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Challenges for productivity measurement in OECD countries

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Introduction

1. Productivity growth is the basis for improvements in real incomes and welfare. Slow productivity growth limits the rate at which real incomes can improve, and also increases the likelihood of conflicting demands concerning the distribution of income (Englander and Gurney, 1994). Measures of productivity growth and of productivity levels therefore constitute important economic indicators.

2. In principle, productivity is a rather straightforward indicator. It describes the relationship between output and the inputs that are required to generate that output. Despite its apparent simplicity, several problems arise when measuring productivity. These issues are particularly important for comparing productivity growth across countries, whether for the entire economy or for different industries, and for comparing productivity levels internationally. Some of these measurement difficulties are closely related to technological developments - currently of great interest. For example, assessing the role of information and communication technology (ICT) in productivity growth requires the construction of accurate price and quantity indices of ICT products that are internationally comparable. Other issues, such as the measurement of labour input, have been around for much longer, but remain important. The most important productivity measurement issues have recently been brought together in the *OECD Productivity Manual* (OECD, 2001*a*) and part of the discussion below draws on this manual.

3. There are many different measures of productivity growth. The choice between them depends on the purpose of productivity measurement and, in many instances, on the availability of data. Broadly, productivity measures can be classified as single-factor productivity measures (relating a measure of output to a single measure of input) or multi-factor productivity measures (relating a measure of output to a bundle of inputs).[1] Another distinction, of particular relevance at the industry or firm level is between productivity measures that relate gross output to one or several inputs and those which use a value-added concept to capture movements of output.

4. Table 1 uses these criteria to enumerate the main productivity measures. The list is incomplete insofar as single productivity measures can also be defined over intermediate inputs and labour-capital multi-factor productivity can, in principle, be evaluated on the basis of gross output. However, in the interest of simplicity, the table was restricted to the most frequently used productivity measures. These are measures of labour and capital productivity, and multi-factor productivity measures (MFP), either in the form of capital-labour MFP, based on a value-added concept of output, or in the form of capital-labour-energy-materials-services MFP (KLEMS), based on a concept of gross output. Among those measures, value-added-based labour productivity is the single most frequently computed productivity statistic, followed by capital-labour MFP and KLEMS MFP.

5. A full discussion of the entire set of productivity measures would go beyond the scope of this paper. The following pages will therefore highlight some key measurement issues associated with productivity growth. The next section starts out with a brief review of the theoretical foundations for labour productivity and multi-factor productivity measures, and then goes on to discuss measurement of output, labour and capital inputs. The last section briefly discusses the interpretation of measures of productivity growth.

1. Multi-factor productivity is sometimes referred to as total factor productivity. Multi-factor productivity implies that several factors are included as inputs, though not necessarily all. Total factor productivity suggests that all possible factors are included. In practice, this is seldom the case.

Table 1: Overview of the main productivity measures

Type of output measure:	*Type of input measure*			
	Labour	***Capital***	***Capital & labour***	***Capital, labour & intermediate inputs (energy, materials, services)***
Gross output	Labour productivity (based on gross output)	Capital productivity (based on gross output)	Capital - labour MFP (based on gross output)	KLEMS multi-factor productivity
Value-added	Labour productivity (based on value-added)	Capital productivity (based on value-added)	Capital – labour MFP (based on value-added)	-
	Single factor productivity measures		***Multi-factor productivity (MFP) measures***	

Measuring productivity growth

Labour productivity and multi-factor productivity – concepts and relevance

6. The simplest and most frequently used measure of productivity is labour productivity. The level of labour productivity is measured as a ratio between output (Q) and hours worked (L):

$$\text{Labour productivity (LP)} = \frac{Q}{L}.$$

7. Labour productivity can be computed at various levels of aggregation: for individual firms, industries, industry groupings such as manufacturing and for the economy as a whole. Statistical offices are rarely, if ever, concerned with productivity measures for individual units but do take interest in productivity measures at higher levels of aggregation.

8. Labour productivity measures indicate how efficiently labour is used in production. It is important to note that a change in labour productivity does not necessarily mean that labour is used more intensively, i.e., that the effort per worker has changed. As is further explained below, there are several other factors – potentially more important - that influence labour productivity growth.

Multi-factor productivity measures

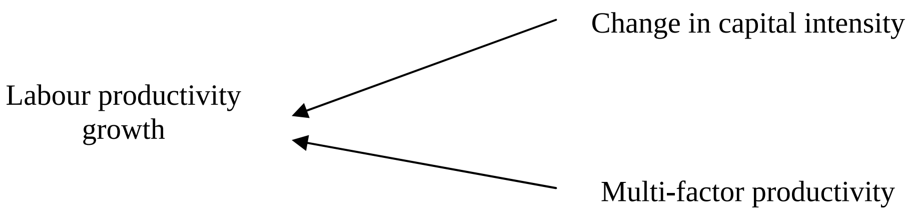
9. Labour productivity is a single (partial) productivity measure that is not based on any specific economic theory. Multi-factor productivity (MFP) measures reflect how efficiently combined labour and capital inputs are used to generate output and MFP measures are based on economic theory. In 1957, Robert Solow formulated productivity measures in a production function context and linked them to the analysis of economic growth. The field has developed considerably since and now offers a consistent approach that integrates the theory of the firm, index number theory and national accounts. Robert Solow’s growth accounting approach identifies the contributions of different inputs to output growth. In its simplest form, where output Q is measured as deflated value-added and inputs are confined to labour L and capital services K, the growth accounting equation can be stated as:

$$\ln\left(\frac{Q^t}{Q^{t-1}}\right) = s_L \ln\left(\frac{L^t}{L^{t-1}}\right) + s_K \ln\left(\frac{K^t}{K^{t-1}}\right) + \ln\left(\frac{A^t}{A^{t-1}}\right)$$

10. In this expression, labour and capital each contribute to value-added growth and their contribution is measured as the rate of change of each input times its share in total costs. The change in value added that is not explained by these contributions is attributed to multi-factor productivity growth, captured by the variable A. Thus, the rate of change of A is measured residually, i.e. by subtracting the contributions of labour and capital from the rate of output growth. Another, useful way of presenting the growth accounting equation is in terms of a decomposition of the rate of change of labour productivity.

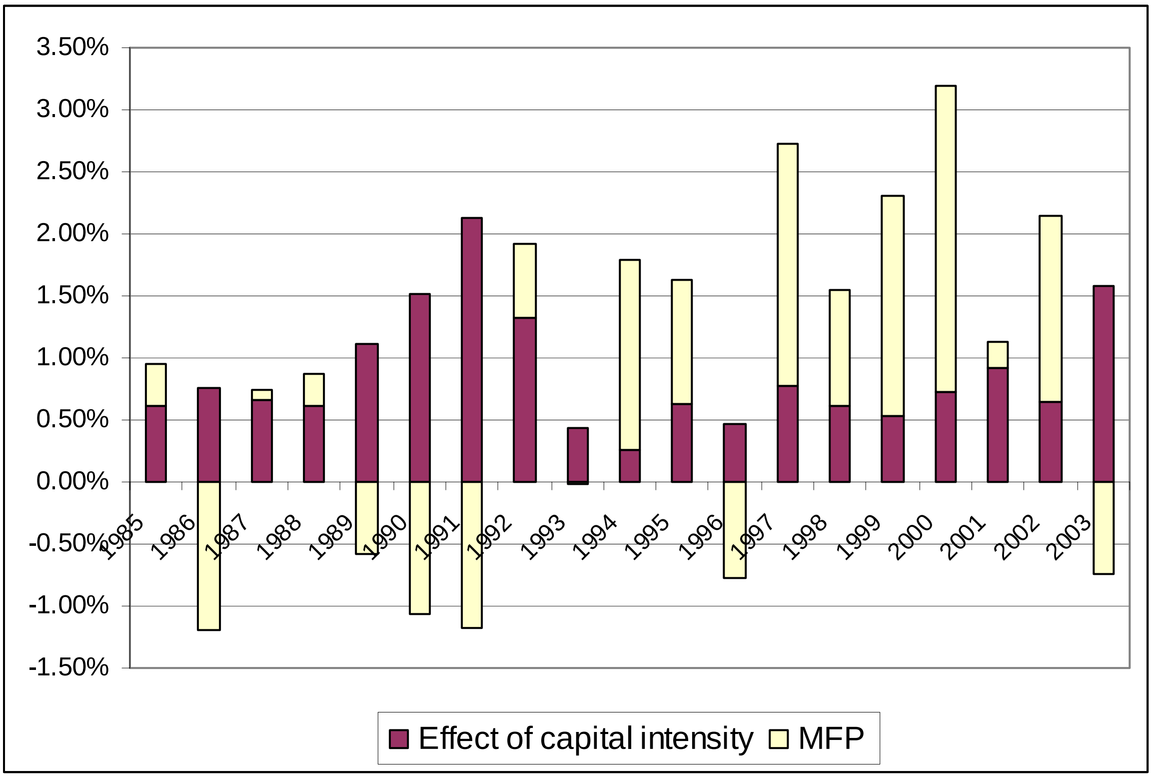
11. Labour productivity growth is measured as the difference between the rate of change of output growth and the rate of change of labour input growth, or as $\ln(Q^t / Q^{t-1}) - \ln(L^t / L^{t-1})$. Re-arranging the above expression gives a decomposition of the movement in labour productivity into two components. The first depicts the change in labour productivity due to capital deepening (labour productivity rises when more capital is used per worker) and the second shows the effects of MFP growth:

$$\ln\left(\frac{Q^t}{Q^{t-1}}\right) - \ln\left(\frac{L^t}{L^{t-1}}\right) = (1-s_L)\left(\ln\left(\frac{K^t}{K^{t-1}}\right) - \ln\left(\frac{L^t}{L^{t-1}}\right)\right) + \ln\left(\frac{A^t}{A^{t-1}}\right).$$



12. As an example, Figure 1 presents this decomposition for Canada. It shows that up to the early 1990s, capital deepening has played an important role in explaining labour productivity growth. This does not imply that investment has been unimportant in the process of growth. For instance, if output growth is driven both by capital and employment growth, capital intensity remains stable. During the 1990s, on the other hand, there was a clear dominance of MFP growth, only reverted in 2003. The identification of the sources of growth is of interest for policy-makers because it helps understanding whether labour productivity growth is driven by investment in ‘traditional’ capital or whether innovation, organisational change and the effects of R&D – all drivers of MFP – account for changes in labour productivity.

Figure 1: Decomposition of labour productivity, Canada
Total economy, percentages



Source: OECD Productivity Database 9 Nov. 2004.

Measuring output

13. Quantity indices of output are normally obtained by dividing a current-price series or index of output by an appropriate price index (*i.e.* by deflation). Only in a few instances are quantity measures derived by direct observation of volume output series. Measurement of volume output is therefore often tantamount to constructing price indices – a task whose full description far exceeds the scope of the present paper. Some of the more difficult issues associated with the deflation of output are nevertheless mentioned here.

14. Independence of measures of output from measures of input. An important precondition for the validity of productivity measures is that price and quantity indices of output should be constructed independently of price and quantity indices of inputs. Such dependence occurs, for example, when quantity indices of outputs are extrapolated using quantity indices for one or several inputs. The quantity indicators used are often inputs to the industry under consideration, in particular observations on employment.

15. In other instances, output-related measures are used to extrapolate real value-added. Though often imperfect, it is apparent that the implied bias for productivity measurement is less severe than in the case of input-based extrapolation. For example, Eldridge (1999) reports that, in the United States, the quantity indicator for auto insurance expenditure is the deflated value of premiums, where deflation itself is based on a component index of the CPI. In other instances, physical output data are used as the quantity indicator; the United States quantity indicator for brokerage charges is based primarily on BEA estimates of orders derived from volume data from the Security and Exchange Commission and trade sources.

16. From the perspective of productivity measurement, the independence of statistics on inputs and outputs is key. Using input-based indicators to construct output series generates an obvious bias in productivity measures; productivity growth will reflect whatever assumption about productivity growth was made by statisticians in constructing the output series (*e.g.* that labour productivity was unchanged). Occurrences of input-based extrapolation are concentrated in activities where market output prices are difficult to observe. For this reason, input-based extrapolation is more frequent and quantitatively more important for service industries than for other parts of the economy and can lead to biased productivity measures.

17. Quality change. The rapid development of information and communication technology products has brought to centre-stage two long-standing questions for the construction of price indices: how to deal with quality changes of existing goods and how to account for new goods (see Triplett 2004). The distinction between these two issues is blurred because it is unclear where to draw the borderline between a 'truly' new good and a new variety of an existing good.

18. Typically, statistical agencies derive price indices for products by observing price changes of items in a representative sample. New products, quality changes and new variants are common phenomena in the observation of price changes of items and statistical offices have well-established procedures to deal with them. Unfortunately, these methods are not the same across countries and sometimes yield implausibly large differences. The most widely quoted case is price indices for information and communications technology products such as computers. Their prices decline by between 30% per year in the United States, and about 5 % per year in a number of European countries. Given the homogeneity and international tradability of these products, it is likely that some of the differences are due to statistical methods rather than actual price developments. In the present context, the question arises: how much do these differences matter for comparisons of measures of output?

Labour input

19. Different measures of employment. In the spirit of production theory, labour input for an industry is most appropriately measured as the quality-adjusted number of hours actually worked. The simplest, though least recommended, measure of labour input is a head count of jobs or employees. Such a measure fails to reflect changes in average work time per employee, multiple job holding (when the number of employees is the measure), self-employment and the quality of labour.

20. A first refinement to this measure is its extension to total employment, comprising both wage and salary earners, and the self employed (including contributing family members). A second refinement is the conversion from simple job (or person) counts to estimates of total 'hours actually worked'. Rates of change of the number of persons employed differ from the rates of change of total hours worked when the number of average hours worked per person shifts over time. Such shifts may be due to a move towards more paid vacations, shorter 'normal' hours for full-time workers and greater use of part-time work. Moreover, hours worked will also vary over the business cycle as labour demand rises and falls. These developments have taken place in many OECD countries and underline the importance of choosing 'hours actually worked' as the variable for labour input in productivity measurement because it bears a closer relation to the amount of productive services provided by workers than simple head counts.

21. An example of the impact on labour productivity measures of choosing different measures for employment is given in Figure 2 below. For France, for the period 1987-98, labour productivity indices were calculated using total hours, the number of full-time equivalent persons, the number of employed persons (head counts) and the number of employees (head counts). Results are presented for industry (comprising mining, manufacturing and construction) and for market services. Not surprisingly, the

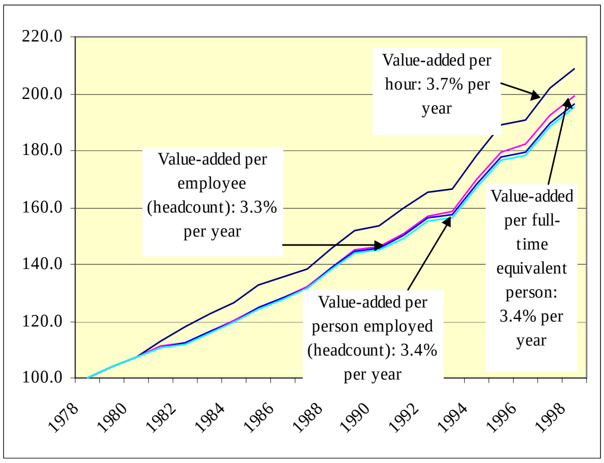
productivity measures based on total hours rise significantly faster than those based on other employment measures. In manufacturing, moving from head counts to full-time equivalent measures hardly changes the productivity series. This is quite different for the service sector where part-time employment has grown rapidly in many countries and now plays an important role in total employment. Even more pronounced are the effects of including or excluding the self-employed in the service sector, as reflected by the differences in productivity estimates based on total employment and based on the number of employees only.

22. Full-time equivalent jobs (or persons) are another variable sometimes used for measuring labour input. By definition, full-time equivalent employment is the number of total hours worked divided by average annual hours actually worked in full-time jobs. Conceptually, then, in full-time equivalent measures part-time employed persons are counted with a smaller weight than persons working full time. Consequently, the full-time equivalent measure should avoid the bias arising from a shifting share of part-time employment in the work force but will not adjust for changes in the number of hours which constitutes a full-time job, *e.g.* as a consequence of changes in legislation or collective agreements. In addition, methodologies underlying the construction of full-time equivalent persons (or jobs) are not always transparent and may vary internationally. For example, in some cases full-time equivalents are based on crude estimates, such as counting each part-time job (often defined as any job with less than normal working hours) as half a full-time job.

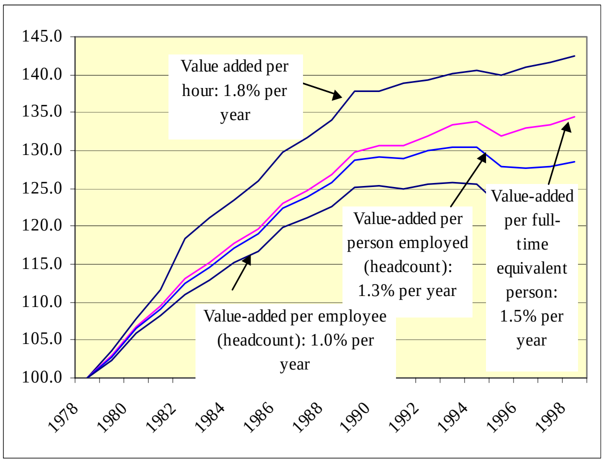
23. ***Statistical sources.*** There are two main statistical sources for measures of labour input: household-based labour force surveys (LFS) and establishment or firm-based surveys (ES). LFS are typically conducted from a socio-economic perspective to provide reliable information about personal characteristics of the labour force, such as educational attainment, age, or the occurrence of multiple job holding, as well as information about the jobs (*e.g.* occupation and type of contract). Also, LFS have the advantage of full coverage of the economy. ES are conducted from a production perspective, and describe labour as an input factor. One distinguishing feature of establishment surveys is that they gather information on jobs rather than on persons employed, thus persons who have jobs in more than one establishment will be counted more than once. Another feature is that ES will often only cover a subset of all establishments in an industry, normally those above a certain size limit. If establishments included in the survey have systematically higher productivity levels than those excluded, productivity estimates based on ES will inadequately reflect the effects of the size composition in an industry.

Figure 2: Labour productivity* based on different measures of employment in France

Industry (mining, manufacturing and construction)



Market services



*Output is measured as a quantity index of value-added.
Source: INSEE.

24. In a few OECD countries (*e.g.* the Netherlands), statistical offices fully consolidate the two sources into a single, final set of labour accounts. In most countries, both sources are used to construct employment data for national accounts (NA). As such, these NA data qualify as the preferred source for productivity analysis. However, NA statistics often stop short of producing all the relevant labour input measures (in particular hours worked) or such variables are not available at the required sectoral detail. In such cases, multiple sources sometimes have to be combined, although this introduces the risk of not comparing like with like. One such example is the application of data on average hours worked per person, based on LFS, to NA-based statistics on the number of persons employed. This may be acceptable for purposes of constructing measures of productivity *growth* but can create important non-comparabilities when measuring productivity *levels*.

25. The measurement of labour input is also very important for international comparisons of labour productivity levels. Employment statistics are quite well standardised across OECD countries as most countries provide labour force statistics along agreed guidelines. In principle, therefore, they pose few problems for international comparisons. The main difficulty is to ensure that the employment data are consistent in coverage with other data that are required to make comparisons of productivity, notably GDP and hours worked.

26. There are two issues that arise here. The first question is whether countries integrate estimates of force surveys and enterprise statistics, and would, in principle, be more consistent with GDP than estimates relying on only one single source. In practice, not all OECD countries integrate employment statistics in the national accounts, implying that labour force statistics remain the most comparable source.

27. The second, closely related, problem is whether estimates of hours worked are consistent with the employment data. Estimates of hours worked are typically based on two alternative sources, labour force surveys and enterprise statistics. Labour force surveys are based on surveys of households, whereas enterprise statistics survey firms. Both sources seem to have some advantages and disadvantages for comparisons of productivity levels (OECD, 1999*a*; Van Ark and McGuckin, 1999):

- Labour force surveys may underestimate absences due to illness and holidays.

- Evidence on time use related to labour force surveys suggests that persons who work long hours may overestimate their working time.

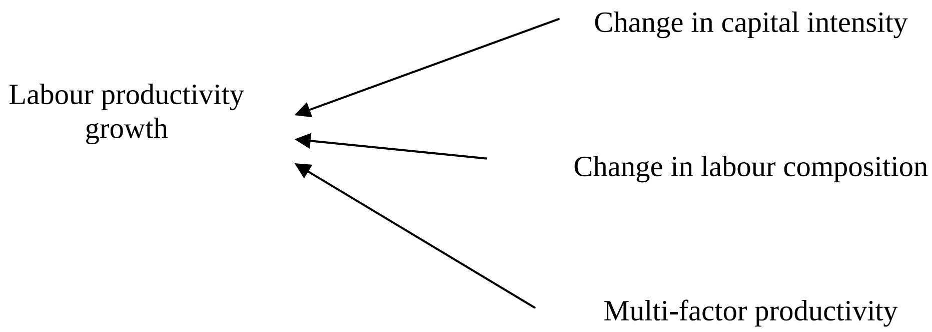
- Labour force surveys potentially pick up extra hours worked by managers and professionals that are over and above the conventional hours of work in an establishment and that are clearly not picked up by establishment sources.

- Enterprise statistics are less likely to provide full coverage of all persons engaged in the economy, and may underestimate overtime.

28. In principle, this suggests that labour force surveys may somewhat overestimate total hours worked, whereas enterprise surveys may underestimate hours worked. Much depends on the quality and coverage of the surveys, however, and several OECD countries provide comprehensive estimates of hours worked based on a mix of sources. The OECD has recently produced estimates of hours worked that draw on such a mix of sources, where hours worked estimates from labour force surveys were adjusted downwards to compensate for known biases (Scarpetta, et al., 2000). Cross-country comparability can thus be improved as compared to the use of original national sources for some countries, but there remains a margin of uncertainty.

29. Skill composition of labour. Labour input reflects the time, effort and skills of the work force. While data on hours worked capture the time dimension, they do not reflect the skill dimension. When total hours worked are the simple sum of all hours of all workers, no account is taken of the heterogeneity of labour. For the estimation of productivity changes, the question is whether, over time, the composition of the labour force changes, *i.e.*, whether there is an increase or decrease in the average quality of labour input. By most measures, there has been a steady increase in the quality of labour (OECD, 1998*a*). An increase in the average quality of labour implies that a quality-adjusted measure of labour input would rise faster than an unadjusted measure of labour input. Successful quality-adjustment is tantamount to measuring labour in constant-quality units. In the context of productivity measurement, Jorgenson *et al.* (1987), Denison (1985) and the U.S. Bureau of Labor Statistics (BLS, 1993) have tackled this issue

30. Measuring constant-quality labour input is interesting from several perspectives. First, it provides a more accurate indication of the contribution of labour to production. One recalls that MFP measures the residual growth in output that cannot be explained by the rate of change in the services of labour, capital and intermediate inputs. When quality-adjusted measures of labour input are used in growth accounting instead of unadjusted hours worked, a larger share of output growth will be attributed to the factor labour instead of the residual factor productivity growth. In other words, substituting quality-adjusted labour input measures for unadjusted measures can better identify the sources of growth, by distinguishing between externalities or spill-overs -- captured by the productivity residual -- and the effects of investment in human capital.



31. Second, a comparison of an adjusted and unadjusted measure of labour input yields a measure of the corresponding compositional or quality change of labour input. This can usefully be interpreted as one aspect of the formation of human capital, and is thus a step towards measuring the effects of intangible investment. It also brings in another determinant of labour productivity growth that helps decomposing the sources of growth. Changes in labour composition have, for example, been an important factor in explaining labour productivity growth in France during the 1990s.

32. However, even when labour input is differentiated only by a simple trait, such as occupation, information requirements are severe: data are needed that distribute the number of total hours worked across different occupations, by individual industry and by individual year. In addition, quantity measures of labour input (*i.e.* hours worked) have to be accompanied by price measures (*i.e.* relative average compensation) to construct weights for aggregation. Such rich data sets are normally both difficult and costly to collect and therefore not readily available in practice.

33. Even when such data are not available, "implicit differentiation" can provide a useful, albeit incomplete, adjustment for labour quality. Implicit differentiation arises when labour input (*i.e.* total hours worked) is measured by detailed industry without, however, distinguishing between different types of labour within each industry. If the rate of change in hours worked by industry are aggregated to the economy-wide level using each industry's share in total labour compensation as its aggregation weight, these weights will be relatively large for industries that pay above-average wages and relatively small for industries with below-average wages. Assuming that above-average wages reflect an above-average skill composition of the work force, some of the quality change of labour input is implicitly taken into account. Statistics Canada's industry-level productivity statistics provide an example of implicit differentiation, since the indices of labour input at the sectoral level are built up from hours-worked data for more detailed industries that are weighted by their shares in total sectoral labour compensation.

Capital input

34. In a production process, labour, capital and intermediate inputs are combined to produce one or several outputs. Conceptually, many facets of capital input measurement are directly analogous to labour input measurement. Capital goods, whether purchased or rented by a firm, provide a flow of capital services that constitutes the actual input to the production process. Similarly, employees hired for a certain period can be seen as providing flows of labour services from their stocks of human capital. Differences between labour and capital arise because producers usually own capital goods. When the capital good

‘delivers’ services to its owner, no market transaction is recorded. The measurement of these implicit transactions – whose quantities are the services drawn from the capital stock during a period and whose prices are the user costs or rental prices of capital – is one of the challenges of capital measurement.

35. Constructing measures of capital services. Conceptually, capital services reflect a quantity or physical concept that should not to be confused with the value or price concept of capital. Because flows of the quantity of capital services are not usually directly observable, they have to be approximated. Most often, this is done by assuming that service flows are in proportion to the stock of assets, after each vintage has been converted into standard ‘efficiency’ units. The capital stock, so computed, is sometimes referred to as the ‘productive stock’ of a given type of asset. Accordingly, the importance of capital stock measures to productivity analysis derives solely from the fact that they offer a practical tool to estimate flows of capital services – were the latter directly observable, there would be no need to measure capital stocks.

36. Several measures of capital frequently encountered in economic statistics do not provide estimates of capital services suited to use in measuring productivity. These include the net or wealth capital stock, which is the current market valuation of an industry’s or a country’s productive capital. One of the purposes of the wealth stock is to measure economic depreciation, *i.e.* the loss in value of an asset as it ages. Total depreciation across all vintages of an asset is exactly the amount by which the value of the net capital stock of an asset declines as an effect of ageing. However, the wealth stock is not the appropriate tool to capture the quantity side of capital services.

37. The ‘gross capital stock’ is a closely related capital measure. It represents the cumulative flow of investments, corrected only for the retirement of capital goods, but based on the assumption that an asset’s productive capacity remains fully intact until the end of its service life (sometimes called ‘one-hoss-shay’). For a single, homogenous asset, the gross capital stock can be considered a special case of the productive stock, where an asset loses nothing of its physical productive capacity until it is retired.

38. In empirical applications, the growth rate of capital services typically exceeds that of the wealth stock. Using the wealth stock as a measure of capital input in productivity calculations would thus imply an overstatement of MFP growth compared with the MFP associated with capital services (see below). On the other hand, gross capital stock measures in productivity calculations potentially lead to an understatement of MFP growth, as gross stocks grow more rapidly than capital services.

39. The price of capital services is measured by their rental price. If there were complete markets for capital services, rental prices could be directly observed. In the cases of, for example, office buildings or cars, rental prices do exist and are observable in the market. However, this is not the case for many other capital goods that are owned by producers and for which rental prices have to be imputed. The implicit rent that capital good owners ‘pay’ themselves gives rise to the terminology ‘user costs of capital’.

40. Because many different types of capital goods are used in production, an aggregate measure of the capital stock or of capital services must be constructed. For net (wealth) stocks this is a straightforward matter of summing estimates for different types of assets. In so doing, market prices serve as aggregation weights. The situation is different in productivity analysis. Typically, each type of asset is associated with a specific flow of capital services and strict proportionality is assumed between capital services and capital stocks at the level of individual assets. This ratio is not the same, however, for different kinds of assets, so that the aggregate stock and the flows covering different kinds of assets must diverge. A single measure cannot serve both purposes except when there is only one single homogenous capital good (Hill, 1999*a*).

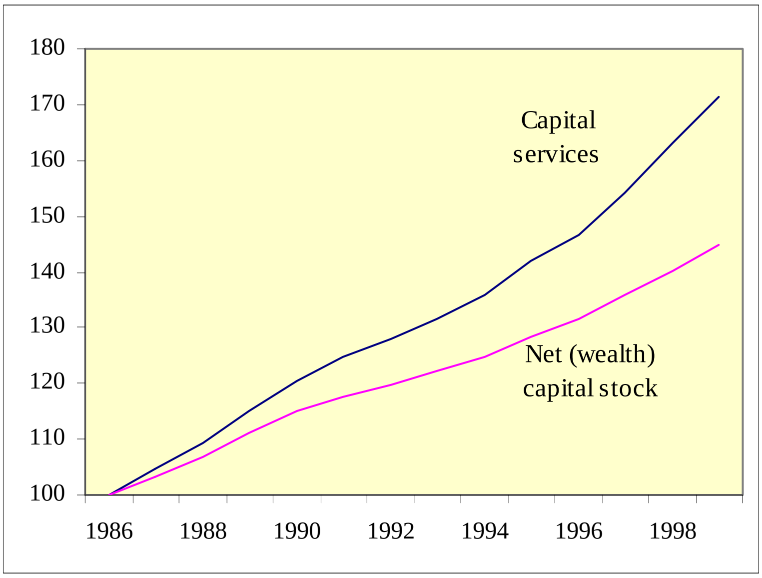
41. Under competitive markets and equilibrium conditions, user costs reflect the marginal productivity of the different assets. User cost weights thus provide a means to effectively incorporate

differences in the productive contribution of heterogeneous investments as the composition of investment and capital changes. Jorgenson (1963) and Jorgenson and Griliches (1967) were the first to develop aggregate capital service measures that take the heterogeneity of assets into account. They defined the flow of quantities of capital services individually for each type of asset, and then applied asset-specific user costs as weights to aggregate across services from the different types of assets.

42. Figure 3 shows an example for the differences in capital measures that arise from the two concepts. Over the period under consideration, the capital services measure in Australia grew at a significantly faster pace than the wealth measure in that same country. To explain, note that wealth measures are based on an aggregation across different assets where each asset is weighted by its market price. The weights that are used to construct capital service measures are higher for short-lived assets than for long-lived ones: one dollar invested in a short-lived asset must yield a higher return per year than a dollar invested in a long-lived asset to make that investment worthwhile. If shorter-lived assets grow more rapidly than longer-lived ones, the measure of capital services will grow faster than the wealth measure.

43. This feature can also be found in other countries, in particular the United States (Dean *et al.* 1996). It implies that the choice of the capital measure may have non-negligible impacts on measured productivity growth. For example, Australia's multi-factor productivity grew by an annual average rate of 2.0% over the period 1995-99, when based on a capital services measure. The capital services indicator grew by 4.7% per year over the same period, whereas the net (wealth) capital stock measure only showed a 3.1% rise. Assuming a capital share of about 0.3, the resulting 1.6 percentage point difference implies approximately a 0.5 percentage point adjustment to the MFP measure (0.3 x 1.6% = 0.48%). Thus, based on net stock rather than a measure of capital services, Australia's MFP growth would have been evaluated at 2.5% over the years 1995-99, and hence over-estimated compared with the correct capital services measure; too large a share of output growth would have been attributed to a change in MFP rather than to an increased contribution of physical capital to output.

Figure 3 Capital services and net capital stock measures
Australia, 1986-99



Source: Australian Bureau of Statistics.

44. ***Capital and capacity utilisation***. There are many reasons why the rate of utilisation of capital, or more generally, the rate of utilisation of capacity of a firm varies over time: a change in demand conditions, seasonal variations, interruptions in the supply of intermediate products or a breakdown of machinery are all examples of factors that lead to variations in the flow of capital services drawn from a stock of assets. And yet, it is frequently assumed (for want of better information on utilisation rates) that the flow of services is a *constant* proportion of the capital stock. This is one of the reasons for the pro-cyclical behaviour of productivity series: variations in output are reflected in the data series, but the corresponding variations in the utilisation of capital (and labour) inputs are inadequately captured. If machine hours were measured, adjustments could be made. However, in practice, the required data rarely exist and consequently, swings in demand and output are picked up by the residual productivity measure. There have been several attempts to deal with this issue, but a generally accepted solution has yet to be found.

Index numbers

45. Productivity is usually measured as the ratio of a quantity index of output to a quantity index of inputs. Indices are required because the heterogeneity of goods and services does not permit simply adding up units of different types of commodities. However, aggregation results are in general sensitive to the choice of a specific index number formula. These formulae should therefore be chosen carefully on both conceptual and practical grounds.

46. A first choice that must be made for comparisons over several periods is whether to compare two periods directly (say, between period 0 and period 2), or indirectly (in which case the change between period 0 and 2 is derived from the change between period 0 and 1, combined with that from period 1 to 2). The economics literature, as well as the 1993 System of National Accounts, are quite unanimous that inter-temporal comparisons over longer periods should be obtained by chaining, *i.e.* by linking the year-to-year movements. The main reason for chaining is that it allows one to adopt weights that reflect economic behaviour: for example, a relative price fall of a good will typically lead to higher consumption of this good and changes in the expenditure share of this item. Chained indices reflect such changes in expenditure patterns because weights are regularly updated. When indices are based on weights that only reflect conditions in a base period that is several years away from the comparison period, there is a risk of weights being out of date and this may introduce a bias into the price or volume measure.

47. A second choice pertains to the specific index number formula. The most widely used index number formulae are the Laspeyres and Paasche indices (the former uses base-period weights, the latter current period weights), the Fisher index (a geometric average of the Laspeyres and Paasche indices) and the Törnqvist index (a weighted geometric average of its components).

The interpretation of productivity measures

48. Productivity is an important yardstick of economic performance. Different productivity measures are, however, often used without sufficient clarity about the specific measure that is being used and its correct interpretation. This section briefly touches on the most common uses made of productivity measures and possible pitfalls: the relationship between productivity growth and technological change; the link between productivity and costs; productivity over the business cycle; the difference between productivity and efficiency; the links between industry and firm-level productivity growth; and innovation and productivity growth.

The link with technological change

49. Multi-factor productivity growth is often interpreted as an indicator of technological progress. This is not entirely correct for three reasons: (i) technological change does not necessarily translate into MFP growth; (ii) MFP growth is not necessarily caused by technological change; and (iii) MFP may understate the eventual importance of productivity change in stimulating the growth of output. These three factors are discussed below.

50. Some technological change does not translate into MFP growth because embodied technological change, such as advances in the quality of new vintages of capital or improved human capital, is reflected instead in the measured contributions of capital and labour to output growth. Disembodied technical change, on the other hand, will be reflected in MFP growth as it relates to advances in scientific knowledge, and to the diffusion of knowledge on how things are done, including better management and organisational change. MFP should also include the spill-over effects from capital and labour, *e.g.* network effects arising from investment in information technology products.

51. Conceptually, and following Jorgenson (1995*a*), the MFP term reflects all those effects on output growth that are *not* investment, where investment is understood as the commitment of current resources in the expectation of future returns, implying that these returns can be internalised by the investor. The distinction is important because the diffusion of embodied technical change is dependent on market transactions: investment in the improved capital or intermediate good will be undertaken until its marginal contribution to revenue generation just equals its user cost, itself dependent on the market price of the capital good. The diffusion of disembodied technical change is not necessarily associated with market transactions. Information may circulate freely and its use by one person does not normally restrict its use by another one.

52. One notes that when the measure for the quantity of capital services used in the MFP calculation is based on a price index that reflects quality change in capital goods, embodied technological change is captured by the growth contribution of capital and not by the residual MFP. Conversely, when the capital goods price index is not adjusted for quality changes, both embodied and disembodied technological change will be picked up by the MFP residual. As Hulten (1992) showed, the embodiment part of technology can be measured by comparing capital input based on quality-adjusted price indices and capital input based on unadjusted price indices.

53. Data and resource constraints often do not permit a careful differentiation and full coverage of all labour and capital inputs. As a consequence, some of the embodiment effects of technological change and some or all of the changes in the skill composition of labour input are picked up by the MFP residual. Thus, the correct interpretation of the productivity term with respect to technological change requires knowledge about the methodology used to compute time series of capital and labour input.

54. Just as some technological change does not correspond to MFP growth, some MFP growth is not caused by technological change. Even where the residual reflects part or all of technological change, several other factors will also bear on measured MFP. Such factors include adjustment costs, economies of scale, cyclical effects, inefficiencies and measurement errors. This is confirmed by econometric studies that link MFP growth to technology variables, in particular research and development and patents or those that explicitly control for adjustment costs or allow for non-constant returns to scale. Research and development expenditure, for example, tends to show a statistically significant relation to productivity growth, but only explains a relatively small part of the overall annual movements in MFP. This indicates the presence of other factors. Measures of MFP are thus better interpreted as measures of improvements in overall efficiency than as pure expressions of technical change.

55. Finally, MFP may understate the eventual importance of productivity change in stimulating the growth of output. This reflects the fact that in growth accounting models, capital is considered an exogenous input to the production process. In a dynamic context, this is no longer the case and a feedback mechanism exists between productivity change and capital. Suppose that technical change allows more output to be produced per person. The static MFP residual measures just this effect of technical change. Typically, however, additional output per person will lead to additional savings and investment, and to a rise in the capital-labour ratio. A traditional growth accounting framework would identify this induced effect as a growth contribution of capital, although it can be traced back to an initial shift in technology. Thus, the MFP residual correctly measures the shift in production possibilities but does not capture the induced effects of technology on growth (Rymes, 1971; Hulten 2001).

The role of the business cycle in productivity growth

56. Most productivity measures are pro-cyclical, accelerating during periods of economic expansion and decelerating during periods of recession. In part, this is due to inadequate measurement. While cyclical variations in volume output tend to be measured quite accurately in economic statistics, variations in the rate of utilisation of inputs are not picked up as fully. In particular, changes in the rate of utilisation of capital equipment (*i.e.* changes in machine hours) are rarely captured in these measures. Labour input, if measured by hours actually worked, better reflects the changing rate of utilisation of manpower, but remains an imperfect measure. Consequently, increases in the rate of capacity utilisation in periods of expansion will cause output measures to show more rapid growth, but input measures may remain stable or grow less rapidly. The result is a rise in measured productivity growth. The converse holds for periods of recession.

57. Even if capacity utilisation were accurately measured, difficulties would remain in reconciling the standard productivity model with the realities of the business cycle. Much of the economic and index number theory used to guide the construction of these measures relies on long-term, equilibrium relationships. Since little or no account is taken of unforeseen events or disequilibria, the economic model of productivity measurement is more appropriately applied to periods of continued and moderate expansion, than to rapidly changing phases of the business cycle. This limitation means that year-to-year changes in productivity growth should not be interpreted *prima facie* as shifts in disembodied technology. For this purpose it is preferable to examine productivity growth patterns over longer periods of time or adjust productivity estimates for cyclical fluctuations. Moreover, it is wise not to draw strong conclusions about shifts in productivity from the evidence of just a few years.

The difference between productivity and efficiency

58. Productivity and efficiency are related, but not identical concepts. A firm or industry is considered to be inefficient if it could produce more output with existing inputs, *i.e.* the firm is not on the production possibility curve, but within it. Productivity relates the quantity of output produced to one or more inputs used in its production, irrespective of the efficiency of their use. In analysing productivity growth across countries, the difference between these two concepts allows a distinction between three different processes. First, productivity growth can result from innovative activity that results in an outward shift of the global production possibility frontier. Second, firms can improve productivity by adopting production processes and products developed elsewhere (imitation). Diffusion differs conceptually from efficiency gains, as the latter relates to improvements made in using a given technology - even when this technology is outdated by international standards. Third, productivity growth may also be due to reduced (technical) inefficiency. An inefficient firm or industry uses more resources and factor inputs than required by a particular technology, thus tying resources to low-productivity activities and reducing the overall

allocative efficiency of an economy. Understanding the reasons behind productivity growth is therefore necessary before attributing such changes to specific sources.

Innovation and productivity

59. Most approaches to measuring productivity are firmly rooted in a neo-classical equilibrium concept. Equilibrium conditions are very important because they help to guide measurement of parameters that would otherwise be difficult to identify. Although its usefulness is generally recognised, it has been argued that an equilibrium approach sits uneasily with the notion of innovation and productivity growth. Evolutionary economists (*e.g.* Dosi, 1988; Nelson and Winter, 1982; Nelson, 1981) argue that innovation and technical change occur as a consequence of information asymmetries, and market imperfections. In a quite fundamental sense, innovations and information asymmetries are one and the same phenomenon. Indeed, such asymmetries can scarcely be termed market imperfections when they are necessary conditions for any technical change to occur in a market economy (Metcalfe, 1996). The point made by evolutionary economists is that equilibrium concepts may be the wrong tools to approach the measurement of productivity change, because if there truly was equilibrium, there would be no incentive to search, research and to innovate, and there would be no productivity growth.

60. Such criticism has to be taken seriously in the interpretation and use of productivity measures. An important lesson from this debate is that accounting is not explaining the underlying causes of growth. Griliches (1997) makes a related point:

> *"We can take productivity growth calculation and allocate it in great detail to the various missed components, reducing thereby the role of the 'unallocated' residual. But this, while very instructive and valuable, only shifts the problem to a new set of questions: why was there all this investment in human capital? Will it continue? Where did the improvements in capital equipment come from? […] Real explanations will come from understanding the sources of scientific and technological advances and from identifying the incentives and circumstances that brought them about and that facilitated their implementation and diffusion. Explanation must come from comprehending the historical detail."*

61. This does not invalidate the usefulness of the standard equilibrium approach to productivity measurement, discussed in this paper, but alerts us to some of its limits. What emerges is the complementarity of approaches: growth accounting and productivity measurement allow the systematic and consistent quantification of the proximate sources of growth. It has explanatory power in that it captures the workings of supply of, demand for and substitution between categories of measurable inputs. At the same time, growth accounting has to be complemented by institutional, historical and case studies if one wants to explore the underlying causes of growth, innovation and productivity change.

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