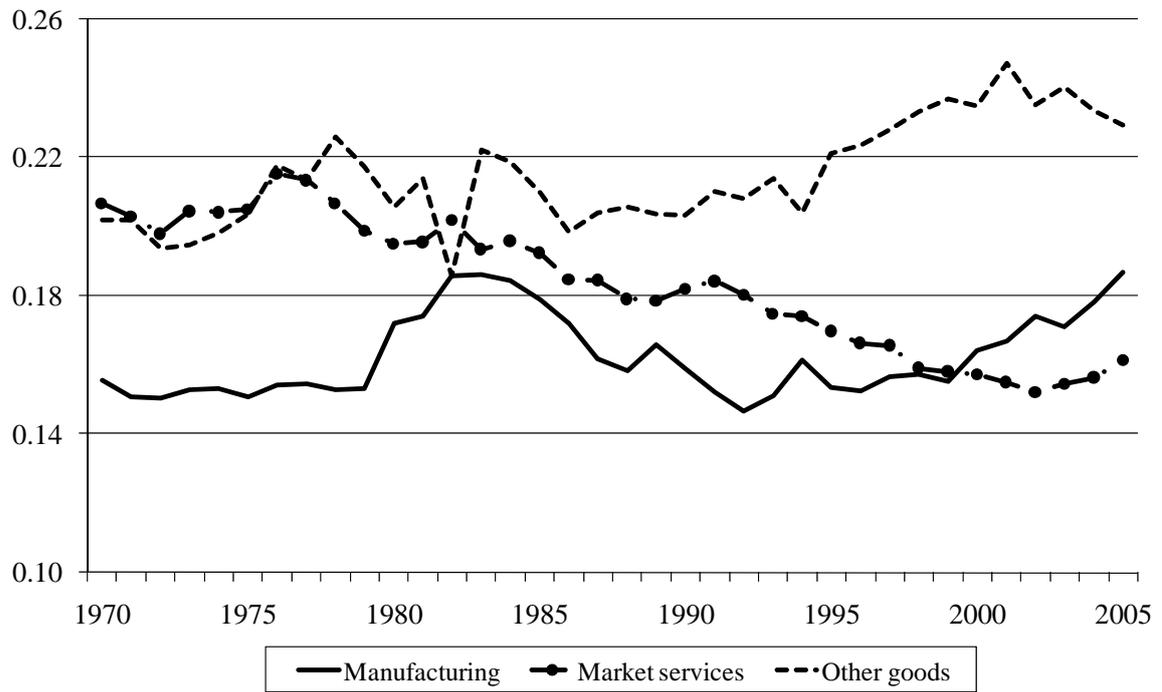
Appendix Table 1, Various alternative measures of output PPPs

| | GDP (OECD) | Value added PPPs | | | | Exchange rate |
		Market economy	Manu-facturing	Other goods	Market services	
Australia	1.32	1.44	1.88	0.99	1.48	1.35
Austria	0.92	1.26	1.36	1.19	1.22	0.89
Belgium	0.91	1.06	0.94	1.26	1.06	0.89
Czech Republic	12.7	16.0	15.2	15.4	18.1	31.7
Denmark	8.43	9.07	11.16	11.22	7.81	6.60
Finland	1.00	1.02	1.01	0.85	1.08	0.87
France	0.97	1.18	1.07	1.48	1.13	0.89
Germany	0.99	1.08	1.05	1.52	1.01	0.89
Hungary	85.0	96.5	89.9	132.1	90.9	186.8
Ireland	0.85	0.99	1.13	1.17	0.94	0.84
Italy	0.82	0.96	0.70	1.02	1.07	0.88
Japan	168	229	166	366	230	121
Luxembourg	0.96	0.94	1.13	1.77	0.75	0.89
Netherlands	0.91	0.99	1.09	1.44	0.88	0.89
Portugal	0.67	0.75	0.91	0.82	0.68	0.87
Slovenia	0.46	0.59	0.53	0.69	0.62	0.67
Spain	0.72	0.86	0.87	0.93	0.84	0.88
Sweden	9.30	10.3	10.4	10.0	10.2	7.63
United Kingdom	0.63	0.75	0.74	0.85	0.71	0.61
United States	1.00	1.00	1.00	1.00	1.00	1.00

Source: GDP PPP and exchange rate from OECD (2002). Value added PPPs based on the *GGDC Productivity Level database* (Inklaar and Timmer, 2008). For countries that joined the euro in 1999, the 1999 conversion rate was used on the old pre-euro currencies. All in national currency per US$.

ENDNOTES

---

[1] See Islam (2003) and Barro and Sala-I-Martin (2004) for an overview.

[2] See for example Aghion and Howitt (2006), Restuccia, Yang and Zhu (2008) and Keller (2002).

[3] See also Harrigan (1999) and Caselli (2005).

[4] Jorgenson and Yip (2001) provide relative MFP levels at the aggregate level for the G7 countries, see also Schreyer (2008). At the industry level applications of this methodology to small sets of countries can be found in for example Jorgenson, Kuroda and Nishimizu (1987), van Ark and Pilat (1993), O'Mahony (1999), Lee and Tang (2000) and most recently Inklaar and Timmer (2007).

[5] Level accounting is also known as development accounting (see e.g. Caselli, 2005). The methodology for level accounting is akin to the methodology for growth accounting. Instead of comparing two points in time as in growth accounting, we compare two countries at a similar point in time. We stick to the name level accounting as it most clearly indicates the difference and similarity with growth accounting.

[6] Comparisons of multi-factor productivity can be made using the so-called primal and dual approaches. In the primal approach relative MPF levels are based on comparisons of quantities as we do here. Alternatively, in the dual approach they are based on comparisons of prices. Usually, productivity measures are expressed in terms of relative quantities, as this is most closely related to the notion of production as a physical process in which quantities of inputs are converted into quantities of outputs. In theory, the two different estimates should be close, but in practice this is not always the case, in particular when production structures differ considerably between the two countries being compared. We opt for the primal approach as we are interested in a full and consistent decomposition of output quantities, rather than output prices.

[7] The GGDC Productivity Level accounts provide also gross-output based MFP levels, taking into account labour, capital and intermediate inputs.

[8] A subscript for time is left out to avoid notational cluttering in the level equations. All variables refer to the same year.

[9] Bilateral comparisons do not satisfy transitivity. Alternatively, one can use the multilateral approach advocated by Caves, Christensen and Diewert (1982b) who derive translog multilateral productivity indices that satisfy the transitivity requirement. The main reason not to opt for a multilateral approach is that this approach does not provide a consistent decomposition of relative output in terms of relative inputs and MFP levels. This is an important disadvantage given our interest in such decompositions.

[10] Note that because of our ex-ante approach to capital measurement, capital compensation V in this formula is based on ex-ante measures of rates of return and will differ from the ex-post measure of capital compensation used as weight in equation (2). This is the so-called hybrid approach, see Oulton (2007) and Inklaar and Timmer (2008) for further discussion.

[11] We aggregate over prices rather than over quantities as variation in prices across countries is much less than variation in quantities (see also Allen and Diewert, 1981).

[12] See Inklaar and Timmer (2008) for more details.

[13] The summation of capital compensation over all assets will typically differ from the capital compensation as given in the National Accounts. The latter is used in the calculation of MFP, see endnote 8.

[14] The expenditure approach to sectoral PPPs has been pioneered by Jorgenson, Kuroda and Nishimizu (1987) and most recently applied by Biesebroeck (2007) and Sørenson and Schjerning (2009). The production approach based on producer unit values has been popularized by van Ark and Pilat (1993) and is explained in detail, with recent advances, in van Ark and Timmer (2001).

[15] One is referred to Timmer *et al.* (2007) for further details about the construction and data sources underlying these PPPs.

[16] Subscripts to indicate this have been dropped to avoid cluttering.

[17] See Table 5 for definitions of these sectors.

[18] Sectoral value added PPPs are generally higher than GDP PPPs, so most ratios in Table 1 are bigger than one. This is mainly due to the fact that the latter includes non-market services which, according to the OECD results, are expensive in the US compared to other countries.

[19] Absolute log differences.

[20] What is measured is actual hours worked, not hours paid, so it takes differences in the number of vacation days, sick days, etc. into account.

[21] This broadly corresponds to workers with a tertiary education, such as a bachelor's degree, or higher.

[22] For the 1970-1979 period, we partly rely on educational attainment data from de la Fuente and Domenech (2006) to estimate labour composition change.

[23] By construction, our productivity levels pass the Sørensen (2001) test since we account for sectoral differences in output *and* input prices, both across countries and over time.

[24] These are Australia, Austria, Belgium, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Spain, United Kingdom and United States.

[25] BJ split up other-goods producing industries into agriculture, mining, utilities and construction and find no convergence in mining and construction and convergence in agriculture and utilities. For a comparison at this level of detail, see Table 5.

[26] Tests for differences in standard deviations at the industry group level from Figure 1 show no significant changes over the 1970-2005 period.

[27] Using PPPs based on expenditure prices only, van Biesebroeck (2007) arrives at the same conclusion.

[28] See Griliches and Jorgenson (1967), Diewert (1976), Caves, Christensen and Diewert (1982a), Diewert and Morrison (1986) and studies in Jorgenson (1995a,b).

[29] See e.g. Corrado, Hulten and Sichel (2005) and Basu, Fernald, Oulton and Srinivasan (2003)..

[30] See e.g. Abraham (2005).

[31] Inklaar and Timmer (2009) find that although measurement error is higher for detailed measures, this is outweighted by the improvements in precision of the estimates in cross-country studies.

Papers issued in the series of the Groningen Growth and Development Centre

All papers are available in pdf-format on the internet: http://www.ggdc.net/

536 (GD-1)   Maddison, Angus and Harry van Ooststroom, The International Comparison of Value Added, Productivity and Purchasing Power Parities in Agriculture (1993)

537 (GD-2)   Mulder, Nanno and Angus Maddison, The International Comparison of Performance in Distribution: Value Added, Labour Productivity and PPPs in Mexican and US Wholesale and Retail Trade 1975/7 (1993)

538 (GD-3)   Szirmai, Adam, Comparative Performance in Indonesian Manufacturing, 1975-90 (1993)

549 (GD-4)   de Jong, Herman J., Prices, Real Value Added and Productivity in Dutch Manufacturing, 1921-1960 (1993)

550 (GD-5)   Beintema, Nienke and Bart van Ark, Comparative Productivity in East and West German Manufacturing before Reunification (1993)

567 (GD-6)   Maddison, Angus and Bart van Ark, The International Comparison of Real Product and Productivity (1994)

568 (GD-7)   de Jong, Gjalt, An International Comparison of Real Output and Labour Productivity in Manufacturing in Ecuador and the United States, 1980 (1994)

569 (GD-8)   van Ark, Bart and Angus Maddison, An International Comparison of Real Output, Purchasing Power and Labour Productivity in Manufacturing Industries: Brazil, Mexico and the USA in 1975 (1994) (second edition)

570 (GD-9)   Maddison, Angus, Standardised Estimates of Fixed Capital Stock: A Six Country Comparison (1994)

571 (GD-10)   van Ark, Bart and Remco D.J. Kouwenhoven, Productivity in French Manufacturing: An International Comparative Perspective (1994)

572 (GD-11)   Gersbach, Hans and Bart van Ark, Micro Foundations for International Productivity Comparisons (1994)

573 (GD-12)   Albers, Ronald, Adrian Clemens and Peter Groote, Can Growth Theory Contribute to Our Understanding of Nineteenth Century Economic Dynamics (1994)

574 (GD-13)   de Jong, Herman J. and Ronald Albers, Industrial Output and Labour Productivity in the Netherlands, 1913-1929: Some Neglected Issues (1994)

575 (GD-14)   Mulder, Nanno, New Perspectives on Service Output and Productivity: A Comparison of French and US Productivity in Transport, Communications Wholesale and Retail Trade (1994)

576 (GD-15)   Maddison, Angus, Economic Growth and Standards of Living in the Twentieth Century (1994)

577 (GD-16)   Gales, Ben, In Foreign Parts: Free-Standing Companies in the Netherlands around the First World War (1994)

578 (GD-17)   Mulder, Nanno, Output and Productivity in Brazilian Distribution: A Comparative View (1994)

579 (GD-18)   Mulder, Nanno, Transport and Communication in Mexico and the United States: Value Added, Purchasing Power Parities and Productivity (1994)

580 (GD-19) Mulder, Nanno, Transport and Communications Output and Productivity in Brazil and the USA, 1950-1990 (1995)

581 (GD-20) Szirmai, Adam and Ren Ruoen, China's Manufacturing Performance in Comparative Perspective, 1980-1992 (1995)

GD-21 Fremdling, Rainer, Anglo-German Rivalry on Coal Markets in France, the Netherlands and Germany, 1850-1913 (December 1995)

GD-22 Tassenaar, Vincent, Regional Differences in Standard of Living in the Netherlands, 1800-1875, A Study Based on Anthropometric Data (December 1995)

GD-23 van Ark, Bart, Sectoral Growth Accounting and Structural Change in Postwar Europe (December 1995)

GD-24 Groote, Peter, Jan Jacobs and Jan Egbert Sturm, Output Responses to Infrastructure in the Netherlands, 1850-1913 (December 1995)

GD-25 Groote, Peter, Ronald Albers and Herman de Jong, A Standardised Time Series of the Stock of Fixed Capital in the Netherlands, 1900-1995 (May 1996)

GD-26 van Ark, Bart and Herman de Jong, Accounting for Economic Growth in the Netherlands since 1913 (May 1996)

GD-27 Maddison, Angus and D.S. Prasada Rao, A Generalized Approach to International Comparisons of Agricultural Output and Productivity (May 1996)

GD-28 van Ark, Bart, Issues in Measurement and International Comparison of Productivity - An Overview (May 1996)

GD-29 Kouwenhoven, Remco, A Comparison of Soviet and US Industrial Performance, 1928-90 (May 1996)

GD-30 Fremdling, Rainer, Industrial Revolution and Scientific and Technological Progress (December 1996)

GD-31 Timmer, Marcel, On the Reliability of Unit Value Ratios in International Comparisons (December 1996)

GD-32 de Jong, Gjalt, Canada's Post-War Manufacturing Performance: A Comparison with the United States (December 1996)

GD-33 Lindlar, Ludger, "1968" and the German Economy (January 1997)

GD-34 Albers, Ronald, Human Capital and Economic Growth: Operationalising Growth Theory, with Special Reference to The Netherlands in the 19th Century (June 1997)

GD-35 Brinkman, Henk-Jan, J.W. Drukker and Brigitte Slot, GDP per Capita and the Biological Standard of Living in Contemporary Developing Countries (June 1997)

GD-36 de Jong, Herman, and Antoon Soete, Comparative Productivity and Structural Change in Belgian and Dutch Manufacturing, 1937-1987 (June 1997)

GD-37 Timmer, M.P., and A. Szirmai, Growth and Divergence in Manufacturing Performance in South and East Asia (June 1997)

GD-38 van Ark, B., and J. de Haan, The Delta-Model Revisited: Recent Trends in the Structural Performance of the Dutch Economy (December 1997)

GD-39 van der Eng, P., Economics Benefits from Colonial Assets: The Case of the Netherlands and Indonesia, 1870-1958 (June 1998)

GD-40 Timmer, Marcel P., Catch Up Patterns in Newly Industrializing Countries. An International Comparison of Manufacturing Productivity in Taiwan, 1961-1993 (July 1998)

GD-63   Stuivenwold, Edwin and Marcel P. Timmer, Manufacturing Performance in Indonesia, South Korea and Taiwan before and after the Crisis; An International Perspective, 1980-2000 (July 2003)

GD-64   Inklaar, Robert, Harry Wu and Bart van Ark, "Losing Ground", Japanese Labour Productivity and Unit Labour Cost in Manufacturing in Comparison to the U.S. (July 2003)

GD-65   van Mulligen, Peter-Hein, Alternative Price Indices for Computers in the Netherlands using Scanner Data (July 2003)

GD-66   van Ark, Bart, The Productivity Problem of the Dutch Economy: Implications for Economic and Social Policies and Business Strategy (September 2003)

GD-67   Timmer, Marcel, Gerard Ypma and Bart van Ark, IT in the European Union, Driving Productivity Divergence?

GD-68   Inklaar, Robert, Mary O'Mahony and Marcel P. Timmer, ICT and Europe's Productivity Performance, Industry-level Growth Accounts Comparisons with the United States (December 2003)

GD-69   van Ark, Bart and Marcin Piatkowski, Productivity, Innnovation and ICT in Old and New Europe (March 2004)

GD-70   Dietzenbacher, Erik, Alex Hoen, Bart Los and Jan Meist, International Convergence and Divergence of Material Input Structures: An Industry-level Perspective (April 2004)

GD-71   van Ark, Bart, Ewout Frankema and Hedwig Duteweerd, Productivity and Employment Growth: An Empirical Review of Long and Medium Run Evidence (May 2004)

GD-72   Edquist, Harald, The Swedish ICT Miracle: Myth or Reality? (May 2004)

GD-73   Hill, Robert and Marcel Timmer, Standard Errors as Weights in Multilateral Price Indices (November 2004)

GD-74   Inklaar, Robert, Cyclical productivity in Europe and the United States, Evaluating the evidence on returns to scale and input utilization (April 2005)

GD-75   van Ark, Bart, Does the European Union Need to Revive Productivity Growth? (April 2005)

GD-76   Timmer, Marcel and Robert Inklaar, Productivity Differentials in the US and EU Distributive Trade Sector: Statistical Myth or Reality? (April 2005)

GD-77   Fremdling, Rainer, The German Industrial Census of 1936: Statistics as Preparation for the War (August 2005)

GD-78   McGuckin, Robert and Bart van Ark, Productivity and Participation: An International Comparison (August 2005)

GD-79   Inklaar, Robert and Bart van Ark, Catching Up or Getting Stuck? Europe's Troubles to Exploit ICT's Productivity Potential (September 2005)

GD-80   van Ark, Bart, Edwin Stuivenwold and Gerard Ypma, Unit Labour Costs, Productivity and International Competitiveness (August 2005)

GD-81   Frankema, Ewout, The Colonial Origins of Inequality: Exploring the Causes and Consequences of Land Distribution (July 2006)

GD-82   Timmer, Marcel, Gerard Ypma and Bart van Ark, PPPs for Industry Output: A New Dataset for International Comparisons (March 2007)

GD-83   Timmer, Marcel and Gerard Ypma, Productivity Levels in Distributive Trades: A New ICOP Dataset for OECD Countries (April 2005)

GD-85   Ypma, Gerard, Productivity Levels in Transport, Storage and Communication: A New ICOP 1997 Data Set (July 2007)

GD-86   Frankema, Ewout, and Jutta Bolt, Measuring and Analysing Educational Inequality: The Distribution of Grade Enrolment Rates in Latin America and Sub-Saharan Africa (April 2006)

GD-87   Azeez Erumban, Abdul, Lifetimes of Machinery and Equipment. Evidence from Dutch Manufacturing (July 2006)

GD-88   Castaldi, Carolina and Sandro Sapio, The Properties of Sectoral Growth: Evidence from Four Large European Economies (October 2006)

GD-89   Inklaar, Robert, Marcel Timmer and Bart van Ark, Mind the Gap! International Comparisons of Productivity in Services and Goods Production (October 2006)

GD-90   Fremdling, Rainer, Herman de Jong and Marcel Timmer, Censuses compared. A New Benchmark for British and German Manufacturing 1935/1936 (April 2007)

GD-91   Akkermans, Dirk, Carolina Castaldi and Bart Los, Do 'Liberal Market Economies' Really Innovate More Radically than 'Coordinated Market Economies'? Hall & Soskice Reconsidered (March 2007)

GD-93   Frankema, Ewout and Daan Marks, Was It Really "Growth with Equity" under Soeharto? A Theil Analysis of Indonesian Income Inequality, 1961-2002 (July 2007)

GD-94a   Fremdling, Rainer, (Re)Construction Site of German Historical National Accounts: Machine Building: A New Benchmark before World War I (July 2007)

GD-94b   Fremdling, Rainer, (Re)Construction Site of German Historical National Accounts: German Industrial Employment 1925, 1933, 1936 and 1939: A New Benchmark for 1936 and a Note on Hoffmann's Tales (July 2007)

GD-94c   Fremdling, Rainer, (Re)Construction Site of German Historical National Accounts: German Agricultural Employment, Production and Labour Productivity: A New Benchmark for 1936 and a Note on Hoffmann's Tales (January 2008)

GD-95   Feenstra, Robert C., Alan Heston, Marcel P. Timmer and Haiyan Deng, Estimating Real Production and Expenditures Across Nations: A Proposal for Improving the Penn World Tables (July 2007)

GD-96   Erumban, Abdul A, Productivity and Unit Labor Cost in Indian Manufacturing A Comparative Perspective (October 2007)

GD-97   Wulfgramm, Melike, Solidarity as an Engine for Economic Change: The impact of Swedish and US political ideology on wage differentials and structural change (June 2007)

GD-98   Timmer, Marcel P. and Gaaitzen J. de Vries, A Cross-country Database For Sectoral Employment And Productivity in Asia and Latin America, 1950-2005 (August 2007)

GD-99   Wang, Lili and Adam Szirmai, Regional Capital Inputs in Chinese Industry and Manufacturing, 1978-2003 (April 2008)

GD-100   Inklaar, Robert and Michael Koetter, Financial dependence and industry growth in Europe: Better banks and higher productivity (April 2008)

GD-101   Broadberry, Stephen, Rainer Fremdling and Peter M. Solar, European Industry, 1700-1870 (April 2008)

GD-102   Basu, Susanto, Robert Inklaar and J. Christina Wang, The Value of Risk: Measuring the Service Output of U.S. Commercial Banks, (May 2008)

GD-103 Inklaar, Robert, The Sensitivity of Capital Services Measurement: Measure all assets and the cost of capital, (May 2008)

GD-104 Inklaar, Robert and Marcel P. Timmer, GGDC Productivity Level Database: International Comparisons of Output, Inputs and Productivity at the Industry Level (September 2008)

GD-105 De Vries, Gaaitzen J., Did Liberalization Start A Retail Revolution In Brazil? (October 2008)

GD-106 Fremdling, Rainer and Reiner Stäglin, An Input-Output Table for Germany and a New Benchmark for German Gross National Product in 1936 (January 2009)

GD-107 Smits, Jan-Pieter , Pieter Woltjer and Debin Ma, A Dataset on Comparative Historical National Accounts, ca. 1870-1950: A Time-Series Perspective (March 2009)

GD-108 De Jong, Herman and Pieter Woltjer, A Comparison of Real Output and Productivity for British and American Manufacturing in 1935 (March 2009)