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A Comparison of Gross Output and Value-Added Methods of Productivity Estimation

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Abbreviations

ABS	Australian Bureau of Statistics
GPO	gross product originating
MFP	multifactor productivity
OECD	Organisation for Economic Co-operation and Development
PC	Productivity Commission

1 Introduction and main points

Productivity estimates are derived as a ratio of an index of output and inputs. Output can be measured in different ways and this can lead to different estimates of productivity growth. This paper discusses different ways of measuring output and their impact on estimates of productivity growth.

Two basic measures of output are by value added and gross output. The former measure excludes intermediate inputs (materials, energy and services used up in the process of production) while the latter measure includes those inputs. Either output measure can be used to estimate labour productivity growth and multifactor productivity (MFP) growth. For example, multifactor measures can take the form of capital-labour MFP based on a value-added concept of output or a capital-labour-intermediate inputs MFP based on a gross output concept (see OECD 2001, p. 10). In the former measure, a value-added output measure is related to capital and labour as inputs. In the latter, gross output is related to capital, labour and intermediate inputs.

The difference between the two concepts of productivity growth is less pronounced at the aggregate (or national) level than it is at the sectoral or industry level. At the aggregate level, gross output-based and value-added based measures are close, only differing to the extent that intermediate inputs are sourced from imports. In proportional terms, this tends to be low. At the industry or sector level, however, intermediate usage tends to be a much higher proportion of gross output. This results in greater variation between the two measures.

The paper examines both the theoretical issues and the difference in practice that the choice of approach makes. Labour productivity measures based on gross output are sensitive to substitution between factor inputs (including labour) and intermediate inputs, particularly through outsourcing. Outsourcing leaves gross output little affected, but reduces labour input. The value-added measure is more meaningful in the presence of outsourcing and is generally favoured for estimating labour productivity.

For MFP estimates, most studies have used the value-added approach, although there are theoretical grounds for preferring the gross output approach, particularly at the industry level. Under the value-added approach, improvements in the efficiency of use of intermediate inputs are overlooked. The gross output-based measure is potentially a better indicator of the full extent of disembodied technological change. On the other hand, gross output-based measures do not provide as reliable an indication of the relative importance of industry productivity performance for aggregate MFP trends.

There are examples of studies that have used the gross output approach to compute MFP at the industry level (Jorgensen et al. 1987; Oulton and O'Mahony 1994; Gullickson and Harper 1999b; Sorensen and Fosgerau 2000; Gu and Ho 2001; Gu, Lee and Tang 2001; Baldwin et al. 2001; Gullickson and Harper 2002). The Bureau of Labor Statistics in the US publishes MFP estimates for certain industries, based on the gross output approach.

In Australia, the ABS publishes value-added based industry labour productivity estimates but no industry MFP estimates. However, it has undertaken exploratory work on measuring industry MFP based on gross output (Zheng et al. 2002).

2 The value-added measure

The value-added approach has considerable advantages because it is a simple measure that ignores the difficulties of dealing with inter-industry and intra-industry flows of goods and services. Intermediate inputs are simply excluded by the value-added measure.

The value-added approach provides a simple conceptual link of industry-level MFP and sectoral or aggregate MFP growth (see OECD 2001, p. 30). Value added in an industry represents the contribution of that industry to sectoral or aggregate gross product. Current price values of value added can simply be summed across different industries without regard to any inter-industry flows of inputs. Quantity indices of value added can be aggregated by forming weighted averages, with weights adding to unity. The weights are simply each industry's current price share in total value added.

As a result, value-added based productivity measures are weighted averages of their components and can be compared across sectors or industries. For example, the productivity growth of a sector can be compared with the average for all sectors and if, in a two-sector economy, both sectors grew at one per cent a year then aggregate productivity would also grow at one per cent a year.

In addition, under conditions of profit maximisation by firms, the value-added approach is more consistent with firms' aims than the gross output concept (van der Wiel 1999, p. 11).

Nevertheless, value-added based measures have been criticised as:

- conceptually flawed;
- providing biased estimates of industry growth rates; and
- providing misleading estimates of the contributions to growth.

2.1 Conceptual issues

The existence of a value-added production function is challenged by analysts. It is said that the relationship of real value added to the production function is at best ambiguous (Sudit and Finger 1981, p. 14; see also Oulton and O'Mahony 1994, pp. 33–6). There is nothing in the real world that resembles real value added as plants do not produce things in units of value added (Oulton and O'Mahony 1994, p. 33; Hulten 2000, p. 58).

Microeconomic theory requires models of sectoral/industry production with no restrictions on either the particular form of technical change or the marginal rates of substitution among the elements of the production function (Gollop and Roberts 1981, p. 151). Since value added (VA) is defined as the difference between separately deflated gross output (Y) and intermediate inputs (M), the use of value added as a measure of output in productivity studies assumes that the underlying production function is additive-separable of the form Y = VA + M.

This function imposes restrictions on the generality of the model of producer behaviour and on the role of technological change (see Gollop 1979, pp. 320–1; Bruno 1980; Diewert 1980). The model of sectoral production is restricted because it does not allow for substitution possibilities between the elements of the value-added function (capital and labour) and intermediate inputs. For example, it assumes that price changes in intermediate inputs do not influence the relative use of capital and labour. Intermediate input is treated differently from labour and capital in the value-added approach (Jorgenson et al. 1987, p. 9; Dean and Harper 2000, p. 48). In effect, estimates of "real value-added" output are based on the unlikely assumption that the prices of output and intermediate input always rise at the same rate.

It also restricts the role of technological change by assuming that such change only affects the usage of capital and labour so that intermediate inputs cannot be the source of improvements in productivity (Gollop 1979, p. 322).

> In short, intermediate inputs are excluded from consideration in the value-added model on the basis of the assumption that they are insignificant to the analysis of productivity growth. (Gullickson 1995, p. 17)

Empirical testing suggests that there is no separability between the value-added function and intermediate inputs. A study by Jorgenson et al. (1987) found that the conditions necessary and sufficient for the existence of a sectoral value-added function did not exist in forty out of forty-five industries analysed.

One response to these considerations is that the idea of an industry production function is in any case a flawed concept. Growth accounting assumes the existence of a production function at either the sectoral or industry level that is representative of each firm within the relevant industry. However, a number of studies have found large differences in productivity across firms within industries that are persistent over time (for example, Baily et al. 1992; Bartelsman and Doms 2000; Barnes and Haskel 2000; Gretton, Gali and Parham 2002). The review of research studies by

Bartelsman and Doms concluded that productivity dispersion is extremely large. The extent of the dispersion varies between sectors, with greater dispersion in the non-manufacturing sectors (Oulton 1998).

Such results cast doubt on the usefulness of the notion of an aggregate production function based on a representative firm as Bartelsman and Doms (2000, p. 584) note:

> The existence of productive heterogeneity, even among producers of comparable products with comparable equipment, has forced analysts to rethink and reassess some old "truths" that find no support in the microdata.
>
> For instance, these results begin to cast doubt on the usefulness or the appropriateness of an aggregate production function that is based on a representative firm. Industry output is not produced with industry inputs in such an orderly fashion.

van der Wiel (1999, p. 9) says that the "tremendous heterogeneity that exists across firms within industries indicts the centerpiece of the growth accounting literature".

2.2 Biased estimates of productivity growth

Value-added based estimates of productivity growth may be misleading in several respects:

- they are higher than gross output-based estimates;
- they may distort industry productivity growth rates over time; and
- they may distort inter-industry comparisons of productivity growth.

There appear to be few empirical studies that compare industry/sectoral productivity growth rates according to value-added and gross output-based estimates. Oulton and O'Mahony (1994) provided estimates of aggregate manufacturing MFP for the period 1953-1986 based on both methods. van der Wiel (1999) has estimated labour productivity and MFP according to both approaches for Dutch manufacturing and service industries and Sichel (2001) provided a comparison for the US communication sector. Harchaoui et al. (2001) provide estimates of industry MFP in Canada according to several different output measures. Oulton (2000) obtained gross output-based estimates of MFP growth for UK industry sectors by using the ratio of value added to gross output to convert value-added based MFP estimates.

Comparison of value-added and gross output estimates

MFP growth as measured by the value-added method will systematically exceed the measure based on gross output by a factor equal to the ratio of gross output to value added. This can be shown following Diewert (2001, p. 18). Productivity in the gross output formulation is Y/(I+L+K) where Y is gross output, I is intermediate input use, L is labour input and K is capital input. Productivity in the real value-added framework is roughly (Y-I)/(L+K). With a productivity improvement of ΔY with all inputs remaining constant, the gross output productivity growth rate is $((Y+\Delta Y)/(I+L+K))/(Y/(I+L+K)) = (Y+\Delta Y)/Y = 1+(\Delta Y/Y)$, which is less than the real value-added productivity growth rate $(Y+\Delta Y\text{-}I)/(L+K))/((Y\text{-}I)/(L+K) = 1+(\Delta Y/(Y\text{-}I))$. Thus, the smaller denominator in the value-added MFP measure translates into larger MFP growth measures.

The formal relationship between value-added and gross output-based MFP growth is as follows

$$MFP_{VA} = (G/VA) \times MFP_{G}$$

where MFP_{VA} is multifactor productivity growth based on value added, MFP_{G} is multifactor productivity growth based on gross output, G is nominal gross output and VA is nominal value added (Harchaoui et al. 2001, p. 153; see also OECD 2001, p. 26).

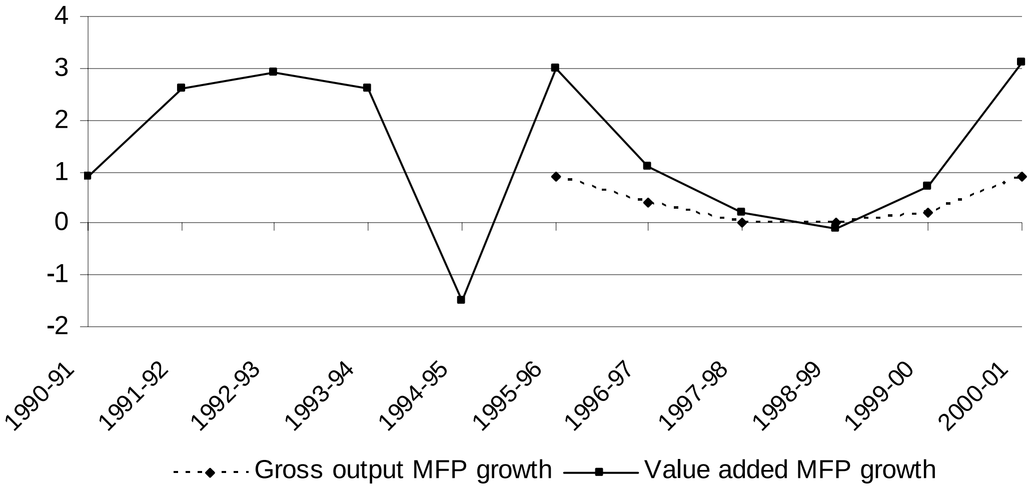
In a closed economy, the differences between the two measures of productivity growth diminish as the level of aggregation increases. At the total economy level, the value-added based measure of productivity growth is the same as the gross output-based measure. However, in the presence of imports, the two measures produce different results even at the aggregate level (Schreyer 2001, p. 42).

Several studies show that productivity growth measured according to a value-added model is greater than that derived from a model that takes all inputs into account. For example, Oulton and O’Mahony (1994, pp. 132–3) show that the value-added method produces estimates of MFP growth for manufacturing in the UK that are twice those given by the gross output method. Oulton’s later study (2000) also shows large differences between the MFP estimates for each industry sector with the value-added based measure always exceeding the gross output-based estimates. Similarly, van der Wiel (1999) shows that MFP estimates for various Dutch industries are much higher according to the value-added approach than those under the gross output method.

Comparisons of gross output and value-added measures of industry MFP growth in Australia, on a year-to-year basis, confirm this observation. The trends in the two measures are the same but the amplitude of the value-added measure is greater than that of the gross output-based measure (ABS 2003). Figure 2.1 demonstrates this for Manufacturing.

Figure 2.1 **Gross output and value-added measures of MFP growth, Manufacturing**

Per cent per year



Data source: ABS (2003).

Sectoral *labour* productivity growth estimates also vary according to the measure of output adopted. However, in this case there is no consistent relationship between the estimates. Dutch industry sector estimates show that gross output-based labour productivity growth may be above or below the value-added based estimates for the same sector in different periods (van der Wiel 1999). Sichel's (2001) estimates of labour productivity growth in US communications sector for several periods between 1977 and 1999 show that gross output-based productivity growth was generally above that of value-added based estimates, but not always.

Differences in productivity growth trends

Since the ratio of gross output to value added varies considerably across industries, not only will the average MFP growth rate be higher when measured by the value-added method, but industry growth trends and inter-industry comparisons may be distorted.

> …(value-added) based measures can lead to distorted intertemporal comparisons of productivity and also distorted interindustry comparisons of productivity. (Gullickson and Harper 1999b, p. 19)

The implications for industry growth trends are considered first.

The relationship between the two measures for a given industry may not be stable over time because the share of value-added in gross output changes as shifts occur in the use of intermediate inputs relative to capital and labour. As a result, a constant rate of MFP growth measured on a gross output basis could be consistent with an accelerating or decelerating rate of MFP growth measured on a value-added basis.

The effects can be considered in relation to the common phenomenon of outsourcing. The value-added based measure of productivity growth is affected by outsourcing and vertical integration. This is demonstrated by a simple illustration provided by Gullickson and Harper (1999b, p. 18) based on the following form of the relationship between value added MFP_{VA} growth and gross output MFP_G growth

$$MFP_{VA} = (1 + M/VA)\ MFP_G$$

where M is the value of intermediate inputs.

Suppose an industry with a 1 per cent growth rate in gross output-based MFP increasingly outsources parts of its production. Suppose further that intermediate inputs initially amount to one-half of value added for the industry and that they grow over time to equal value added. The value-added based MFP measure would be 1.5 per cent in the first period but increase to 2 per cent in the second period as a consequence of the outsourcing.

Value-added based MFP depends also on the share of value added in gross output and thus on the time paths of inputs, outputs and prices, as well as the level of technology in the period under consideration. As a result, value-added based MFP industry measures increase much faster than gross output-based MFP as a result of outsourcing.

The estimates provided by van der Wiel (1999) found that the two measures had broadly similar MFP growth trends in several manufacturing and service industries. The direction of change was the same in each case. However, in some sectors, there were quite significant differences in the rates of change under each measure, with the value-added based estimates fluctuating more widely than the gross output-based estimates. The two measures also produced similar trends for the UK manufacturing sector (Oulton and O'Mahony 1994, p. 132) and the US communications sector (Sichel 2001).

Thus, while the two measures are consistent in showing whether MFP growth is increasing or falling, the value-added based measure is likely to overstate the extent of the change in the growth rate in comparison with the gross output-based measure.

On the other hand, labour productivity growth trends differed between the output measures in half of the industries in the Dutch study and there were larger proportionate changes in productivity growth under the value-added measure.

Labour productivity growth in some sectors was shown to be increasing in some periods under one measure but declining in the same period under the other measure. The two measures also produced different labour productivity growth trends in the US communications sector.

Inter-industry comparisons of productivity growth

Similarly, inter-industry comparisons of productivity growth may be distorted. Two industries may have the same rate of MFP growth on a gross output basis, but different rates measured on a value-added basis if the proportion of intermediate inputs in total costs differed.

Suppose a service industry buys no intermediate inputs while supplying a manufacturing industry with intermediate inputs equal to half of the latter's value added. Further suppose both industries have gross output-based MFP growth of 1 per cent. In these circumstances, the service industry's value-added based MFP growth would also be 1 per cent, while that of the manufacturing industry would be 1.5 per cent.

This possibility is demonstrated for both MFP and labour productivity growth in several Dutch industries between 1985 and 1995 (van der Wiel 1999). For example, the gross output-based MFP growth rate in the Food, beverages and tobacco, Chemical and rubber, Metal and Other industries was 0.5 per cent a year between 1986 and 1990, while the respective value-added based MFP growth rates in each industry were 2.75, 1.25, 1.0 and 1.25 per cent a year.

Similarly, the value-added based labour productivity growth rate in the Metal and Other industries was 1.5 per cent a year between 1986 and 1990, while the gross output-based rates were 3.25 and 2.5 per cent year, respectively.

Interpretations of such data may be severely distorted, depending on which rates are used for inter-sectoral analysis. For example, the gross output-based MFP rates reported above were the same as the manufacturing sector average for the period, whereas value-added based MFP measures indicate that productivity growth in Food, beverages and tobacco was high relative to the manufacturing sector average of 1.4 per cent. On the other hand, while the Metal industry growth rate was relatively low compared with the manufacturing average under the value-added based measure, it was similar to the manufacturing average under the gross output-based measure.

2.3 Contributions to growth

By excluding intermediate inputs, value-added based estimates of productivity growth deny an important source of economic growth. As Gullickson (1995, p. 17) notes, intermediate inputs are excluded from consideration in the value-added model on the basis of the assumption that they are insignificant to the analysis of productivity growth. However, improvements in productivity growth can arise from increases in efficiency in the use of intermediate inputs. Intermediate inputs are clearly important in many sectors as seen by the growth of business, finance and computer services. Modern productivity improvement techniques are aimed at improving the efficiency with which both intermediate and primary inputs are used. For example, in the manufacturing sector, just-in-time production, statistical process control, computer-aided design and manufacturing, and other developments reduce error rates and cut down on sub-standard rejected production. In so doing, they reduce the wastage of materials as well as workers' time. Such efficiencies add to productivity and should be taken into account in measuring productivity growth.

Similarly, improvements in productivity in supplying industries may contribute to improvements in productivity in the using industry in several ways. A supplying industry may be able to increase the quality of its output without changing the inputs used in the production process and industries purchasing this output may gain a benefit from this quality improvement in the form of an increase in their own productivity. For example, improved miniaturisation of electrical circuits on semi-conductors may feed through into improved productivity in the semi-conductor, computer production and computer-using industries.

Another possibility is that an increase in MFP in the supplying industry will permit an increase in production without reducing resources in other industries and thereby enable increased production in the using industries. Alternatively, the increase in MFP in the supplying industry will enable the same amount of goods or services to be supplied with fewer resources, thus releasing resources to be employed in using industries.

From this point of view, the inputs taken into account should be as comprehensive as possible so that productivity growth does not merely reflect changes in unmeasured inputs.

> … analysis of productivity for industries cannot be restricted to capital and labor as inputs. In manufacturing, intermediate inputs — energy, non-energy materials, and business services — constitute a large part of the cost structure. Firms' managers make decisions based on prices of all inputs and other market conditions, adjusting input mix, labor force, and investment levels accordingly. A specification of productivity which excludes intermediate inputs from consideration makes mismeasurement of growth

trends more likely, while severely limiting the kinds of analyses to which the measures can be put. (Gullickson 1995, p. 26)

Jorgenson et al. (1987) and Jorgenson and Stiroh (2001) show that intermediate inputs are the predominant source of output growth at the industry level, exceeding both productivity growth and the contributions of capital and labour in the large majority of industries. The estimates prepared by Oulton and O'Mahony (1994) for UK manufacturing show that input growth explains a much higher proportion of productivity growth according to the gross output estimates than in the case of the value-added estimates. However, Diewert and Nakamura (1998, p. 14) point out that these findings largely follow from the way in which these studies define productivity and factor inputs at the industry level, although this assertion is not fully explained.

2.4 Interpretation

The value-added measure of productivity growth is clearly not a measure of technological change in an industry or a measure of overall improvements in efficiency. It is better seen as an industry's capacity to translate technological change into income and a contribution to final demand (OECD 2001, p. 25). That is, it reflects changes in an industry's contribution to aggregate income.

> Productivity estimates based on this version of the production function indicate changes in the efficiency with which the primary inputs of an industry are used to add real value to the intermediate products purchased from other industries. (National Research Council 1979, p. 38)

3 The gross output measure

The value-added concept of output is frequently used despite its non-intuitive appeal. Productivity is a volume measure and the output of a baker, for example, is loaves of bread, not value added in baking. This suggests that the gross output approach has greater intuitive appeal.

In theory, the gross output-based MFP measure is a valid representation of disembodied technological change. The use of gross output combined with labour, capital and intermediate inputs corresponds directly to a specific model of a production function with 'neutral' or 'output augmenting' technical change. MFP measures based on a gross output concept mean that productivity growth approximates the rate of neutral, disembodied technical change. Disembodied technological change can be the result of research and development that leads to improved production processes or it can be the consequence of learning-by-doing. It is disembodied because it is not physically tied to any specific factor of production.

However, in practice, MFP measures based on gross output reflect a variety of influences including changes in efficiency, economies of scale, variations in capacity utilisation and measurement error as well as disembodied technological change.

The advantage of gross output-based estimates of MFP growth is that they acknowledge and allow for intermediate inputs as a source of industry growth. In this sense, they provide a more complete picture of the production process (Sichel 2001, p. 7). It is true that the net productivity measures based on value added reflect savings in intermediate inputs because real value added per unit of primary input rises when unit requirements for intermediate inputs are reduced, but the effect is not explicit. Gross output-based measures explicitly indicate the contribution of savings in intermediate inputs.

For example, Jorgenson and Stiroh (2001) show that productivity improvement lowers the price of semi-conductors and increases their flow as intermediate inputs to other industries. By correctly accounting for the contribution of these inputs, industry productivity growth is reduced in the using industries and allocated to the industry producing semi-conductors.

Moreover, with appropriate treatment of intermediate inputs, a mutually consistent set of estimates can be obtained at each level of economic activity. This is important because consistent aggregation is necessary to answer questions about the contribution of individual industries to overall productivity growth, a key matter of interest in analysing productivity growth.

> By correctly accounting for the quantity and quality of intermediate inputs, the gross output concept allows aggregate TFP gains to be correctly allocated among industries. (Jorgenson and Stiroh 2001, p. 53)

The method of aggregation is crucial (Gullickson 1995, p. 15). Aggregate outputs and inputs are not simple sums of their industry/sector counterparts and inconsistencies can arise between aggregate and industry productivity estimates. Aggregate output and input measures exclude all intermediate transactions between domestic industries to avoid double counting and to capture movements in inputs and outputs resulting from technological change and other efficiency changes. However, industry inputs include purchases from other industries and industry outputs include sales to other industries as well as sales to final demand. As a result, aggregate productivity growth cannot be obtained as an average using a set of weights that sum to one (Gullickson and Harper 1999a, p. 51).

Consistency between aggregate and industry/sectoral estimates of MFP based on gross output is enhanced by exclusion of intra-industry inputs and by adopting a special system of weighting of industry productivity growth rates to derive aggregate estimates.

3.1 Sectoral output

Inclusion of intra-industry flows of intermediate products would involve double counting on both the input and output side of an industry production function. The input measure would include both the intra-industry transactions and the inputs required to produce them and the output measure would include the intra-industry transactions and the goods made from them.

This form of double counting as output and intermediate inputs presents two problems (see Gullickson 1995, p. 18).

First, it tends to obscure the extent of technological change or changes in efficiency taking place in the industry/sector as a whole.

> … with identical components included as both input and output, change in productivity is always closer to zero than if the component is removed. (Gullickson 1995, p. 18)

Thus, the extent of productivity change is artificially reduced by including intra-sector transactions and this is compounded by basing industry/sector aggregates on increasingly smaller and smaller statistical units so that outputs and inputs are made larger and larger (OECD 2001, pp. 29–30). For example, an industry output measure based on establishments would be larger than one based on firms.

Another problem is that changes in integration would introduce a bias into productivity growth trends. For example, if an establishment is divided into two with all output of one consumed by the other, the measure of output and material input would increase compared with the previous year. The addition of equal quantities to both output and input would result in a tendency toward zero in the rate of change of the materials/output ratio and in the growth of MFP.

Consequently, it is preferable to exclude intra-industry intermediate inputs from estimates of industry outputs and inputs. This measure of output is called ‘sectoral output’ (see Gullickson and Harper 1999a, p. 50). MFP measures that exclude intra-industry sales have been referred to as intra-industry MFP indices (Harchaoui et al. 2001, p. 150).

As Gullickson (1995, p. 18) states, it is important to note that this concept of output is dependent on the level of industry or sectoral aggregation under consideration. It means that, as the sector size increases, the proportion of all transactions that are intra-sector tends to rise and the ratio of intermediate inputs to value added tends to fall. That is, as the level of aggregation increases, the difference between gross output-based estimates of MFP growth and value-added based estimates tends to decrease. In the case of a closed economy, sectoral output at the most aggregate level is identical to total value added (OECD 2001, p. 91).

3.2 Aggregation procedure

Domar (1961) proposed that MFP growth at the aggregate level should be measured as a weighted sum of industry-level MFP growth rates (see Oulton and O’Mahony 1994, pp. 13–14 and pp. 118–21). The industry productivity growth rates are estimated using gross output and incorporate intermediate inputs from other sectors. The ‘Domar’ weight is the ratio of the value of gross output of an industry/sector to the sum of value added in all industries/sectors.

This weighting scheme can be adapted to different aggregates, whether a sectoral aggregate, the business sector or the market economy. For example, Gullickson and Harper (1999a) conduct their study of private business sector productivity in terms of ‘sectoral output’ and the ‘Domar’ weight is the ratio of the value of the industry’s sectoral output to the value of the sectoral output of the private business sector as a whole. A similar procedure is used by Oulton and O'Mahony (1994) in their study of the UK manufacturing sector. Here the weights for each industry growth rate are the ratios of nominal gross output in each industry to aggregate nominal final output, which is total sales of manufacturing firms less sales to other manufacturing firms of products that will be used up within the current period.

The effect of weighting industry growth rates is to scale the industry MFP estimates by their relative importance and permit a reconciliation with the aggregate estimates (Gullickson and Harper 1999a, p. 57).

The weights sum to more than one since aggregate gross output exceeds aggregate value added because of the inclusion of intermediate inputs in the estimation of industry/sector productivity growth rates. Each industry gross output exceeds its value added so that the sum of industry outputs exceeds aggregate value added. Aggregate MFP growth, therefore, depends not only on the industry MFP trends but also on the proportion of intermediate transactions (Gullickson and Harper 1999b, p. 16).

The intuitive justification for the sum of the weights exceeding one is that an industry contributes not only directly to aggregate MFP growth but also indirectly, through helping to lower costs elsewhere in the economy when other industries buy its product (Oulton and O'Mahony 1994, p. 14; Oulton 2000, p. 25).

> These weights reflect the direct contribution of sectoral productivity change to economic growth through deliveries to final demand and the indirect contribution through deliveries to intermediate demand. (Jorgenson et al. 1987, p. 7)
>
> This weighting methodology implies that economy-wide TFP growth can grow faster than productivity in any industry, since productivity gains are magnified as they work their way through the production process. (Jorgenson and Stiroh 2001, p. 53)

For example, in an economy composed of a final good industry and an intermediate good industry that constitutes half the cost of producing the final good, a one per cent increase in MFP in both industries will translate into a 1.5 per cent increase in aggregate MFP. The growth in the intermediate input industry augments growth in the next stage of production (Gullickson and Harper 1999b, p. 16) or cumulates productivity gains from intra-industry deliveries (OECD 2001, p. 30).

Hulten (2000, p. 56) explains this result as follows:

> This inflation in the aggregate number is needed in order to account for the fact that, while an increase in industry-level productivity augments the production of intermediate goods, these intermediate goods have subsequently disappeared in the process of aggregation.

Consider the case of computers and semi-conductors as described by Jorgenson and Stiroh (2001, pp. 56–7). Computers are part of final demand, sold as consumption and investment goods, and can be identified in aggregate data. Semi-conductors, on the other hand, do not appear at the sectoral or aggregate level, since they are sold almost entirely as an intermediate input into computers, telecommunications equipment and an increasingly broad range of products, such as machine tools, automobiles and appliances. Semi-conductors production is an important source of sectoral and aggregate MFP growth since it is ultimately responsible for the lower prices and improved quality of goods, such as computers, produced for final demand.

An interesting and pertinent implication of applying Domar weights is that a rise in the resource share of an industry with no productivity growth need not lower aggregate productivity growth because the share of an industry with productivity growth declines. As Oulton (2000, pp. 25–7) shows, the Domar weight for an industry can increase without a corresponding fall for any other sector. This may occur if an industry supplying only intermediate products increases its sales because other industries supplying only final demand purchase more intermediate products, substituting them for primary inputs. With the rise in the Domar weight of the industry supplying the intermediate product, the aggregate productivity growth rate will increase, even if that industry has below-average productivity growth. Hence the conclusion:

> … if resources are shifting to industries producing intermediate inputs, the aggregate productivity growth rate will rise, however low the TFP growth rate (in the gross output sense) are in those industries, provided only that they are positive. (Oulton 2000, p. 27)

The Domar aggregation of gross output-based MFP measures across industries provides an accurate picture of the contributions of industries to aggregate MFP change. However, there are significant data problems associated with input-output tables and their consistency with national accounts. This issue is discussed below.

One cost of this approach is that industry/sectoral productivity growth rates cannot be compared with the aggregate because the aggregate is built up as weighted sums, but not averages, from its components. In contrast, as noted earlier, value-added based productivity measures of aggregates are weighted averages of their components and can be compared across levels of aggregation because the weights add to unity. This measure provides a simple conceptual link between industry-level MFP and aggregate MFP growth and can be used in the analysis of structural change.

4 Comparative data requirements

Value added can be easily measured in current dollar terms as the value added of an economic unit is its current dollar income or payments to labour and capital. The data for estimating value-added output are directly available from the national accounts.

The gross output-based approach imposes considerable demands on data availability in that it requires resort to supply and use tables that are consistent with the national accounts.

> The development of a consistent set of supply, use and industry-by-industry tables and their full integration with national accounts at current and constant prices is an important element in deriving reliable productivity measures. (OECD 2001, p. 20)

However, the need to identify intra-industry purchases and sales on an annual basis can be difficult.

> … industry estimates of output and intermediate input are rather fragile in all countries due to the lack of surveys on *intermediate input flows* and in particular, of *service flows* between industries. (Diewert 2001, p. 4)

In addition, identification of intra-industry deliveries requires annual input-output tables and depends on their timely availability.

The data requirements associated with estimating intra-industry transactions have led some researchers not to adjust outputs and intermediate inputs for these transactions (see, for example, Berndt and Wood 1975).

> Gross output and GPO [gross product originating] are both important measures of industry output. Many economists prefer to use gross output in studies of industry production and output per employee because it reflects the use of both primary and secondary inputs. Until recently, the lack of gross output measures for many service industries limited the analytical possibilities for the nonmanufacturing group. These gaps in available gross output measures were largely attributable to the lack of detailed source data for current-dollar gross output and for price indexes, but they were also due to conceptual problems in defining the output of some service industries — such as depository institutions, which includes banking, and business services, which includes computer services. As a result, some analysts used GPO as an output measure because of GPO's comprehensive coverage and widespread availability from the national economic accounts of most countries. (Lum, Moyer and Yuskavage 2000, p. 25)

5 Estimating real output

Deflation of gross output is conceptually straightforward. An index of the nominal value of output is divided by an output price index to derive a quantity index of gross output.

The process is more complicated in the case of value-added output measures. It involves double deflation because the volume change for value added combines the volume change of gross output and intermediate inputs. The term ‘double’ indicates that both production and intermediate inputs must be deflated in order to measure changes in the real output attributable to the factors of production in an industry.

In principle, sales and inputs should be deflated by separate price indexes. The deflation of inputs is problematic since the mix of services inputs used by a unit can vary considerably. The ‘double deflation’ method is generally used but the reliability for one industry can affect those for many others (Steindel and Stiroh 2001, p. 6).

Real value added can be obtained by subtracting a constant-price value of intermediate inputs from a constant-price value of gross output. This is only possible with Laspeyres quantity indexes, and there are a number of theoretical and practical problems associated with fixed-weight Laspeyres indexes (see OECD 2001, pp. 14, 32). In particular, the form of index imposes restrictive assumptions on the underlying production technology.

A single deflation measure can be used instead of double deflation. It uses a single price index to deflate current-price series of value added and thus appears to make redundant data on intermediate input quantities and prices. However, the wedge between double-deflated and single-deflated value-added increases, the less stable the share of intermediate inputs in gross output (OECD 2001, p. 33). A fall in the relative price of intermediate inputs can cause a rise in real value added, thus confusing a price effect with a quantity effect. With real output and real intermediate input held constant, a fall in intermediate price raises single deflated value added. Single deflation can only be defended if it so happens that the price of output and that of intermediate inputs rise at the same rate, an unlikely occurrence.

> … measuring value added by single deflation is invalid, unless output and intermediate input prices happen to be rising at the same rate. Double deflation is superior, though the commonly employed method of double deflation is incorrect. When double deflation is done correctly, the data requirements are just as great as for the gross output method. (Oulton and O’Mahony 1994, p. 35)

6 Conclusions

The OECD Productivity Manual (2001, p. 10) states that the choice between productivity measures depends in part on the purpose of the productivity measure.

In principle, the value-added and gross output-based measures are measures of two different concepts. The gross output method is intended to measure disembodied technological change whereas the value-added based measure reflects an industry's capacity to translate technical change into income and into a contribution to final demand.

The OECD (2001, p. 27) concludes that each measure has its place, depending on the interpretation adopted.

> In conclusion, it would appear that gross output and value-added based MFP measures are useful complements. When technical progress affects all factors of production proportionally, the former is a better measure of technical change. Empirically, it is important to base productivity calculations on superlative index number formulae because they provide approximations to independent measures of outputs, inputs and technical change. Generally, the gross output-based MFP measures are less sensitive to situations of outsourcing, i.e., to changes in the degree of vertical integration between industries. Value-added based MFP measures vary with the degree of outsourcing and provide an indication of the importance of the productivity improvement for the economy as a whole. They indicate how much extra delivery to final demand per unit of primary inputs an industry generates.

The general conclusion of the literature is to favour the gross output approach to MFP measurement. For example:

> It seems clear that the literature on industry productivity measurement unambiguously favors the use of gross output, or a closely related concept, for multifactor productivity measurement. (Dean, Harper and Sherwood 1996, p. 192)

The overall advantage of a gross ouput-based MFP measure is that it minimises certain sources of productivity measurement bias.

> Specifically, those biases resulting from an incomplete definition of productivity and those biases resulting from an improper allocation of productivity to industries can be evaluated separately from other sources of bias. (Gullickson and Harper 1999a, p. 47)

This remains despite data problems related to input-output tables and appropriate price deflators.

The choice between output measures is not so clear-cut for labour productivity measurement. Increasing or decreasing labour productivity estimates based on gross output may not reflect a change in technology or efficiency but, rather, substitution between labour and intermediate inputs. For example, outsourcing activities previously conducted in-house will cause gross output per unit of labour input to increase even though the total amount of labour used to produce the output may not have changed, or only changed a little. In such a case, direct labour input is reduced and replaced by intermediate purchases and gross output may not necessarily increase, yet the substitution of inputs will result in an increase in measured labour productivity. In practice, of course, some gain in efficiency is the goal of the outsourcing but, while it may be realised, it is not reflected as the measured change in labour productivity.

Consequently, sectors experiencing significant increases in outsourcing or in-house production may appear to have higher rates of productivity growth relative to other sectors than if labour productivity was measured on a value-added output basis. The growth of value-added labour productivity is less dependent on changes in the ratio of intermediate inputs to labour or the degree of vertical integration. As outsourcing increases, value added is reduced, as well as labour input, and labour productivity is not artificially boosted by the outsourcing. Both the numerator and the denominator change in the same direction when outsourcing or in-house production increase. Any change in labour productivity is dependent on the efficiencies achieved within the industry by the outsourcing.

> … gross output-based labour productivity measures are more sensitive to the degree of vertical integration and outsourcing than value-added based labour productivity measures. (OECD 2001, p. 27)

As patterns of outsourcing and in-house production are constantly changing on an industry basis, these considerations constitute a case to adopt labour productivity estimates based on a value-added concept of output. However, Dean et al. (1996, p. 192) state some of the reasons for adopting a gross output-based estimate of MFP also apply to labour productivity.

> The use of value-added output for measurement of labor productivity — as distinct from its use in MFP measures — has not been closely examined in the theoretical literature and value-added is in fact frequently used in studies of labor productivity. A persuasive case can be made for the use of gross or sectoral output in labor productivity series also. Some of the considerations that underlie the choice of sectoral or gross output for multifactor productivity measurement carry over to the area of labor productivity.

In summary, gross output-based measures of MFP are clearly preferable in principle in terms of estimating sectoral contributions to aggregate productivity estimates. However, data requirements and the need for consistency between supply and use tables and national accounts data has meant that sectoral estimates of gross output-based MFP are unavailable at present.

Labour productivity estimates provide an alternative, although partial, measure of productivity. Here value-added based estimates have greater validity. Increasing or decreasing labour productivity estimates based on gross output may not reflect a change in technology or efficiency but, rather, substitution between labour and intermediate inputs. The growth of value-added labour productivity is less dependent on changes in the ratio of intermediate inputs to labour or the degree of vertical integration. As patterns of outsourcing and in-house production are constantly changing on an industry basis, these considerations constitute a case to adopt labour productivity estimates based on a value-added concept of output.

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