The Challenge of Total Factor Productivity Measurement

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In order to measure industry total factor productivity accurately, we require reliable information not only on the outputs produced and the labour input utilized by the industry but we also require accurate information on *eight* additional classes of input used by the industry. One of these additional classes of input is *intermediate* input; i.e., inputs that are utilized by the industry but which are produced by other industries. Information on the real and nominal purchases of intermediate inputs by industry comes from the system of *input-output tables* published by Statistics Canada. In section 4, we explain why the estimates of real intermediate input utilization by industry that one can obtain from the real input-output tables of *any* country are likely to be inaccurate. In section 5, we go on to make the case that *national* productivity estimates are likely to be more accurate than *subnational industry* estimates. Section 6 concludes on an optimistic note.

The *total factor productivity* of a firm, industry or group of industries is defined as the *real output* produced by the firm or industry over a period of time divided by the *real input* used by the same set of production units over the same time period. However, it turns out to be difficult to provide a meaningful definition of real output or real input due to the heterogeneity of outputs produced and inputs utilized by a typical production unit. On the other hand, it is possible to provide meaningful definitions of *output growth* and *input growth* between any two time periods using index number theory.[1] Essentially, any sensible *quantity index* aggregates up a weighted average of the rates of growth of each of its components over the two periods in question, which provides a meaningful aggregate growth rate. The two periods are generally taken to be consecutive periods (the chain principle is used in this case) or the current period and a base period (the fixed base principle is used in this case).[2] *Thus total factor productivity growth* of a production unit over *two* time periods can be meaningfully defined as an output quantity index divided by an input quantity index where the quantity indexes utilize the output and input price and quantity data that pertain to the production unit for the two periods. This *index number approach* to the measurement of total factor productivity growth was perhaps first systematically explained by Jorgenson and Griliches (1967).[3] Thus if outputs grow

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[1] For reviews of the issues involved in choosing the specific functional form for the index number formula using the economic approach, see Diewert (1976; 124-129) (1980; 487-498) (1992a; 177-190) and Caves, Christensen and Diewert (1982). For reviews of the issues involved in choosing the functional form for the index number formula using the axiomatic approach, see Diewert (1992b) and Balk (1995).
[2] Diewert (1978a; 895) (1996; 245-246) and Hill (1988; 136) (1993; 387-389) recommended the use of the chain principle for annual data.
[3] Jorgenson and Griliches drew on the earlier work by Solow (1957). However Jorgenson and Griliches (1967) took a much more disaggregated approach, used a more sophisticated index number formula to compute output and input growth and they also used a user cost of capital approach to measure the price of

faster than inputs, we say that there has been a total factor productivity improvement. Over long periods of time, advanced economies have achieved rates of total factor productivity growth in the range of about 0.5 to 1.5 percentage points per year; i.e., aggregate output has grown about 0.5 to 1.5% faster than aggregate input. Clearly, TFP growth is an important determinant of improvements in living standards. Note that simply measuring TFP growth does not tell us anything about what causes this growth. However, in order to have explanations for TFP growth, it is first necessary to measure it accurately.

First, we note that there can be problems in comparing the TFP growth for an industry which has a large proportion of intermediate inputs relative to its gross output compared to an industry that uses very little intermediate input. Consider industry A, which uses no intermediate input and has a productivity improvement of 1% in the current year compared to the previous year and compare it to industry B which uses one dollars worth of intermediate input for every two dollars worth of output produced. Suppose industry B also has a 1% productivity improvement; i.e, its gross output grew 1% faster than an aggregate of its intermediate and primary (labour and capital) input. At first glance, it seems that both industries A and B have had similar productivity improvements. But note that the input base for industry B includes intermediate inputs and so its productivity improvement per unit of primary input used is actually much larger than the productivity improvement per unit of primary input used by industry A. To make the TFP growth rates for the two industries comparable, it is necessary to treat intermediate inputs as negative outputs and aggregate them up with the gross outputs of the production unit under consideration. Then TFP growth is defined as an index number aggregate of gross outputs and (negative) intermediate inputs divided by an index number aggregate of primary inputs.

A second technical problem associated with the measurement of TFP growth is that it is difficult to figure out what is the "correct" way of aggregating heterogeneous labour inputs. One immediately thinks of classifying workers according to their "occupations" and then the relevant price and quantity variables to enter into the index number formula are the hours worked by each occupational type along with the corresponding average (or marginal) wage rates. However, it proves to be extremely difficult to define homogeneous occupational classes over even moderate periods of time. Thus Jorgenson and Griliches (1967), Griliches (1970) and Christensen and Jorgenson (1970) eventually decided to disaggregate hours worked by the demographic characteristics of the worker such as age, sex race, years of schooling and so on. The required information was obtained by using Census information and interpolation techniques between census years. This treatment of labour input was adopted by the Bureau of Labor Statistics (1983) in their classic study of U.S. TFP growth and it continues to be used today.[4]

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capital services, as was suggested earlier by Griliches and Jorgenson (1966). For further refinements of this Jorgenson and Griliches index number approach, see Christensen and Jorgenson (1969) (1970).

[4] Alternative approaches to the problem of defining labour input are discussed and implemented by Denison (1985), Jorgenson, Gollop and Fraumeni (1987) and Jorgenson and Fraumeni (1989) (1992). Dean and Harper (2000) provide an accessible summary of the literature in this area.

Why is it so Difficult to Measure the Total Factor Productivity of an Industry?

In order to measure the TFP growth of a firm or an aggregate of firms, it is necessary to have accurate price and quantity information on all of the outputs produced by the set of production units for the two time periods under consideration as well as accurate price and quantity information on all of the inputs utilized. We discuss some of the measurement problems that are associated with 10 broad classes of inputs and outputs in sections 3.1 to 3.10 below.

3.1 Gross Outputs

In order to measure the productivity of a firm, industry or economy, we need information on the outputs produced by the production unit for each time period in the sample along with the average price received by the production unit in each period for each of the outputs. In practice, period by period information on revenues received by the industry for a list of output categories is required along with either an output index or a price index for each output. In principle, the revenues received should not include any commodity taxes imposed on the industry's outputs, since producers in the industry do not receive these tax revenues. The above sentences sound very straightforward but many firms produce thousands of commodities so the aggregation difficulties are formidable. Moreover, many outputs in service sector industries are difficult to measure conceptually: think of the proliferation of telephone service plans and the difficulties involved in measuring insurance, gambling, banking and options trading.

3.2 Intermediate Inputs

Again, in principle, we require information on all the intermediate inputs utilised by the production unit for each time period in the sample along with the average price paid for each of the inputs. In practice, period by period information on costs paid by the industry for a list of intermediate input categories is required along with either an intermediate input quantity index or a price index for each category. In principle, the intermediate input costs paid should include any commodity taxes imposed on the intermediate inputs, since these tax costs are actually paid by producers in the industry.

The major classes of intermediate inputs at the industry level are:

- materials
- business services
- leased capital.

The current input–output framework deals reasonably well in theory with the flows of materials but not with intersectoral flows of contracted labour services or rented capital equipment. The input-output system was designed long ago when the leasing of capital was not common and when firms had their own in house business services providers. Thus there is little or no provision for business service and leased capital intermediate inputs in the present system of accounts. With the exception of the manufacturing sector, even the intersectoral value flows of materials are largely incomplete in the industry statistics.

This lack of information means the current input–output accounts will have to be greatly expanded to construct reliable estimates of real value added by industry. At present, there are no surveys (to our knowledge) on the interindustry flows of business services or for the interindustry flows of leased capital. Another problem is that using present national accounts conventions, leased capital resides in the sector of ownership, which is generally the Finance sector. This leads to a large overstatement of the capital input into Finance and a corresponding underestimate of capital services into the sectors actually using the leased capital.

3.3 Labour Inputs

Using the number of employees as a measure of labour input into an industry will not usually be a very accurate measure of labour input due to the long term decline in average hours worked per full time worker and the recent increase in the use of part time workers. However, even total hours worked in an industry is not a satisfactory measure of labour input if the industry employs a mix of skilled and unskilled workers. Hours of work contributed by highly skilled workers generally contribute more to production than hours contributed by very unskilled workers. Hence, it is best to decompose aggregate labour compensation into its aggregate price and quantity components using index number theory. The practical problem faced by statistical agencies is: how should the various categories of labour be defined.

Another important problem associated with measuring real labour input is finding an appropriate allocation of the operating surplus of proprietors and the self employed into labour and capital components. There are two broad approaches to this problem:
If demographic information on the self employed is available along with hours worked, then an imputed wage can be assigned to those hours worked based on the average wage earned by employees of similar skills and training. Then an imputed wage bill can be constructed and subtracted from the operating surplus of the self employed. The reduced amount of operating surplus can then be assigned to capital.
If information on the capital stocks utilized by the self employed is available, then these capital stocks can be assigned user costs and then an aggregate imputed rental can be subtracted from operating surplus. The reduced amount of operating surplus can then be assigned to labour. These imputed labour earnings can then be divided by hours worked by proprietors to obtain an imputed wage rate.

The problems posed by allocating the operating surplus of the self employed are becoming increasingly more important as this type of employment grows. As far as we can determine, little has been done in countries other than the U.S. to resolve these problems. Fundamentally, the problem appears to be that the current System of National Accounts (SNA) does not address this problem adequately.

3.4 Reproducible Capital Inputs

When a firm purchases a durable capital input, it is not appropriate to allocate the entire purchase price as a cost to the initial period when the asset was purchased. It is necessary to distribute this initial purchase cost across the useful life of the asset. National income accountants recognize this and use depreciation accounts to do this distribution of the initial cost over the life of the asset. However, national income accountants are reluctant to recognize the interest tied up in the purchase of the asset as a true economic cost. Rather, they tend to regard interest as a transfer payment. Thus the user cost of an asset (which recognizes the opportunity cost of capital as a valid economic cost) is not regarded as a valid approach to valuing the services provided by a durable capital input by many national income accountants. However, if a firm buys a durable capital input and leases or rents it to another sector, national income accountants regard the induced rental as a legitimate cost for the using industry. It seems very unlikely that the leasing price does not include an allowance for the capital tied up by the initial purchase of the asset; ie, market rental prices include interest. Hence, it seems reasonable to include an imputed interest cost in the user cost of capital even when the asset is not leased. Put another way, interest is still not accepted as a cost of production in the SNA, since it is regarded as an unproductive transfer payment. But interest is productive; it is the cost of inducing savers to forego immediate consumption.

The treatment of capital gains on assets is even more controversial than the national accounts treatment of interest. In the national accounts, capital gains are not accepted as an intertemporal benefit of production but if resources are transferred from a period where they are less valuable to a period where they are more highly valued, then a gain has occurred; ie, capital gains are productive according to this view.

However, the treatment of interest and capital gains poses practical problems for statistical agencies. For example, which interest rate should be used?

- An ex post economy wide rate of return which is the alternative used by Christensen and Jorgenson (1969) (1970)?
- An ex post firm or sectoral rate of return? This method seems appropriate from the viewpoint of measuring ex post performance.
- An ex ante safe rate of return like a Federal Government one year bond rate? This method seems appropriate from the viewpoint of constructing ex ante user costs that could be used in econometric models.
- Or should the ex ante safe rate be adjusted for the risk of the firm or industry?

Since the ex ante user cost concept is not observable, the statistical agency will have to make somewhat arbitrary decisions in order to construct expected capital gains. This is a strong disadvantage of the ex ante concept. On the other hand, the use of the ex post concept will lead to rather large fluctuations in user costs, which in some cases will lead to negative user costs, which in turn may be hard to explain to users. However, a negative user cost simply indicates that instead of the asset declining in value over the period of use, it rose in value to a sufficient extent to offset deterioration. Hence, instead of the asset being an input cost to the economy during the period, it becomes an intertemporal output.

The distinction between depreciation (a decline in value of the asset over the accounting period) and deterioration (a decline in the physical efficiency of the asset over the accounting period) is now well understood but has still received little recognition in the latest version of the SNA.

A further complication is that our empirical information on the actual efficiency decline of assets is weak. We do not have good information on the useful lives of assets. The UK statistician assumes machinery and equipment in manufacturing lasts on average 26 years while the Japanese statistician assumes machinery and equipment in manufacturing lasts on average 11 years; see the OECD (1993; 13). The problems involved in measuring capital input are also being addressed by the Canberra Group on Capital Measurement, which is an informal working group of international statisticians dedicated to resolving some of these measurement problems.

A final set of problems associated with the construction of user costs is the treatment of business income taxes: should we assume firms are as clever as Hall and Jorgenson (1967) and can work out their rather complex tax–adjusted user costs of capital or should we go to the accounting literature and allocate capital taxes in the rather unsophisticated ways that are suggested there?

3.5 Inventories

Because interest is not a cost of production in the national accounts and the depreciation rate for inventories is close to zero, most productivity studies neglect the user cost of inventories. This leads to misleading productivity statistics for industries where inventories are large relative to output, such as retailing and wholesaling. In particular, rates of return that are computed neglecting inventories will be too high since the opportunity cost of capital that is tied up in holding the beginning of the period stocks of inventories is neglected.

The problems involved in accounting for inventories are complicated by the way accountants and the tax authorities treat inventories. These accounting treatments of inventories are problematic in periods of high or moderate inflation. A treatment of inventories that is suitable for productivity measurement can be found in Diewert and Smith (1994). These inventory accounting problems seem to carry over to the national accounts in that for virtually all OECD countries, there are time periods where the real change in inventories has the opposite sign to the corresponding nominal change in inventories. This seems logically inconsistent.

3.6 Land

The current SNA has no role for land as a factor of production, perhaps because it is thought that the quantity of land in use remains roughly constant across time and hence it can be treated as a fixed, unchanging factor in the analysis of production. However, the quantity of land in use by any particular firm or industry does change over time. Moreover, the price of land can change dramatically over time and thus the user cost of land will also change over time and this changing user cost will, in general, affect correctly measured productivity.

Land ties up capital just like inventories (both are zero depreciation assets). Hence, when computing ex post rates of return earned by a production unit, it is important to account for the opportunity cost of capital tied up in land. Neglect of this factor can lead to biased rates of return on financial capital employed. Thus, industry rates of return and TFP estimates will not be accurate for sectors like agriculture which are land intensive.

Finally, property taxes that fall on land must be included as part of the user cost of land. In general, it may not be easy to separate the land part of property taxes from the structures part. In the national accounts, property taxes (which are input taxes) are lumped together with other indirect taxes that fall on outputs which is another shortcoming of the current SNA.

3.7 Resources

Examples of resource inputs include:

- Depletion of fishing stocks, forests, mines and oil wells.
- Improvement of air, land or water environmental quality (these are resource “outputs” if improvements have taken place and are resource “inputs” if degradation has occurred).

The correct prices for resource depletion inputs are the gross rents (including resource taxes) that these factors of production earn. Resource rents are usually not linked up with the depletion of resource stocks in the national accounts although some countries, including the U.S. and Canada), are developing statistics for forest, mining and oil depletion; see Nordhaus and Kokkelenberg (1999).

The pricing of environmental inputs or outputs is much more difficult. From the viewpoint of traditional productivity analysis based on shifts in the production function, the ‘correct’ environmental quality prices are marginal rates of transformation while, from a consumer welfare point of view, the ‘correct’ prices are marginal rates of substitution; see Gollop and Swinand (2000).

The above seven major classes of inputs and outputs represent a minimal classification scheme for organizing information to measure TFP at the sectoral level. Unfortunately, no country has yet been able to provide satisfactory price and quantity information on all seven of these classes. To fill in the data gaps, it would be necessary for governments to expand the budget of the relevant statistical agencies considerably. This is one area of government expenditure that cannot be readily filled by the private sector. Given the importance of productivity improvements in improving standards of living, the accurate measurement of productivity seems necessary.

There are also additional types of capital that should be distinguished in a more complete classification of commodity flows and stocks such as knowledge or intellectual capital, working capital or financial capital and infrastructure capital. Knowledge capital, in particular, is important for understanding precisely how process and product innovations (which drive TFP) are generated and diffused. In the following subsections, we will comment on some of the measurement problems associated with these more esoteric kinds of capital.

3.8 Working Capital, Money and other Financial Instruments

Firms hold money and other forms of working capital so since there is an opportunity cost associated with holding stocks of these assets over an accounting period, these assets must provide useful services in the production process. In theory, the demand for working capital and other financial assets could be modeled in the same way that the demand for physical inventories is modeled. However, the firm's demand for money is complicated by the fact that the need for money is somewhat dependent on the price level (and changes in the price level). It turns out that both in the consumer and producer theory contexts, it is not a trivial matter to derive the "right" price deflator for monetary balances. The "right" deflator depends on ones theory of how money enters the constraints of the consumer's and producer's constrained maximization problems. The two most satisfactory models are perhaps the producer model of Fischer (1974) and the consumer model of Feenstra (1986). But both of these models are highly aggregated and there is a need to generalize their deflator results to higher dimensionality models. Until economists come up with a detailed satisfactory theory of the demand for money, it is difficult to ask statistical agencies to construct appropriate user costs for money.

Increasingly, nonfinancial firms hold an array of "regular" financial instruments such as stocks, bonds, insurance policies and mortgages but also of "esoteric" financial instruments such as futures contracts, currency and commodity options and other contracts that manage risks. Obviously, the demand for these commodities that involve risk in an essential way is not easy to model. Although there is a huge theoretical literature on this topic, no clear direction seems to have been provided to statistical agencies on how to calculate appropriate prices and quantities for these risky financial instruments.[5]

3.9 Knowledge Capital

In view of the recent stock market boom involving firms that provide knowledge intensive or high tech products, it is important to be able to define a firm's stock of

[5] For some hints on how to proceed, see Diewert (1993) (1995) and Barnett and Serletis (2000).

knowledge capital. However, it is difficult to define what we mean by *knowledge capital* and the related concept of *innovation*. We attempt to define these concepts in the context of production theory.

We think in terms of a local market area. In this area, there is a list of establishments or production units. Each establishment produces outputs and uses inputs during each period that it exists. *Establishment knowledge* at a given time is the set of input and output combinations that a local establishment could produce during at that given time period t. It is the economist's period t production function or period t production possibilities set. *Establishment innovation* is the set of *new* input-output combinations that an establishment in the local market area could produce in the current period compared to the previous period; i.e., it is the growth in establishment knowledge or the increase in the size of the current period production possibilities set compared to the previous period's set. Since the statistical agency cannot know exactly what a given establishment's production possibilities is at any moment in time, it will be difficult to distinguish between *substitution* of one input for another within a given production possibilities set versus an *expansion* of the production possibilities set; i.e., it will be difficult to distinguish between substitution along a production function versus a shift in the production function.

Note that both process and product innovations are included in the above definition of establishment innovation. Product innovations lead to additions to the list of outputs, which traditional index number theory is not well adapted to deal with but the shadow price technique introduced by Hicks (1940)[6] and implemented by Hausman (1997)(1999) could be used.

Note also that our definition of establishment innovation includes all technology transfers from outside of the establishment. We could further decompose innovations into *local* ones or *global* ones. A *global innovation* is the invention of a new set of input-output coefficients for the first time in the world; i.e., the invention of a brand new product or process or method of organization. A *local innovation* to a given establishment is merely the application of a global innovation to the local marketplace. However, local innovations are just as important as global innovations. A global innovation developed somewhere in the world is useless to a local business unit if the new technology is not *transmitted* or *diffused* to the local establishment. In our view, the diffusion of a new product or process to the local economy is at least as important as the actual creation of the new knowledge for the first time.[7]

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[6] Hicks (1969; 55-56) later described these index number difficulties as follows: "Gains and losses that result from price chages (such as those just considered) would be measurable easily enough by our regular index number technique, if we had the facts; but the gains which result from the availability of new commodities, which were previously not available at all, would be inclined to slip through. (This is the same kind of trouble as besets the modern national income statistician when he seeks to allow for quality changes.) … The variety of goods available is increased, with all the widening of life that that entails. This is a gain which quantitative economic history which works with index numbers of real income, is ill-fitted to measure or even describe."

[7] This highlights the important role that business consulting firms can play in diffusing best practice technology or organizational techniques into the local economy.

How can we measure knowledge capital?[8] Given the way we have defined knowledge (as time dependent, firm specific production possibility sets), it is extremely difficult to measure knowledge and changes in knowledge (innovation). Some of the possible input-output combinations that a production unit can produce are imbedded in its capital equipment and the accompanying manuals. Other possible combinations of inputs and outputs might be imbedded in its patents or the unpublished notes of the scientists that developed the patents. Yet other combinations might be imbedded in the brains of its workers. However, there are certain stocks that we can measure that will probably be positively correlated with the size of local knowledge stocks. A *science and technology statistical system* should concentrate on collecting information on these knowledge related stocks. Some possible candidates for data collection are:

- stocks of patents; (how should these be valued and what depreciation rate should be used?)
- research and development expenditures; (how should these be deflated and what depreciation rate should be used?)
- education and training undertaken in the firm; (how to value this?)
- trade fairs and professional meetings; (in the local area only or do we also count the fairs and meetings abroad attended by local employees?)
- availability of universities and research labs in the local region;
- stocks of books, journals, blueprints within the firm;
- availability of local libraries;
- local availability of trade magazines, newspapers, and how to do it books; (i.e., availability of local bookstores);
- availability of mail service;
- availability of internet services;
- ease of access to business consultants who can inform firms of what best practice input-output coefficients look like and then help the business unit to achieve the best practice technology;
- participation of the local community in business associations, clubs and societies.

Obviously, it is very difficult to pin down exactly how knowledge flows into the local economy. However, the growth in information available over the internet, the growth in business consulting services and the growth in "how to do it books" all play an important role.

The above considerations bring up the positive role of advertising and marketing in transmitting useful information about new products and technologies to other business units.

[8] One can form rough estimates of how the market *values* the knowledge capital of publicly traded firms by subtracting estimates of the firm's physical capital stock plus net financial assets from the firm's stock market valuation. However, the problem of converting this value estimate into a real magnitude remains.

3.10 Infrastructure Capital

Examples of infrastructure capital inputs are:

- roads
- airports
- harbors
- water supply
- electricity supply
- sewage disposal
- garbage disposal
- telephone, cable TV and internet hookup.

Many of the above stocks will appear in the list of reproducible capital stocks if privately owned. However, it still may be useful to distinguish the various types of infrastructure capital from ordinary structures. Publicly owned roads present special problems: they provide valuable services to business users but their price to the users is zero. Here is another example (in addition to the example of environmental prices) of demand prices being quite different from supply prices.

There is a connection of infrastructure capital with knowledge capital. From Adam Smith and Alfred Marshall, we know that the bigger the market, the more establishments can specialize; i.e., create new local commodities. Thus reduction of transportation costs within and without the local region can widen the market and reduce the costs of importing knowledge.

Similarly, a reduction in communication costs can make international and interregional knowledge more accessible to local establishments. Thus it seems likely that regions that are “large” and have “good” infrastructure facilities will have easier access to knowledge stocks, which in turn, should lead to higher rates of productivity growth.

Before moving on to other productivity related topics, we sum up the above material on measuring inputs and outputs of a production unit. We note that most total factor productivity studies use only the information associated with output category 1 (outputs) and input categories 2 (intermediate inputs), 3 (labor) and 4 (reproducible capital). Typically, labor productivity studies use only information from categories 1 and 3 while many total factor productivity studies use only information from categories 1, 3 and 4. I believe that these productivity studies are of very limited use. A more meaningful productivity study would use information on all categories and use at least categories 1-6. However, the valuation problems in categories 7-10 are formidable, both from the practical and conceptual points of view.

In the following section, we note that there are some additional measurement problems that arise at the sectoral level that are due to the impossibility of calculating accurate input-output coefficients for real commodity flows across industries that add up properly.

4. On the Difficulty of Obtaining Accurate Real Input-Output Coefficients

All of the productivity comparisons for manufacturing industries between Canada and the U.S. rely on the information on gross output and intermediate input flows that can be obtained from the country current and constant dollar input-output tables. However, in addition to the measurement difficulties mentioned above associated with the accurate measurement of prices and quantities for the various classes of inputs and outputs, there are some *additional* measurement difficulties that are associated with the use of the constant dollar (or real) industry input-output tables.

Before we explain the problems, it is useful to give a bit of background information on how the input-output tables are constructed. Basically, one starts with a commodity classification for outputs. Usually, the most detailed commodity classification for which information is collected has around one or two thousand separate commodity classifications. Then all of the outputs of the given collection of production units in an industry are put into say 1000 separate commodity cells in value terms. Then the intermediate inputs used by the production units in the industry are also put into another 1000 separate commodity cells; i.e., the commodity classification for intermediate input usage is the same as for the outputs produced by each industry. So far, so good. Now to convert these value flows into constant dollar flows, the statistical agency constructs a price index for each of the 1000 outputs and simply divides each industry output cell by the corresponding price index. Similarly, to construct real intermediate input flows by industry, each of the 1000 intermediate input value flows for each industry is divided by the corresponding price index, where the *same* output commodity price index is used to deflate the corresponding class of intermediate input flows.

There are a number of problems associated with the above methodology:

- The *same* commodity price deflator is generally used to deflate the appropriate commodity value flows for *each and every industry*. This procedure is correct if *each* industry produces precisely the same mix of micro commodities within each of the 1000 broad commodity classes in the commodity classification and micro commodity prices are constant across industries.[9] Since a typical advanced economy produces millions of commodities, it is extremely unlikely that this mix condition will be satisfied.
- Even worse, the *same* commodity price index that is used to deflate outputs across industries is also used to deflate intermediate inputs across industries. This multiple use of the *same* price index is justified if each industry faces the *same* micro commodity prices (both for outputs and intermediate inputs) and *uses* the same mix of

[9] If an industry produces absolutely no outputs in a particular commodity class, then this industry obviously does not have to have the same mix of micro commodity production as the nonzero industries. Another case where the traditional procedure of using only a single deflator for a given commodity class to deflate value flows across industries will work is the case where the micro prices for that commodity class vary in strict proportion over time over all industries. This is an application of Hicks' (1946; 312-313) Aggregation Theorem to the producer context; see Khang (1971), Bruno (1978) and Diewert (1978b) for additional material.

micro commodities as intermediate inputs and in addition, *each* industry *produces* precisely the *same* mix of micro commodities within each of the 1000 broad commodity classes in the commodity classification. Again, it is extremely unlikely that this set of necessary conditions will be met.[10] Moreover, there are very strong reasons for the micro commodity *output prices* for a given commodity class to differ substantially from the corresponding micro commodity intermediate *input prices* due to the existence of *transportation costs* that occur as an output produced by one firm is shipped to another firm to be used as an intermediate input. Finally, certain classes of commodities, such as gasoline, are subject to commodity taxes that occur within the aggregate production sector. Thus the refiner of gas gets a lower price per liter of product produced than the trucking firm pays per liter when it purchases a liter of gas, due to the existence of substantial indirect taxes.

- Often the statistical agency has information on the disposition of the total supply less intermediate demand for some of the commodity classes. This information can be used to correct gross errors in the basic input-output data, at least in value terms, because the values are additive across cells. This same value information can also used in order to make the corresponding deflated data add up to the "correct" total provided that the same price deflator is used to deflate all of the value cells. Recalling the above two points, it can be seen that these constant dollar estimates will be subject to potentially very large measurement errors and will probably fluctuate quite erratically. However, if the statistical agency has independent information on quantities (in addition to value information) and attempts to balance the constant dollar supplies less intermediate demands using this information, this will just tend to introduce additional measurement errors because there is no reason to expect these "real" flows to be additive.[11] Thus *this balancing of real flows exercise has the potential to introduce very large errors into the constant dollar input-output matrices*.

In my opinion, the above problems with the existing statistical agency input-output methodology make the use of constant dollar input-output tables as a source of data for industry productivity studies a very risky undertaking. These data are bound to be filled with measurement errors. Thus there is an urgent need for statistical agencies to take a new look at the existing input-output methodology.

How could the above problems with the existing input-output methodology be corrected? The answer to this question of course depends on ones purpose. If our purpose is to measure industry productivity, then the answer is reasonably straightforward (but expensive). The existing theoretical framework is fine for allocating value flows so no conceptual changes are required for the current dollar input-output matrices. However, when calculating the constant dollar input-output matrices, *each value cell for outputs*

[10] For example, the existence of quantity discounts on the part of a supplier of a good or service to other firms will create a dispersion in output prices for selling firms as well as in intermediate input prices for the purchasing firms. Also randomly distributed government subsidies will create dispersion in output prices for the same commodity across firms and industries.

[11] Essentially, what we are saying here is that there is still an index number problem in aggregating up commodities *within* each of the 1000 or so commodity classes. While values within each commodity class are additive, the corresponding deflated values are not because we require specific deflators for each industry.

and each value cell for inputs needs to be deflated by a separate price index that matches up with the value flows in that cell. Thus if we have 100 industries and 1000 commodity classes, the current methodology requires only 1000 commodity price deflators. The revised "productivity" methodology[12] would require, in principle, (if there were no empty value cells), 100,000 separate output price deflators and an additional 100,000 separate intermediate input price deflators![13] To complete the system, we would require an additional 1000 deflators to deflate deliveries to final demand[14] by the production system as a whole for each of our 1000 commodity classifications.

In addition to the above *conceptual* index number problems with the constant dollar input-output accounts, there are some other *practical* problems associated with the current statistical system:

- *The present input-output commodity classification has remained frozen in time since the 1950's*. There is a good reason for this: if the statistical agency attempts to change the classification, users tend to howl with outrage that they can no longer obtain long time series on a consistent basis. This is true[15] but the present commodity classification pertains to a time period when primary and manufacturing industries were perhaps 60% of the economy and services were the remaining 40%. Now, service industries might represent 70% of the economy but the commodity and industry classifications have not kept up with this change in the structure of a modern economy.[16] In the 50 years since the first input-output tables have appeared, thousands of important new goods and services have appeared. These new goods and services are simply arbitrarily lumped in with the older goods and services that happened to be around 50 years ago. In particular, the interindustry flows of business services and leased capital are almost entirely absent from the current input-output matrices.
- Not only is the classification system outdated, but even using the existing classification system, *the information on interindustry value flows is very*

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[12] A conceptual framework for the *output* and *intermediate input price deflators* emerges from this framework as well. An economy wide aggregate *output price deflator* could be constructed by aggregating the 100,000 (conceptually) separate industry by commodity output price indexes into an aggregate index using the 100,000 industry by commodity output values as weights. Similarly, an economy wide *aggregate intermediate input price deflator* could be constructed by aggregating the 100,000 (conceptually) separate industry by commodity intermediate input price indexes into an aggregate index using the 100,000 industry by commodity intermediate input values as weights. Finally, an aggregate GDP deflator could be obtained by aggregating the output price index and the intermediate input price index using a suitable bilateral index number formula with the value of gross production as the value weight for the gross output price and *minus* the value of intermediate input usage as the value weight for the aggregate intermediate input price.

[13] Obviously, this is too many deflators to construct. Some deflators would have to be used for more than one industry or we would have to reduce the number of commodities and/or industries.

[14] This is gross output less intermediate demands at producers' prices. Additional deflators would be needed on the demand side and these price indexes would incorporate any indirect commodity taxes that are levied as final demand purchases are made.

[15] In order to deal with this objection, it is necessary for the statistical agency to provide data on both the old and new classification systems for a number of years.

[16] In the 1991 Canadian input-output tables (see Statistics Canada (1995)), out of approximately 200 industries, about 40 are service sector industries and out of approximately 600 commodities, about 60 are service commodities.

> *incomplete*. There simply are no adequate surveys on the interindustry flows of services. Even in manufacturing, where information on commodity flows is relatively complete thanks to explicit surveys of manufacturing industries, no information on the flow of purchased services is collected.[17] In service industries, the situation is even worse: there is hardly any information collected on intermediate input purchases by service industries.

The reader will now understand why all intercountry comparisons of productivity growth at the industry level should be taken with a large grain of salt. The information base upon which these comparisons are based is far from being adequate. Statistical agencies, the government and ultimately the public will have to allocate additional resources so that the limitations of the currently available data from the system of input-output accounts can be remedied.

5. National Productivity Measurement versus Industry Productivity Measurement

Obviously, it would be useful if we could obtain accurate information on the growth of total factor productivity at the industry level because then we could determine more precisely where the growth (or lack of growth) is originating. However, as we have seen in the previous section, the current input-output statistics that are available from national statistical agencies in all countries are far from being accurate. However, the situation is not nearly as bleak when we attempt to measure TFP growth at the national level. This is due to the fact that generally speaking, deliveries to final demand made by the aggregate production sector are in fact accurately measured and moreover, there are reasonably accurate price indexes that are constructed for the various components of final demand.[18] Moreover, at the level of the entire market economy, intermediate inputs collapse down to just imports plus purchases of government and other nonmarket inputs. This simplification of the hugely complex web of interindustry transactions of goods and services explains why it is much easier to measure productivity at the national level than at the industry level. Also, when we measure the input of primary factors of production at the national level, we do not have to worry about errors that might have been made in classifying these inputs into an industry.[19] Similarly, we do not have to keep track of changes in the classification of firms to industries and of sales of used assets from one industry to another. Thus measurement of total factor productivity at the national level is

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[17] Again, the origin of these manufacturing surveys dates back 50 or more years when interindustry flows of services were not important.

[18] There is one difficulty with using these price indexes for productivity measurement purposes: they include indirect taxes (less subsidies). This is the correct treatment of indirect taxes from the viewpoint of modeling the behavior of purchasers but it is not correct for modeling the behavior of producers. Producers do not get any revenue from these indirect taxes and so these taxes should be removed (and subsidies added) from the price indexes. However, indirect taxes that fall on inputs (such as property taxes) should be included in prices for purposes of productivity measurement. This "correct" treatment of indirect taxes dates back to Jorgenson and Griliches (1967) (1972) at least. Thus conceptually, the producer commodity price indexes that pertain to net deliveries to final demand will be different from the corresponding consumer price indexes.

[19] Actually, we still have to worry about the classification of inputs into the private business sector and the general government sector.

likely to be much more accurate than the measurement of total factor productivity at the industry level.

6. Conclusion

The current system of industry statistics that is used by every advanced country today has not kept up with the evolution of the world economy from primary and manufacturing production to the production of services. As a result, inter country comparisons of total factor productivity growth at the industry level are not likely to be very accurate. Ultimately, the public will have to support additional resources being allocated to statistical agencies so that this neglect of services measurement can be addressed.

There are some positive signs that the neglect of services problem is beginning to be addressed. The new North American Industrial Classification will be implemented in North America in the near future and the number of service sector industries has been greatly expanded in this classification. This in turn is leading to an updating of the commodity classification in North America to add many new service commodities. Finally, the Bureau of Labor Statistics in the U.S. has several initiatives under way to greatly expand their coverage of service sector industries and commodities.

References

Balk, B.M. (1995), “Axiomatic Price Index Theory”, *International Statistical Review* 63, 69-93.

Barnett, W. and A. Serletis (eds.) (2000), *The Theory of Monetary Aggregation*, forthcoming.

Bruno, M. (1978), “Duality, Intermediate Inputs and Value-Added”, pp. 3-16 in *Production Economics: A Dual Approach to Theory and Applications*, Volume 2, M. Fuss and D. McFadden (eds.), Amsterdam: North-Holland.

Bureau of Labor Statistics (1983), *Trends in Multifactor Productivity*, 1948-81, Bulletin 2178, U.S. Government Printing Office, Washington, D.C.

Christensen, L.R. and D.W. Jorgenson (1969), “The Measurement of U.S. Real Capital Input, 1929-1967,” *Review of Income and Wealth* 15(4): 293-320.

Christensen, L.R. and D.W. Jorgenson (1970), “U.S. Real Product and Real Factor Input, 1929-1967,” *Review of Income and Wealth* 16(1): 19-50.

Coulombe, S. (2000), “Three Suggestions to Improve Multifactor Productivity Measurement in Canadian Manufacturing”, paper presented at the CSLS Conference on the Canada-U.S. Manufacturing Productivity Gap”, January 21-22, Ottawa Ontario.

Dean, E. and M. Harper (2000), “The BLS Productivity Program”, paper presented at the Conference on Research in Income and Wealth conference at Washington D.C., 1998 *on New Directions in Productivity Analysis*, University of Chicago Press, forthcoming.

Denison, E.F. (1985), *Trends in American Growth, 1929-1982*, The Brookings Institution, Washington, D.C.

Diewert, W.E. (1976), “Exact and Superlative Index Numbers”, *Journal of Econometrics* 4, 115-145. (Reprinted in *Essays in Index Number Theory*, Volume 1, W.E. Diewert and A.O. Nakamura (eds.), Amsterdam: North-Holland).

Diewert, W.E. (1978a), “Superlative Index Numbers and Consistency in Aggregation”, *Econometrica* 46, 883-900.

Diewert, W.E. (1978b), “Hicks’ Aggregation Theorem and the Existence of a Real Value added Function”, pp. 17-51 in *Production Economics: A Dual Approach to Theory and Applications*, Volume 2, M. Fuss and D. McFadden (eds.), Amsterdam: North-Holland. (Reprinted in *Essays in Index Number Theory*, Volume 1, W.E. Diewert and A.O. Nakamura (eds.), Amsterdam: North-Holland, 1993).

Diewert, W.E. (1980), “Aggregation Problems in the Measurement of Capital”, pp. 433-528 in *The Measurement of Capital*, Dan Usher (ed.), University of Chicago Press, Chicago.

Diewert, W.E. (1992a), “The Measurement of Productivity”, *Bulletin of Economic Research* 44:3, 163-198.

Diewert, W.E. (1992b), “Fisher Ideal Output, Input, and Productivity Indexes Revisited,” *Journal of Productivity Analysis* 3, 211-248.

Diewert, W.E. (1993), “Symmetric Means and Choice Under Uncertainty”, *in Essays in Index Number Theory*, Volume I, W.E. Diewert and A.O. Nakamura (eds.), Amsterdam: North Holland, pp. 355-433.

Diewert, W.E. (1995), “Functional Form Problems in Modeling Insurance and Gambling”, *The Geneva Papers on Risk and Insurance Theory* 20, 135-150.

Diewert, W.E. (1996), “Price and Volume Measures in the System of National Accounts”, pp. 237-297 in *The New System of National Economic Accounts*, J. Kendrick (ed.), Norwell, MA: Kluwer Academic Publishers.

Diewert, W.E. and D. Lawrence (1999), “Progress in Measuring the Price and Quantity of Capital”, Discussion Paper 99-17, Department of Economics, University of British Columbia, Vancouver, Canada, V6T 1Z1.

Diewert, W.E. and A.M. Smith (1994), “Productivity Measurement for a Distribution Firm”, *Journal of Productivity Analysis* 5, 335-347.

Feenstra, R.C. (1986), “Functional Equivalence Between Liquidity Costs and the Utility of Money”, *Journal of Monetary Economics* 17, 271-291.

Fischer, S. (1974), “Money and the Production Function”, *Economic Inquiry* 12, 518-533.

Griliches, Z. (1970), “Notes on the Role of Education in Production Functions and Growth Accounting”, pp. 71-115 in *Education and Income*, Lee Hansen (ed.), NBER Studies in Income and Wealth, volume 35, New York: Columbia University Press.

Griliches, Z. and D.W. Jorgenson (1966), “Sources of Measured Productivity Change: Capital Input”, *American Economic Review* 56:2, 50-61.

Gollop, F. and G. Swinand (2000), “Total Resource Productivity: Accounting for Changing Environmental Quality’, paper presented at the Conference on Research in Income and Wealth conference at Washington D.C. 1998 on *New Directions in Productivity Analysis*, University of Chicago Press, forthcoming.

Gu, W. and M. Ho (2000), "A Comparison of Productivity Growth in Manufacturing between Canada and the United States, 1961-95", paper presented at the CSLS Conference on the Canada-U.S. Manufacturing Productivity Gap", January 21-22, Ottawa Ontario.

Hall, R.E. and D.W. Jorgenson, (1967), "Tax Policy and Investment Behavior", *American Economic Review* 57, 391-414.

Harper, M.J., E.R. Berndt and D.O. Wood (1989), "Rates of Return and Capital Aggregation Using Alternative Rental Prices", pp. 331-372 *in Technology and Capital Formation*, D.W. Jorgenson and R. Landau (eds.), The MIT Press, Cambridge, MA.

Hausman, J.A. (1997), "Valuation of New Goods under Perfect and Imperfect Competition", pp. 209-237 in *The Economics of New Goods*, T.F. Bresnahan and R.J. Gordon (eds.), University of Chicago Press, Chicago.

Hausman, J.A. (1999), "Cellular Telephone, New Products and the CPI", *Journal of Business and Economic Statistics* 17, 1-7.

Hicks, J.R. (1940), "The Valuation of the Social Income", *Economica* 7, 105-140.

Hicks, J.R. (1946), *Value and Capital*, Second Edition, Oxford: Clarendon Press.

Hicks, J.R. (1969), *A Theory of Economic History*, Oxford: Oxford University Press.

Hill, T.P. (1988), "Recent Developments in Index Number Theory and Practice", *OECD Economic Studies* 10, 123-148.

Hill, T.P. (1993), "Price and Volume Measures", pp. 379-406 *in System of National Accounts 1993*, Eurostat, IMF, OECD, UN and World Bank, Luxembourg, Washington, D.C., Paris, New York, and Washington, D.C.

Jorgenson, D.W. and B.M. Fraumeni (1989), "The Accumulation of Human and Non-Human Capital, 1948-1984", pp. 227-282 *in The Measurement of Saving, Investment and Wealth*, R. Lipsey and H. Tice (eds.), University of Chicago Press, Chicago.

Jorgenson, D.W. and B.M. Fraumeni (1992), "Investment in Education and U.S. Economic Growth", *Scandinavian Journal of Economics* 94 (Supplement), 51-70.

Jorgenson, D.W., F.M. Gollop and B.M. Fraumeni (1987*), Productivity and U.S. Economic Growth*, Harvard University Press, Cambridge, Massachussetts.

Jorgenson, D.W. and Z. Griliches (1967), "The Explanation of Productivity Change", *Review of Economic Studies* 34, 249-283.

Jorgenson, D.W. and Z. Griliches (1972), "Issues in Growth Accounting: A Reply to Edward F. Denison", *Survey of Current Business* 52:5 part 2 (May), 65-94.

Khang, C. (1971), "An Isovalue Locus Involving Intermediate Goods and Its Applications to the Pure Theory of International Trade", *Journal of International Economics* 1, 315-325.

Lee, F. and J. Tang (2000), "An Assessment of Competitiveness and Productivity Levels: Canadian and U.S. Manufacturing Industries", paper presented at the CSLS Conference on the Canada-U.S. Manufacturing Productivity Gap", January 21-22, Ottawa Ontario.

Nordhaus, W.D. and E.D. Kokkelenberg (1999), *Nature's Numbers: Expanding the National Economic Accounts to Include the Environment*, Washington D.C.: National Academy Press.

OECD (1993), *Methods Used by OECD Countries to Measure Stocks of Fixed Capital, National Accounts: Sources and Methods No. 2*, Publications Service, Paris France: OECD.

Solow, R.M. (1957), "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics* 39, 312-320.

Statistics Canada (1995), *The Input-Output Structure of the Canadian Economy 1991*, Ottawa: Statistics Canada.

Statistics Canada (1997), *The National Balance Sheet Accounts, 1996*, Ottawa: Statistics Canada.

Wells, J.S., J. Baldwin and J.-P. Maynard (1999), "Productivity Growth in Canada and the United States', *Canadian Economic Observer*, September, Ottawa: Statistics Canada.