The Challenge of Total Factor Productivity Measurement

Erwin Diewert *
Department of Economics
University of British Columbia
Vancouver, Canada

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, namely intermediate inputs; reproducible capital inputs; inventories; land; resources; working capital, money, and other financial instruments; knowledge capital; and infrastructure capital. This article reviews the issues in developing reliable estimates for output, labour input, and the eight additional classes of input for total factor productivity measurement by industry.

The Definition of Total Factor Productivity

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. 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).

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. Thus if outputs grow 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. 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. Productivity researchers eventually decided to disaggregate hours worked by the demographic characteristics of the worker such as age, sex race, years of schooling and so on.

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.

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.

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, and 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.

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.

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.

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.

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; i.e., 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?

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.

A final set of problems associated with the construction of user costs is the treatment of business income taxes: should we assume firms are clever 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?

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.

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.

Resources

Examples of resource inputs include depletion of fishing stocks, forests, mines and oil wells and 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.

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.

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.

There are also additional types of capital that should be distinguished in a more complete classification of commodity flows and stocks. In the following subsections, we will comment on some of the measurement problems associated with these more esoteric kinds of capital.

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.

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.

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 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 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.

How can we measure knowledge capital? 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, such as stocks of patents, research and development expenditures; education and training undertaken in the firm.

Infrastructure Capital

Examples of infrastructure capital inputs are: roads; airports; harbors; water supply; electricity supply; sewage disposal; garbage disposal; telephone, and 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.

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 and inputs of intermediate inputs, labour, and reproducible capital. Typically, labor productivity studies use only information on output and labour input while many total factor productivity studies use only information from categories output, labour input, and reproducible capital. 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 the first six categories. However, the valuation problems for the remaining categories 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.

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. But there are some *additional* measurement difficulties that are associated with the use of the constant dollar (or real) industry input-output tables.

- The *same* commodity price deflator is generally used to deflate the appropriate commodity value flows for *each and every industry*. This procedure is only 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.
- Even worse, the *same* commodity price index that is used to deflate outputs across industries is also used to deflate intermediate inputs across industries.

In my opinion, the above problems 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.

In addition to the above *conceptual* 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.*
- Not only is the classification system outdated, but even using the existing classification system, *the information on interindustry value flows is very incomplete*.

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.

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.

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

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, intercountry 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.

Notes

* The unabridged version of this article with full references is found at www.csls.ca under the *International Productivity Monitor.* Email: diewert@econ.ubc.ca