Productivity Perspective in Australia: Conclusions and Future Directions

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Productivity Perspectives in Australia: Conclusions and Future Directions

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Abstract

The paper suggests some areas where the Australian Bureau of Statistics could improve the measurement of inputs and outputs in Australia so that economy wide and sectoral Total Factor Productivity of the Australian economy could be better measured. The paper also discusses the difficult measurement problems associated with determining the contribution of R&D to productivity growth.

Key words

Productivity, index numbers, measurement of labour input, measurement of capital input, measurement of output, measurement of depreciation rates for Research and Development, entry and exit of firms, treatment of inventory change.

Journal of Economic Literature Classification Codes

C8, C43, D24, E23, O32.

1. Introduction

As the last speaker at this conference, my task is threefold:

- to list any conclusions that might have emerged from the papers that were presented;
- to provide some future directions for improving the measurement of productivity in Australia and
- to provide possible policy directions for improving Australia's productivity performance.

However, before addressing the above topics, I would like to provide a few words of praise for the Australian Bureau of Statistics and the Productivity Commission. The ABS

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produces all of the basic data on inputs and outputs that are required in order to compute Australia's Labour Productivity (LP) and Total Factor Productivity (TFP)[2]. The ABS does an excellent job and is internationally recognized as one of the best statistical agencies in the world. On the other hand, the Productivity Commission educates the public about the importance of improving Australia's productivity performance and it provides some very useful advice on how Australia's productivity performance could be improved. I would also like to praise Australia's financial press, who do an excellent job of covering productivity and related policy issues.

The first task (to list any conclusions that might have emerged from the conference papers) will be discussed in section 2 below, where we will review some of the material presented by Eric Bartelsman (2004a) in his leadoff paper for this conference. We will also review some of the literature that links productivity to investments in R&D. The message that emerges from this section is that we should be cautious in making definitive conclusions on what factors can improve a country's productivity performance for two reasons:

- It is not a trivial exercise to measure productivity, particularly at the industry level (as opposed to the national level) and making cross country comparisons of productivity levels is particularly hazardous;
- Even if the productivity of a sector has been accurately measured, it is not a trivial exercise to determine exactly what factors "explain" the sector's productivity performance.

In view of the above uncertainties, I will not spend much time on my third task (to provide possible policy directions for improving Australia's productivity performance) but I note that the papers by Bartelsman (2004a), Graeme Davis (2004), Steve Dowrick (2004), Sid Shanks (2004), Dean Parham (2004) and Jimmy Louca (2004) all provide some observations on productivity performance that may be of interest to policy makers.[3]

Most of this paper will focus on my second task: to provide some future directions for improving the measurement of productivity in Australia. Thus in sections 3, 4 and 5 below, I follow in the footsteps of Carl Obst (2004) and focus on problem areas in the measurement of productivity for *outputs* (section 3), *labour inputs* (section 4) and *capital inputs* (section 5).

There are some additional measurement difficulties that do not fit neatly into the above three categories. Thus in section 6, we will discuss the problems involved in measuring inventory change. In section 7, we discuss some of the problems associated with the

[2] TFP is sometimes called Multifactor Productivity (MFP). TFP is the term used by Jorgenson and Griliches (1967) (1972) while the U.S. Bureau of Labor Statistics (1983) used the term MFP. Labour Productivity is output or value added divided by labour input while TFP is output or value added divided by total input. For a survey of some of the productivity measurement issues, see Diewert (1990) (2001) and Dean and Harper (2001)

[3] Many of these papers (or summaries of them) may be found on the Productivity Commission website: http://www.pc.gov.au/commission/work/productivity/conferences/pp2004/index.html

quality adjustment of prices, while section 8 discusses some of the difficulties in measuring productivity when *information on outputs and inputs is collected in different surveys*. Section 9 discusses some of the tricky issues that arise in the context of constructing industry productivity statistics: namely how should *indirect taxes* be treated in the productivity accounts? Section 10 offers a few comments on how to measure the contribution to productivity growth of *entering and exiting firms*.[4] Section 11 concludes with some suggestions for future directions that the Australian Bureau of Statistics might want to consider.

2. Productivity: Some of the Main Issues

Eric Bartelsman (2004a) presented an overview of some of the main issues and controversies associated with the measurement of productivity and its policy implications and we will summarize part of his discussion of these issues in this section. We will also treat the problem of measuring the contribution of investments in research and development (R&D) to productivity growth in some detail.

2.1 Approaches to the Measurement of Total Factor Productivity Growth

Total Factor Productivity Growth (TFPG) can be defined as the rate of growth of outputs[5] for some collection of business enterprises divided by the rate of growth of inputs used by these enterprises.[6] In most economies, outputs grow faster than inputs and so TFPG contributes to increases in a country's standard of living.

There are two broad approaches to measuring TFPG:

- The growth accounting or index number approach and
- The econometric estimation approach.

The modern growth accounting approach to the measurement of TFPG dates back to the seminal contribution of Solow (1957), who used the assumption of a single output constant returns to scale production function with aggregate labour and aggregate capital as inputs.[7] Using this framework, Solow was able to show that TFPG could be measured as a weighted average of output growth rates less a weighted average of input growth

[4] This topic is treated at much greater length in Bartelsman (2004b) and Bartelsman, Haltiwanger and Scarpetta (2004).
[5] In section 3 below, we will discuss in more detail the precise meaning of the word "output"; i.e., do we mean gross output or value added or something else?
[6] Labour Productivity Growth (LPG) is defined as the rate of growth of outputs divided by the rate of growth of labour input used by the business units in the aggregate under consideration. Parham (2004) explains the connection between TFPG and LPG. We regard TFPG as the more fundamental concept for "explaining" improvements in the standard of living (although LPG has its uses), since a high rate of labour productivity growth could be explained by a rapid rate of growth of nonlabour primary inputs.
[7] The growth accounting part of Solow's methodology can be traced back to Copeland (1937; 31) and several others including Kendrick (1961) and Abramovitz (1956). Tinbergen (1942) regressed output on labour and capital and a time trend, which is an early example of the econometric approach to productivity estimation. For a relatively recent survey of the index number and econometric approaches to the estimation of productivity, see Good, Nadiri and Sickles (1997).

rates. Jorgenson and Griliches (1967) (1972) improved upon Solow's framework in several respects:

- They generalized Solow's one output and two input methodology to the case of many outputs and many inputs;
- They used a more sophisticated index number formula (the Törnqvist Theil index) to aggregate inputs and outputs[8];
- They realized that labour hours are not homogeneous and advocated using wage rates as price weights for different types of labour[9];
- They introduced the idea of using rental prices or user costs of capital as price weights to aggregate the capital inputs[10] and
- They introduced the convention that indirect taxes that fall on outputs should be subtracted from output prices for productivity measurement purposes but that indirect taxes that fall on intermediate inputs should not be subtracted.[11]

A recent very useful reference that describes in some detail the growth accounting approach to the measurement of Total Factor Productivity Growth is Schreyer (2001).[12]

The second approach to measuring TFP growth dates back to Jan Tinbergen (1942), who econometrically estimated an aggregate production function that had a time trend as an exogenous variable. The coefficient on the time trend was interpreted as a measure of productivity growth. Tinbergen's approach is still in widespread use today.[13]

There are problems with both approaches to the measurement of productivity:

- The growth accounting approach assumes a constant returns to scale technology and competitive price taking behavior.[14]
- The econometric approach is not subject to the above difficulties but has some severe difficulties of its own: namely, it cannot deal adequately with a large

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[8] Diewert (1976) later showed that this index number formula was consistent with flexible functional forms for the production function aggregates.
[9] See also Christensen and Jorgenson (1970).
[10] See also Christensen and Jorgenson (1969).
[11] See Jorgenson and Griliches (1972; 85).
[12] Other useful references include Caves, Christensen and Diewert (1982), Diewert (1980) (1983) (1992), Diewert and Nakamura (2003) and McLellan (2004).
[13] See for example Berndt and Khaled (1979), Fox (1996) (1998) and Coelli, Rao and Battese (1997), where classical econometric approaches to the measurement of productivity change are explained along with new extensions, such as stochastic frontier estimation. Coelli, Rao and Battese also explain the growth accounting and nonparametric (or Data Envelopment) approaches to the estimation of relative efficiency. It is also possible to combine the index number method for estimating TFP with the econometric method; see Nakajima, Nakamura and Yoshioka (1998), Nakajima, Nakamura and Nakamura (2002) and Diewert and Fox (2004).
[14] Strictly speaking, this is not quite true: the growth accounting approach can be justified from an axiomatic perspective. However, the growth accounting approach cannot give us estimates of the degree of returns to scale nor can it determine the effects of externalities or of noncompetitive pricing behavior; econometric estimation is required in order to obtain estimates of these effects. Moreover, the growth accounting approach does not generate standard errors for key parameters as does the econometric approach.

number of inputs and outputs[15] and the results that the econometric approach generates are often fragile and are generally not reproducible.[16]

In the following subsection, we will look in more detail at some of the difficulties associated with the econometric approach to the measurement of productivity. In particular, we will look at the econometric literature on estimating the effects of investments in R&D on productivity growth.

2.2 The Effects of Investments in R&D on Productivity Growth

To illustrate some of the problems with econometric techniques, consider the evidence on spillovers cited by Dowrick (2004) on the social returns to R&D. Dowrick's (2004) review of the R&D and spillovers literature finds social rates of return to R&D investments in the 20% to 85% range. An early paper in this econometric literature is Bernstein and Nadiri (1988), who found that private rates of return to investments in R&D in five U.S. manufacturing industries over the years 1961-1981 averaged 16.7% per year compared to rates of return on physical capital that averaged 9.6% per year.[17] However, Bernstein and Nadiri (1988; 433) found that when they took into account the effects of spillovers, social rates of return to R&D investments in these five industries averaged an astounding 50.0% per year.[18] These rates of return on R&D investments perhaps seem high but they are typical of the rates that are found in this econometric literature.[19]

These econometric estimates of private and social rates of return to investments in R&D are almost surely much too high. These high rates of return are obtained by estimating a

[15] Multicollinearity becomes a problem under these conditions.

[16] By a lack of reproducibility, I mean that if we took two econometricians off the street and posed to them our estimation problem and then asked them to estimate an econometric model, then in general, the results of the two investigations would be different (and frequently quite different). Different investigators will choose different explanatory variables, make different functional form assumptions, choose different instrumental variables in a simultaneous equations model, make alternative stochastic assumptions and use alternative methods of estimation. For example, Diewert and Fox (2004), using exact index number techniques and drawing on the work of Nakajima, Nakamura and Yoshioka (1998) and Nakajima, Nakamura and Nakamura (2002), worked out a simple econometric method for estimating the contribution of returns to scale to productivity growth. Their method involved regressing aggregate input growth on aggregate output growth. However, if output growth were regressed on input growth, the resulting estimate of returns to scale became substantially smaller on average. This inequality is a consequence of the Cauchy Schwarz inequality; see Bartelsman (1995). But which method yields estimates closer to the "truth"? The use of an instrumental variable method of estimation will not resolve the uncertainty since different choices of instruments can lead to very different estimates.

[17] See Table 2 in Bernstein and Nadiri (1988; 432).

[18] See Table 3 in Bernstein and Nadiri (1988; 433). These rates of return include depreciation and income tax effects so they are exaggerated for these reasons.

[19] See also Bernstein and Nadiri (1991) and Nadiri (1993). Bernstein (1996; S464) found that the nominal before tax, gross of depreciation private rates of return to R&D investments for 11 manufacturing industries in the U.S. and Canada over the period 1964-1986 averaged around 13% in Canada and around 16% in the U.S. Bernstein (1996; S466) also found that the average annual social rate of return on R&D investments over this period averaged an astounding 115% per year in both countries. It should be noted that after tax real rates of return on all tangible assets (including land and inventories) averaged around 3 to 5 % per year in most advanced countries; see Robbins and Robbins (1992).

production function (or a factor requirements function) where an output measure is regressed on measures of labour, capital and an R&D stock variable.[20] There is no time trend in the regression so the R&D stock variable picks up not only the output augmenting effects of investments in R&D (which is entirely appropriate) but also the effects of other methods of improving the efficiency of the economy or industrial sector (which is inappropriate).[21] Some of the other productivity improving effects that generally trend with time are the effects of industry annual meetings and trade fairs where successful business practices are diffused into the general population.[22] Business consultants and benchmarking experts also diffuse best practice techniques into general use. A general increase in the education levels of the population could also be a source of productivity gains.[23] Experience or learning by doing is another source of gains. In summary: investments in R&D probably account for only a fraction of the improvements in productivity that occur through other channels but by neglecting these other factors (which are often difficult to measure) in the econometric model, virtually all[24] of the industry's productivity improvement is incorrectly attributed to R&D investments.[25]

In the following subsection, we look more closely at some of the accounting problems associated with investments in R&D (and other intangible asset investments).

2.3 Are Private Sector R&D Investments the Same as Investments in Plant and Equipment?

There is another problem with the econometric literature on measuring the benefits of investments in R&D: R&D investments are treated in a manner similar to investments in

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[20] High rates of return are also estimated in Cobb-Douglas type models that include a time trend; see for example the papers in Griliches (1998). But the Cobb-Douglas framework suffers from other biases due to its restrictive assumptions; i.e., each elasticity of substitution between every pair of inputs is a priori restricted to be one.

[21] It should be mentioned that the recent paper by Bernstein and Mamuneas (2005) does not suffer from this defect. We discuss their work in more detail in section 2.6 below. Using annual data for four US manufacturing industries for the years 1954-2000, they found that R&D investments depreciate at annual rates of 18 percent for chemical products, 26 percent for nonelectrical machinery, 29 percent for electrical products and 21 percent for transportation equipment. They do not attempt to estimate separate rates of return to R&D investments in this paper; i.e., they assume R&D investments earn the same rate of return as reproducible capital investments.

[22] However, Jeff Bernstein in a private communication pointed out that R&D may be the ultimate explanatory variable for some of these other channels for productivity improvements.

[23] See Dowrick (2004) on this topic.

[24] If the econometric model allows for nonconstant returns to scale, then the sector's productivity gains will be attributed to the combined effects of increasing returns to scale and the effects of R&D investments.

[25] This problem has been recognized in the R&D and spillovers literature: "The high correlation between the stock of R&D and time precluded the introduction of time as another exogenous shift variable. Clearly, future research should explore the relative contributions of R&D and exogenous technical change to growth in more detail, possibly based on a more disaggregated data set and a richer model specification." M. Ishaq Nadiri and Ingmar R. Prucha (1996; 44). This multicollinearity problem is even worse if the econometrician attempts to measure nonconstant returns to scale and spillovers, since time, the firm's own R&D capital stock, the R&D capital stock of competitors and output will frequently have a similar upward trend, which means that the separate effects of each of these factors cannot be accurately identified by the use of econometric methods.

physical capital.[26] Thus the econometrician forms nominal dollar estimates of R&D investments in the industry or firm or other production unit under consideration by time period, deflates these investments into constant dollar investments, assumes a depreciation rate (usually between 10 and 15 percent per year) and forms an R&D capital stock in a manner that is analogous to forming a structures capital stock. This R&D capital stock is then used as an exogenous variable in the regression of output on input.[27] Aside from the arbitrariness of the assumption about the magnitude of the R&D depreciation rate, this model of the effects of R&D seems wrong. R&D is not like other depreciable assets which gradually wear out through use; rather R&D can be viewed as the creation of new technologies.[28] These new technologies may just reduce the cost of producing an existing commodity or they may create entirely new goods and services (process versus product innovation). In either case, the R&D "asset" is not like a "normal" reproducible capital asset that depreciates with use. The expenditures incurred in creating the R&D asset are sunk costs and they have no resale value as is the case with a purchase of a reproducible asset. However, a successful private sector R&D venture has created a new product or process that will give rise to a stream of profits in future periods. In many cases, the new technology can be licensed and the rights to use the new technology can be sold. Thus in the case of successful private R&D ventures, a new asset has been created: the rights to a (monopoly) stream of future incremental revenues. However, once a new successful technology has been created, expiry of patents, diffusion of knowledge about the innovation, even newer innovations by competitors and changing tastes all combine to reduce the stream of monopoly profits over time. Note that the effects of these factors, which reduce the value of the R&D asset over time, are difficult to forecast.[29]

To summarize the above discussion: a private sector R&D asset is much more complicated than a typical reproducible capital asset (like a structure or machine).[30] There are actually two "assets" associated with an R&D venture:

- The first *cost asset* is the cumulated costs of the R&D project and
- The second *revenue asset* is the discounted value of the incremental profits that the R&D project is expected to generate.

For any individual R&D project, it is unlikely that the R&D cost "asset" is equal to the R&D incremental revenue asset but, over a large population of R&D projects, we could

[26] This is not true for econometric models that estimate spillovers; see Bernstein (1996) and Bernstein and Nadiri (1991).
[27] This statement is not true of all of the econometric literature; in particular, Bernstein and Nadiri (1988) and Bernstein and Mamuneas (2005) treat R&D investments as endogenous variables.
[28] Note that the growth accounting approach to the treatment of R&D is subject to the same type of criticism: R&D is either expensed or capitalized using a somewhat arbitrary depreciation rate.
[29] Many of these points (and more) were made in Bernstein (2002).
[30] In some circumstances, there can be two assets associated with the purchase of a machine: (i) its cost and (ii) the discounted stream of incremental profits that the use of the machine generates within the firm, which is a substitute for the value of the used asset on the second hand market.

expect to see the value of the cost assets to be approximately equal to the value of the revenue assets.[31]

As defined above, the cost and revenue assets are defined in terms of nominal dollars. It is relatively straightforward to obtain a constant dollar counterpart to the nominal cost asset, provided that deflators are available for the important components of nominal expenditures on R&D projects, such as scientific and engineering personnel, structures, materials and instruments. However, it is not straightforward to obtain constant dollar estimates for the revenue asset. Since the discounted incremental revenues that the project is expected to yield are in units of today's dollar, the simplest approach to obtaining a constant dollar estimate for the revenue asset would be to deflate the current expected discounted profits estimate by a current general index of inflation.[32]

As was mentioned above, the cost asset is not really an asset: it is a sunk cost. In the present system of national accounts, SNA 1993, privately funded R&D expenditures are regarded as intermediate business expenses and are written off as they occur. This point of view is defensible, particularly for unsuccessful R&D ventures. However, for successful R&D ventures, it could be argued that it is "unfair" to write down current period income by these expenditures since these expenditures will eventually be recovered in future periods as the project's incremental revenues pour in to the firm. Hence, from this point of view, it makes sense to capitalize these R&D expenditures into an "asset" and depreciate this "asset" in a proportional manner to the future period incremental revenues. From this point of view, the problem is to determine how to *allocate* the cumulated cost of an R&D project over future periods. This accounting problem has a different character than the usual problems involved in depreciating reproducible capital stock investments, where information on used assets can be used if an opportunity cost approach to depreciation is used. For an R&D cost "asset", the problem is one of *matching* current costs with future expected revenues,[33] which is a rather daunting task!

2.4 How Should Public Sector Investments in R&D be Treated?

The above analysis is applicable for a *profit motivated firm*, which makes R&D investments. However, a substantial fraction of R&D expenditures in all market economies is usually funded by *governments* and often the fruits of government funded

[31] Adjusting for the risk inherent in R&D projects, we would expect that the value of the cost assets be less than the value of the revenue assets. Thus it is completely reasonable that R&D assets earn higher rates of return on average than reproducible capital assets.

[32] A producer price index over the gross outputs produced by the economy could be used but I would recommend the use of a consumer price index as the general deflator. The GDP deflator should *not* be used since imports enter this index with negative weights and so a large increase in the price of imports relative to other prices can lead to a counterintuitive fall in the GDP deflator; see Kohli (1982; 211) (1983; 142) and Diewert (2002; 556) on this point.

[33] Paton and Littleton (1940; 123) argued that the primary purpose of accounting is to match costs and revenues but other points of view are possible. For an excellent early discussion on the importance of matching costs to future revenues, see Church (1917; 193). For a more recent discussion on the problems involved in matching R&D costs to future expected incremental revenues, see Diewert (2004b; 45-49).

R&D are made freely available to all potential users. In the case of government funded R&D projects, the situation is much more complicated than was indicated above for the case of privately funded R&D projects. In the case of a government funded R&D project, there are again two "assets" associated with the venture:

- The first *cost asset* is again the cumulated costs of the R&D project and
- The second *utility asset* is the discounted value of the incremental increases in utility that the R&D project is expected to generate for a reference population.

For a government funded R&D project, the treatment of the cost "asset" is conceptually similar to the case of a privately funded R&D project, except that the matching problem is more complex; i.e., instead of amortizing cumulated R&D costs in a manner proportional to expected future incremental revenues, the government should amortize the costs in a manner proportional to expected future incremental utility flows that will accrue to inhabitants of the country (present and future!) as a result of the project.[34] It can be seen that in the case of government funded R&D projects, the measurement problems are much more severe:

- How should the utility of each household in the reference population be cardinalized?[35]
- How can the expected incremental increases in reference population utilities that are generated by the project be estimated?[36]

The above questions are not simple to answer!

For both a successful private or government funded R&D project, a new set of techniques of production (or input-output coefficients) is created. Typically, there will be no traditional depreciation associated with the project; i.e., typically the new process or product will not be forgotten and so the effects of the innovation in adding to society's stock of blueprints is more or less permanent. But yet the incremental utility value of the project will generally decline over time due to the following factors:

- Even more efficient processes are invented which render an existing process obsolete.
- In the case of a product innovation, over time consumer tastes may shift away from the new product or a new product is invented which renders the existing product obsolete.

Hopefully, the above discussion will convince the reader that an R&D asset is rather different than a typical tangible asset like a machine, building, inventory component or

[34] Or should the national government take international incremental utility spillovers into account as well?
[35] The economic approach to index number theory can be used to answer this question but there is no unique answer; see Pollak (1983) or Diewert (1981).
[36] A very detailed general equilibrium model of the economy would be required and statistical agencies are in no position to construct such a model.

plot of land. Trying to work out the contribution of an R&D project to production and welfare is indeed a very complicated task.

We turn now to a brief (and incomplete) review of methods that have been suggested in the literature to determine the contribution of an R&D project to production and welfare.

2.5 The Patent Renewal Fee Method for Assessing the Benefits of R&D Investments

One method for determining how fast the stream of incremental revenues generated by an R&D project that is patented declines is to look at patent renewal fees; see Pakes and Shankerman (1978) (1986) for such an approach. Nadiri and Prucha endorsed their approach and commented on their approach as follows:

"The estimates for both private and social rates of return in R&D investment have been very high in most industries (see Bernstein and Nadiri (1991)). The private rate of return in R&D investment is affected by the rate of decay of the private revenues accruing to industrially produced knowledge. However, except for the two studies by Pakes and Shankerman (1978) (1986), there are few estimates for the rate of decay of knowledge capital. Pakes and Shankerman correctly emphasize that the conceptually appropriate rate of depreciation of knowledge is the rate at which the appropriable revenues decline. The rate of decay in the revenues does not arise from any decay in productivity of knowledge but from reduction in market valuation, which arises due to inability to appropriate the benefits from the innovations and the obsolescence of original innovations by new ones. Pakes and Shankerman employed data on patent renewal fees to estimate the decay rate for knowledge capital for several European countries. Their estimates are shown in Table III.[37] In their first study, their reported point estimate for the rate of decay was about 0.25 with a 95 percent confidence interval between 0.18 and 0.36." M. Ishaq Nadiri and Ingmar R. Prucha (1996; 51).

Thus the Pakes and Shankerman rates of incremental revenue decay for patented innovations ranged from 11% to 36% per year. Of course, there are two problems with these estimates:

- Their estimated range of revenue decay rates is rather wide and
- Not all innovations are patented and so the Pakes and Shankerman results do not cover all R&D investments.

Given the fact that the patent renewal fees method for assessing the benefits of R&D investments is necessarily incomplete, we turn to the second method that has been used.

2.6 Econometric Methods for the Determination of the Rate of Revenue Decay for R&D Investments

Nadiri and Prucha (1996) took a rather different approach to the problem of estimating rates of revenue decay for R&D investments. They first criticized the "traditional" approach to the estimation of R&D depreciation rates as follows:

"Very little effort has been made, except for Pakes and Shankerman (1978) (1986), to measure the depreciation rates of the stock of R&D. Researchers doing applied work typically assume an arbitrary

[37] These rates were 0.17 to 0.26 for the UK, 0.11 for France and 0.11 to 0.12 for Germany.

depreciation rate of 0.10 to 0.15 to construct the stock of R&D capital using the perpetual inventory method. M. Ishaq Nadiri and Ingmar R. Prucha (1996; 43).

They then noted correctly that R&D investments should act as mechanism for shifting outward society's production possibilities frontier but in their empirical work, they chose instead to treat R&D in the same manner as a reproducible capital stock component:

"As in many studies the stock of R&D may be considered to represent a technological index that shifts the production frontier. Alternatively, given that the technology satisfies appropriate curvature conditions, the stock of R&D may be viewed as a factor input." M. Ishaq Nadiri and Ingmar R. Prucha (1996; 44).

Nadiri and Prucha followed their suggested alternative route and assumed that R&D investments depreciated at the rate δ, where δ is a depreciation rate between 0 and 1. Hence, given an estimate of the initial stock of R&D at the beginning of period 0, say K^0,[38] the stock at the beginning of a subsequent period t is equal to:

(1) $K^t \equiv I^{t-1} + (1-\delta) I^{t-2} + (1-\delta)^2 I^{t-2} + \ldots + (1-\delta)^t I^0 + (1-\delta)^{t+1} K^0$; $\quad t = 1,2,\ldots$

where I^t is (real) R&D investment in period t. Now assume that aggregate output in period t, Y^t, is related to aggregate input (excluding R&D inputs), X^t, and the R&D stock K^t by a production function F so that:

(2) $Y^t = F(X^t,K^t)$; $\quad t = 1,2,\ldots.$

Now substitute (1) into (2), assume a functional form for the production function F, add an error term to (2), and we have a nice econometric model where the parameters of the production function plus the depreciation rate for R&D capital, δ, can be estimated, given data on outputs, Y^t, non R&D inputs X^t and the R&D investments I^t.

A second econometric framework[39] can be obtained by assuming that producers face the period t price for non R&D inputs, w^t, and competitively minimize the (variable) cost of producing the period t output, Y^t, given the R&D stock K^t. Denote the resulting variable cost function as $C(w^t,Y^t,K^t)$. Then by Shephard's (1953; 11) Lemma, the cost minimizing input demand is equal to the partial derivative of the cost function with respect to the input price:

(3) $X^t = \partial C(w^t,Y^t,K^t)/\partial w$; $\quad t = 1,2,\ldots.$

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[38] In order to obtain an estimate for the starting stock of R&D capital, Nadiri and Prucha (1996; 47) argue that if R&D real expenditures have been growing at the rate g over the sample period, then if we make an initial guess for the depreciation rate δ and R&D investments have been growing at the rate g into the indefinite past, then a reasonable estimate for the starting stock of R&D capital is $K^0 \equiv I^{-1}/(\delta+g)$ where I^{-1} is an estimate of R&D investment in the period prior to period 0. Kohli has also used these assumptions to obtain starting stocks in his empirical work over the years. Nadiri and Prucha used an estimate of $\delta = 0.10$ in order to generate their starting stock of R&D capital.

[39] If X^t and w^t are vectors instead of scalars, this alternative framework will add additional degrees of freedom to the econometric model.

Now substitute (1) into (3), assume a functional form for the cost function C, add an error term to (3), and we have an econometric model where the parameters of the cost function plus the depreciation rate for R&D capital, δ, can be estimated, given data on outputs, Y^t, non R&D inputs X^t, input prices w^t and the R&D investments I^t.[40]

A third econometric framework can be obtained by assuming that producers face the period t price for non R&D inputs, w^t, the period t price for output p^t and they competitively maximize the (variable) profits, given the R&D stock K^t. Denote the resulting variable profit function as $\pi(p^t,w^t,K^t)$. Then by Hotelling's (1932; 594) Lemma, the profit maximizing output supply and (minus) the input demand is equal to the partial derivatives of the profit function with respect to the output and input prices:

(4) $Y^t = \partial\pi(p^t,w^t,K^t)/\partial p$; $\qquad$ t = 1,2,….

(5) $X^t = -\partial\pi(p^t,w^t,K^t)/\partial w$; $\qquad$ t = 1,2,….

Now substitute (1) into (4) and (5), assume a functional form for the profit function π, add error terms to (4) and (5), and we have an econometric model where the parameters of the profit function plus the depreciation rate for R&D capital, δ, can be estimated, given data on outputs, Y^t, non R&D inputs X^t, output prices p^t, input prices w^t and the R&D investments I^t. This third econometric framework, while leading to more degrees of freedom, has the disadvantage of assuming competitive behavior with respect to the pricing of outputs. In the context of R&D investments, which are very much concerned with creating monopolies, the assumption of competitive pricing of outputs is somewhat suspect and thus this framework is probably not suitable for estimating R&D depreciation rates.[41]

As mentioned above, Nadiri and Prucha (1996; 48) used a variant of the cost function approach to estimate depreciation rates for R&D and reproducible capital for the U.S. total manufacturing sector. Their estimated depreciation rate for R&D capital turned out to be 12% per year.[42] However, *their econometric model attributed all technical progress to R&D investments*, which is almost surely not correct, and hence, their estimates cannot be accepted as being definitive.[43] Moreover, their econometric model

[40] A two input version of this model is what was estimated by Nadiri and Prucha (1996), where the two variable inputs were materials and labour but they also had two types of capital: R&D capital and reproducible capital; i.e., X^t, w^t and K^t were two dimensional vectors instead of scalars.

[41] However, this framework *is* suitable for estimating depreciation rates for reproducible capital. This profit function methodological approach to the determination of depreciation rates for traditional tangible capital is due to Epstein and Denny (1980).

[42] Their estimated depreciation rate for U.S. reproducible capital turned out to be 5.9%, which is much higher than the official Bureau of Economic Analysis rate of 3.4%; see Musgrave (1992).

[43] The recent work of Bernstein and Mamuneas (2005) used a modification of the Nadiri and Prucha methodology (but using a cost function framework) which included the estimation of disembodied technical progress and so their work is not subject to this criticism. Bernstein and Mamuneas obtained much higher R&D depreciation rates as noted earlier. Bernstein and Mamuneas also assumed that R&D investments could be treated in the same manner as investments in reproducible capital (but they did not attempt to estimate depreciation rates for reproducible capital). They also assumed a constant rate of return to all forms of capital in their user costs of all forms of capital so they did not attempt to estimate rates of return to R&D investments in this paper. Finally, Bernstein and Mamuneas assume constant returns to

was based on the assumption that R&D capital depreciated in much the same manner as reproducible capital; recall (1) above. But as we have explained above, knowledge investments are not at all like investments in structures and machines, which wear out through use. Instead, knowledge investments change the production function in an irreversible manner, allowing additional output to be produced from the same amounts of inputs. As explained above in sections 2.3 and 2.4, tracing out the consequences of these shifts in the production frontier is a very complex process, possibly involving changing tastes and obsolescence. It may be that treating R&D investments like investments in machines can provide a reasonable approximation to a more complete applied general equilibrium model that traces out the consequences of knowledge investments in a more realistic manner, but this has not yet been demonstrated.

The final approach to estimating amortization rates for R&D investments is due to Lev and Sougiannis (1996) (1999). Their model can be very roughly described as follows:[44] suppose that the gross value added[45] of a firm in year t, V^t, is related to the amount of tangible or reproducible capital that it has available at the beginning of year t, K^t, and its real investments in R&D for the past 7 years, R^{t-1}, R^{t-2}, … , R^{t-7}. The relationship between value added in year t to the firm's tangible capital stock and past investments in R&D is assumed to the following one:

$$(6)\ V^t = \alpha_0 + \alpha_1 P_K{}^t K^t + \beta_1 P_R{}^{t-1} R^{t-1} + \beta_2 P_R{}^{t-2} R^{t-2} + \ldots + \beta_7 P_R{}^{t-7} R^{t-7} + \varepsilon^t ;$$

where the α's and the β's are unknown parameters to be estimated, $P_K{}^t$ is the purchase price of a unit of tangible capital at the beginning of period t, $P_R{}^{t-1}$ is the price of a unit of R&D for the firm in year $t-1$, …., $P_R{}^{t-7}$ is the price of a unit of R&D for the firm in year $t-7$ and ε^t is an error term. Given information on the firm's annual value added, value of tangible capital and past R&D investments, the unknown parameters in (6) can be estimated using regression techniques.[46]

However, if there is inflation in the economy, it can be seen that the past R&D investments that appear on the right hand side of (6) are expressed in value units of varying purchasing power. Moreover, V^t on the left hand side of (6) is also expressed in (different) varying units of purchasing power as t changes. These problems with the model can be mitigated under some circumstances. Assume that the firm produces Y^t units of output in year t and sells this amount of output at the price p^t and that it uses X^t units of labour and intermediate inputs and purchases units of this variable input at the

scale in their model, which is an acceptable assumption for the purpose of estimating R&D depreciation rates.

[44] See Lev and Sougiannis (1996) for the details. Their model also estimates the value of advertising expenses for the firm but we ignore this part of their model in our brief description.

[45] Gross value added is equal to revenues less intermediate input costs less labour costs.

[46] The estimation procedure used by Lev and Sougiannis (1996) is more complicated than indicated above (they scaled their data, used a two stage estimation procedure and restricted the β coefficients) but this brief description of their model will suffice to give the reader the flavour of their model.

price w^t. Assume also that the firm in year t faces the user cost u^t for a unit of tangible capital.[47] Then the firm's year t *modified profits*, Π^t, can be defined as follows:

$$(7)\ \Pi^t \equiv p^tY^t - w^tX^t - u^tK^t\ .$$

When calculating (7), we need to exclude expenditures on R&D from X^t. Thus the modified profits Π^t for firms engaging in R&D should be positive and these positive modified profits are equal to pure profits plus the period t profits that can be attributed to past R&D investments. We can adjust period t modified profits for price change by constructing a value added price index[48] that adjusts the year t prices to the level of prices prevailing in a prior year 0, say $P(p^0,w^0,u^0;\ p^t,w^t,u^t;\ Y^0,-X^0,-K^0;\ Y^t,-X^t,-K^t)$, and then we can use this value added price index to deflate Π^t into common units that are free from inflationary effects.[49] Using these definitions, our suggested *inflation adjusted* version of the model (6) is (8) below:

$$\begin{aligned}(8)\ \Pi^t/P(p^0,w^0,u^0;\ p^t,w^t,u^t;\ Y^0,-X^0,-K^0;\ Y^t,-X^t,-K^t)&\\ = \beta_0 + \beta_1 R^{t-1} + \beta_2 R^{t-2} + \ldots + \beta_7 R^{t-7} + \varepsilon^t\ ;&\end{aligned}$$

where β_0 and $\beta_1, \beta_2, \ldots, \beta_7$ are unknown parameters to be estimated. The above model essentially says that if we make a real R&D investment in year 0 of size R then in year 1, it will contribute the amount β_1R to real profits; in year 2, it will contribute the amount β_2R to real profits; … and in year 7, it will contribute the amount β_7R to real profits. Once the β's have been estimated, we can follow the example of Lev and Sougiannis (1996; 117) and normalize these coefficients into the *amortization coefficients*, α_k, defined as follows:

$$(9)\ \alpha_k \equiv \beta_k/[\beta_1 + \beta_2 + \ldots + \beta_7]\ ; \qquad k = 1,2,\ldots,7.$$

Thus if an R&D investment is made by the firm this year, then it should be capitalized and using the matching principle in accounting[50], α_1R should be written off or amortized next year, α_2R should be amortized in the following year, and so on.

[47] Neglecting tax complications and assuming that the expected CPI inflation rate is equal to the expected rate of price increase for the tangible capital asset, the period t user cost u^t will be approximately equal to $(r^t+\delta)P_K^t$, where r^t is the period t real opportunity cost of capital that the firm faces and δ is the annual depreciation rate for tangible capital.

[48] See Archibald (1977) and Diewert (2004d) on the theory of value added price deflators. The Laspeyres and Paasche value added deflators are defined as follows: $P_L \equiv [p^tY^0 - w^tX^0 - u^tK^0]/[p^0Y^0 - w^0X^0 - u^0K^0]$ and $P_P \equiv [p^tY^t - w^tX^t - u^tK^t]/[p^0Y^t - w^0X^t - u^0K^t]$ respectively. All of the value aggregates in the numerator and denominator of these indexes must be positive for them to make sense. For empirical applications, we recommend the use of the Fisher (1922) value added index, $P_F \equiv [P_LP_P]^{1/2}$.

[49] Alternatively, we could just use a measure of general inflation like the Consumer Price Index to do the deflation.

[50] The matching principle says that an intangible investment should be written down in a manner that is proportional to the anticipated stream of incremental revenues that it is expected to generate.

There is one important aspect of the model defined by (8) that should be mentioned: namely, the coefficients $\square_0$, $\square_1$, $\square_2$, …, $\square_7$ should all be *nonnegative.* This is a straightforward observation for the □'s but what about the parameter $\square_0$? We argue that this constant term in the regression (8) should be nonnegative since it represents all of the omitted variables in the regression that increase the firm's productivity in each period *in addition to the firm's R&D investments*. A similar comment applies to the original model of Lev and Sougiannis, (6) above.[51]

One problem with the models (6) and (8) is that because V^t and $\square^t$ are defined as differences of economic variables that are subject to a considerable amount of measurement error, the measurement error in V^t and $\square^t$ could be very large, leading to inaccurate estimates of rates of return to R&D investments and to inaccurate amortization terms. Another problem with the model (8) is that it does not fully capture the complexities mentioned sections 2.3 above about modeling how the monopoly profits of a firm that undertakes R&D are eroded over time due to the diffusion of knowledge about the R&D induced innovations and changing consumer tastes. Our conclusion at this point is that none of the suggested econometric methods for estimating the effects of R&D investments are completely satisfactory.

Bartelsman (2004a) asked what do we really know about the effects of R&D investments on productivity performance? As can be seen from the above discussion, the existing econometric evidence on this question seems, at least to this reader of the evidence, to be unreliable and inconclusive. Hence, at this stage, I do not think that there is much reliable advice that we can give to policy makers on this topic.

2.7 Time Series versus Cross Sectional Comparisons of Productivity

Bartelsman (2004a) also looked at the convergence literature and cross country comparisons of productivity levels. He correctly noted that it is much more difficult to make cross country comparisons of productivity compared to making time series comparisons. The increased difficulties are due to the fact that it is much more difficult to make cross country comparisons of prices than it is to make time series comparisons for the same country or industrial sector. National price statisticians are usually obligated to construct consumer price indexes but they are not obligated to compare prices in their country with the prices of comparable products in other countries and hence accurate information on cross country comparisons of prices is generally not available.[52] Thus in making cross country comparisons of per capita real GDP or of the productivity of a

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[51] Lev and Sougiannis (1996; 120-122) report rates of return to R&D investments for their US data equal to: 28 percent for chemicals and pharmaceutics, 15 percent for machinery and computer hardware, 22 percent for electrical and electronics, 19 percent for transportation vehicles, 20 percent for scientific instruments and 20 percent for other industries. However, for some industries and some years, their estimated constant terms $\square_0$ are fairly large and negative. If these negative coefficients were restricted to be 0, then I suspect that the corresponding estimated □ coefficients would have a tendency to decrease in magnitude, which would reduce somewhat the above rates of return.

[52] There are additional technical problems in making cross country comparisons; e.g., different countries will usually not consume and produce exactly the same products and so there is a problem in *matching* products across countries.

particular industry, there is bound to be much more measurement error than when one compares the productivity performance of a particular sector over time in the same country. Hence *policy makers should be very cautious in drawing any policy conclusions whatsoever from cross country comparisons of productivity levels in particular industries for two reasons*:

- It is much more difficult to measure productivity at the sectoral level than at the national level[53] and
- It is much more difficult to construct accurate price indexes that compare price levels across countries than it is to construct intertemporal price indexes for the same production unit within a country.

Bartelsman (2004a) noted that growth accounting measures of productivity growth do not tell us anything about the sources of this growth. However, these growth accounting measures of TFP growth are used as the dependent variable in thousands of regressions that attempt to find causal factors for the growth. Needless to say, these regressions are not entirely convincing and of course, they are bound to be somewhat contradictory. Again, these regressions are not reliable enough for policy makers to make important decisions based on them.

2.8 Factors that Affect a Country's Productivity Performance

There is a large literature on factors that tend to improve a country's productivity performance.[54] My own summary of some of the factors is given below:

In summary, factors that will tend to *augment* TFP growth are:

- Rapid *investment growth* (in reproducible or physical capital).
- Rapid growth in *investments in education, training and human capital*.
- Rapid *growth in primary inputs* will tend to lead to an even more rapid growth of output due to *increasing returns to scale in production*. The main drivers of increasing returns to scale are: the existence of indivisibilities; the laws of geometry and physics; the existence of fixed costs and the laws of statistics.
- Increases in TFP are associated with *increased specialization*, which in turn is driven by growth in the size of the market. In brief: big tends to be better!
- *Improvements in the functioning of markets*, which could occur in a variety of ways, including: (i) improvements in personal security; (ii) improvements in property rights; (iii) reductions in trade barriers; (iv) improvements in telecommunications (in particular, the growth of internet driven markets) and (v) improvements in transportation and infrastructure.
- *Access to new knowledge* about the development of new commodities and processes. Recall our discussion about the importance of business consultants, trade associations and benchmarking to diffuse knowledge about best practices.

Factors which will tend to *reduce* the growth of Total Factor Productivity (in addition to the negative of the above factors) are:

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[53] See Diewert (2001) on this topic. The problem is that outside of the primary and manufacturing industries, we do not have very accurate information on the use of intermediate inputs by industry since detailed surveys on these flows typically do not exist.

[54] See for example Bates (2001) and Harris (2001).

- *High taxes*. In theory, this factor should just have one time level effects on economic efficiency but it is likely that high taxes have dynamic effects as well, tending to reduce investments in physical and human capital and retarding the formation of specialized markets.
- *High inflation*. High or unpredictable rates of inflation tend to increase uncertainty about the real interest rate and future prices and hence lead to a misallocation of investment and a reduction in productive efficiency.

W. Erwin Diewert (2004a; 21-22).

In the remainder of this paper, we concentrate on outlining some of the measurement problems that the ABS faces in constructing its estimates of Australian TFP. In the following three sections, we follow the example set by Obst (2004) and outline some of the measurement problems associated with the measurement of outputs, labour input and capital input.

3. Output Measurement Problems

Australia is facing a problem that is similar to that faced by North American countries; namely, the industry classification system is changing, leading to hundreds of new service sector industries where *price information on the major products produced by these new industries is at present not collected by most statistical agencies*.[55] When the new classification system is implemented, many industries will lack adequate deflators for their major outputs. Sixty years ago, services did not play such a large role in most economies and so industrial classification systems gave more importance to primary and manufacturing industries (and products). It is only in the last decade or so that statistical agencies have started to devote more resources to measuring service sector outputs more accurately. The ABS does have an impressive service industry price measurement program[56] but even more resources could and should be devoted to this important task.

Many difficult conceptual problems are associated with the measurement of service sector prices and outputs. We list below some general categories of difficult to measure service products:

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[55] An exception to this statement is the U.S. Bureau of Labour Statistics, which has recently implemented a fairly comprehensive program to improve its coverage of the prices of service sector outputs.

[56] The ABS is devoting some resources to the collection of service prices for existing and new industries. Price indexes for the following components of the Property and Business Services Division are being developed or already exist: Commercial property operators; Real estate agents; Motor vehicle hiring, Other transportation equipment leasing; Plant hiring or leasing; Scientific research; Architectural services; Surveying services; Consultant engineering; Data processing services; Information and storage; Computer maintenance; Computer consultancy; Legal services; Accounting services; Advertising services; Commercial art services; Market research services; Business management services; Employment placement; Contract staff services; Secretarial services; Security and investigative services; Pest control services; and Cleaning services. The list of existing and new price indexes for the Transportation and Storage Division includes: Road freight transport; Rail transport; International sea transport; Coastal waters transport; Scheduled international air transport; Domestic air transport; Pipeline transport; Parking services; Stevedoring; Water transport terminals; Port operators; Services to water transport; Customs agents; and Grain storage. Other planned or existing price indexes include: Accommodation; Postal services; Courier services; and some new series in financial services, telecommunication services and retail margins.

- *Unique products*. If products are one of a kind, then obviously the prices of products produced in the present period cannot be compared with the price of the same product in a previous period. This is a pervasive problem in the measurement of the prices of services.
- *Complex products*. Many service products are very complicated; e.g., telephone service plans.
- *Tied products*. Many service products are bundled together and offered as a single unit; e.g., cablevision plans and banking services packages. In principle, hedonic regression techniques could be used to price out these types of service products.
- *Marketing and advertising products*. This class of service sector outputs is dedicated to influencing or informing consumers about their tastes. A standard economic paradigm for this type of product has not yet emerged.
- *Financial products*. What is the "correct" real price of a household's monetary deposits? Somewhat surprisingly, this question has not yet been resolved in a definitive manner.
- *Uncertain products*. What is the correct pricing concept for gambling and insurance expenditures? What is the correct price for a movie or a record original when it is initially released?

Many of these measurement problems are theoretically quite challenging. Hopefully, some of the academics and other researchers at this meeting will be stimulated to work on these measurement problems.[57]

4. Labour Measurement Problems

The most comprehensive information on labour input by industry in Australia comes from the Labour Force Survey, which is a household survey. Unfortunately, respondents to this survey may not provide very accurate answers to some of the questions asked; in particular, they may not know which industries family members work in or precisely how many hours they work.

Every country has some difficulty in determining precisely what the labour input of the self employed is. The *System of National Accounts 1993* puts the labour input of non employees into Gross Operating Surplus and so the contribution to output of the self employed is classified into this category, along with the contribution of any capital that the self employed might be using. Since there is no international standard for extracting the labour contribution of the self employed from Gross Operating Surplus, different countries that have TFP programs estimate the labour input of the self employed in different ways, leading to a lack of international comparability. Since self employment in many advanced countries has rebounded during the past decade (due to outsourcing and the continuing specialization of the labour market), the associated labour input measurement problems are not trivial.

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[57] For additional information on the output measurement problems faced by Statistics Canada, see Diewert (2003). These measurement problems are very similar to those faced by the Australian Bureau of Statistics as it implements its new Australia New Zealand Industrial Classification.

The final labour measurement problem that we note in this section is that there are two alternative methods for calculating labour input. The first method treats all labour hours by all types of worker are regarded as being equivalent.[58] However, as noted by Jorgenson and Griliches (1967), all labour hours are not equivalent. Hence, the second method classifies labour inputs into relatively homogeneous types of labour and then normal index number theory is used to aggregate up the various kinds of labour.[59] The Australian Bureau of Statistics uses both methods but at present uses the first method in its headline series, possibly because it was able to construct this series back to 1964 whereas the weighted hours series could only be constructed back to 1984. It seems to me that the second method is the preferred one.

5. Capital Measurement Problems

The Gross Operating Surplus of a country (less the labour contribution of the self employed) should be decomposed into several components:

- Depreciation;
- A return to the financial capital employed;
- A charge for any obsolescence of the capital employed;
- Rents to land and resources;
- Amortization of intangible capital components such as goodwill, R&D, trademarks, advertising, etc.;
- A charge (or credit) due to changes in the prices of assets over the accounting period; and
- Taxes paid to governments that do not fall on outputs, intermediate inputs or labour.

There are measurement difficulties associated with implementing each of the above decompositions:[60]

- What are the correct depreciation rates to use?[61]
- What is the correct opportunity cost of capital to use? Should the chosen rate be an endogenous one that causes the value of inputs to equal the value of outputs or should it be an exogenous one? And if it is an exogenous one, how exactly should it be chosen?

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[58] This method is frequently used when statistical agencies calculate labour productivity, which they define as output divided by unadjusted labour input hours.
[59] The *System of National Accounts 1993* recommends the construction of wage indexes but relatively few countries seem to have implemented this recommendation.
[60] Diewert (1980; 470-486) (2004b) and Diewert and Lawrence (2000) discussed these issues in more detail.
[61] Different countries assume widely different depreciation rates for the same assets. In section 2, we indicated how various econometric approaches could be used in order to estimate depreciation rates but often such approaches generate depreciation rates that are substantially larger than official ones; see Nadiri and Prucha (1996) on this point.

- How exactly is the obsolescence charge do be determined? Should the obsolescence be foreseen?
- What is the right opportunity cost rate of return to land? Should we take into account the fact that historically, land appreciates in price in real terms and so some of the normal return to land is taken in the form of holding gains?
- Should the capital gains or holding gains term be an expected one or an actual ex post one? Should holding gains even be in the production accounts?[62] And if we want to allow consistently negative holding gains as an obsolescence charge (e.g., computers), how can we not allow consistently positive holding gains in the production accounts?
- How exactly should the intangible capital items be amortized?
- How exactly should the tax component be calculated?

Many of the above issues were discussed in the nice paper by Zheng (2004) but they are not easy to resolve in a definitive manner.

There are a few more issues associated with the measurement of capital:

- Are land stocks productive?
- Are resource stocks productive?
- Are inventory stocks productive?
- Are intangible assets like R&D stocks productive?

Most productivity researchers, would agree that land, resource and inventory stocks are all productive and should be in the productivity accounts.[63] The ABS multifactor productivity measures do include land and inventory stocks and some components of resource stocks are also included in their balance sheets (tree plantations). Presumably, other resource stocks will also be included at some stage in the productivity estimates when the data on resource stocks are refined.

The inclusion of intangible assets such as R&D investments, expenditures on training, advertising and marketing expenditures, trademarks and franchises is more problematical. From the perspective of capital theory, any current expenditure that yields benefits in future periods could be capitalized. However, all of the intangible assets listed above have the character of sunk costs and so from the perspective of the firm’s expected discounted stream of future profits, it is immaterial whether these expenditures are capitalized or not. But from the viewpoint of measuring the periodic (i.e., the period by period) *income* of the firm, it does make sense to capitalize these intangible expenditures and then amortize them over the future periods where the expenditures still generate benefits. The practical problem facing the government statistician is: how exactly should these capitalized expenditures be amortized? We considered this question in some detail

[62] Many national income accountants do not want to allow any form of holding gains into the production accounts but some accountants are willing to include expected holding gains; e.g., see Hill and Hill (2003) and Diewert (2004b). However, Jorgenson (1989) and his coworkers prefer to include ex post holding gains in the user cost of capital and thus ex post holding gains are in his production accounts.
[63] See Jorgenson and Griliches (1967) (1972) and Christensen and Jorgenson (1969) (1970).

in section 2 above for R&D investments and we suggested that the amortization amounts should be proportional to the incremental revenues generated by the investment.[64] But the practical problem for the ABS is how exactly are these future incremental revenues to be estimated? In section 2, we suggested that the academic literature on this topic is not too helpful in answering this question. Again, we leave this question as a challenging problem that academics and other researchers should address.

One problem with the treatment of inventories by most statistical agencies is that the treatment of inventory change in the national accounts is a real dog's breakfast in the sense that at times, the real and nominal inventory change have opposite signs![65] In the following section, we suggest a theoretical methodology that will eliminate this problem.

6. The Treatment of Inventory Stocks and Inventory Change

As was mentioned in the previous section, we need a theoretical framework to measure the contribution of an inventory stock to production. We outline a possible framework taken from Diewert and Smith (1994).

Consider a firm that perhaps produces a noninventory output during period t, Y^t, uses a noninventory input X^t, sells the amount S^t of an inventory item during period t and makes purchases of the inventory item during period t in the amount B^t. Suppose that the average prices during period t of Y^t, X^t, S^t and B^t are P_Y^t, P_X^t, P_S^t and P_B^t respectively. Then neglecting balance sheet items, the firm's period t *cash flow* is:

$$(6)\ CF^t \equiv P_Y^t\, Y^t - P_X^t\, X^t + P_S^t\, S^t - P_B^t\, B^t.$$

Let the firm's beginning of period t stock of inventory be K^t and let its end of period stock of inventory be K^{t+1}. These inventory stocks are valued at the balance sheet prices prevailing at the beginning and end of period t, P_K^t and P_K^{t+1} respectively. Note that all 4 prices involving inventory items, P_S^t, P_B^t, P_K^t and P_K^{t+1} can be different.

The firm's period t *economic income* is defined as its cash flow plus the value of its end of period t stock of inventory items less $(1+r^t)$ times the value of its beginning of period t stock of inventory items:

$$(7)\ EI^t \equiv CF^t + P_K^{t+1}\, K^{t+1} - (1+r^t)\, P_K^t\, K^t$$

where r^t is the nominal cost of capital that the firm faces at the beginning of period t. Thus in definition (7), we assume that the firm has to borrow financial capital or raise equity capital at the cost r^t in order to finance its initial holdings of inventory items. This cost could be real (in the case of a firm whose initial capital is funded by bonds) or it could be an opportunity cost (in the case of a firm entirely funded by equity capital).

[64] This is also the approach taken by the ABS for amortizing the Australian mineral exploration expenses "asset".
[65] Even if this does not occur, the implicit price index obtained by dividing nominal inventory change by the corresponding real change is invariably nonsense, at least for OECD countries over the past 40 years.

The end of period stock of inventory is related to the beginning of the period stock by the following equation:

$$(8)\ K^{t+1} = K^t + B^t - S^t - U^t$$

where U^t denotes inventory items that are *lost, spoiled, damaged or are used internally* by the firm. In the case of livestock inventories, there is a *natural growth rate of inventories* over the period so equation (8) is replaced by:

$$(9)\ K^{t+1} = K^t + B^t - S^t + G^t$$

where G^t denotes the natural growth of the stock over period t.

Define the change in inventory stocks over period t as:

$$(10)\ \Delta K^t \equiv K^{t+1} - K^t .$$

Using (10), both (8) and (9) can be written as:

$$(11)\ K^{t+1} = K^t + \Delta K^t.$$

Now substitute (11) into the definition of economic income (7) and we obtain the following expression:

$$\begin{aligned}(12)\ EI^t &\equiv CF^t + P_K^{t+1}\,[K^t + \Delta K^t] - (1+r^t)\,P_K^{t}\,K^t \\ &= CF^t + P_K^{t+1}\,\Delta K^t - [r^t\,P_K^{t} - (P_K^{t+1} - P_K^{t})\,]K^t.\end{aligned}$$

Thus *economic income is equal to cash flow plus the value of the change in inventory (valued at end of period balance sheet prices) minus the user cost of inventories times the starting stocks of inventories* where this period t user cost is defined as

$$(13)\ P_I^{t} \equiv r^t\,P_K^{t} - (P_K^{t+1} - P_K^{t}).$$

Note that the above algebra works for both livestock and ordinary inventory items.

Of course, there can be two versions of the user cost:

- An ex post version where the actual end of period balance sheet price of inventories is used or
- An ex ante version where at the beginning of period t, we estimate a predicted value for the end of period balance sheet price.

In practice, beginning of period inventory stocks should be estimated along with appropriate balance sheet prices. When aggregating over a number of inventory stock items, normal index number theory can be used in order to decompose balance sheet values of inventory items into price and quantity components. Then the change in stocks can be obtained by differencing the stock volume series and the end of period balance sheet price (or a predicted version of it) could serve as the flow price for the change in inventories. Note that normal index number theory breaks down for value aggregates that can be either positive or negative over time.[66]

What is new in this section is the development of a methodology that can deal with livestock inventories, where there is a natural biological growth rate associated with the stock. What we have shown above is that a biological inventory stock can be treated just like any other inventory stock: what is necessary is the ability to estimate the size of the stock at the balance sheet dates (and of course, we have to keep track of any product flows that occur during the period such as sales and purchases of the inventory item or transformations of it into other products).[67]

7. The Problems of New Products and of Quality Adjustment

Increasingly, the world economy devotes more and more resources to the development of new goods and services. This creates severe problems for statistical agencies when they attempt to measure real economic growth because their methodology to measure price change is based on the list of products remaining constant from period to period.; i.e., the price of a product produced in the present period is compared with the price of the same product produced in a prior period. Obviously, this matched model methodology breaks down when what is being produced is constantly changing.

Two broad approaches to deal with this new goods problem have been suggested over the years:

- The *hedonic regression approach* pioneered by Court (1939) and
- The *reservation price approach* pioneered by Hicks (1940; 114).

The reservation price technique has not caught on with statistical agencies but Hausman (1997a) (1997b) has implemented it for some forms of telecommunications services.[68] However, starting in the 1980's, various statistical agencies have used hedonic regression techniques to quality adjust the prices of new products that have varying amounts of a given list of characteristics.[69]

[66] To see the problem, consider the problem of calculating a Laspeyres price or quantity index when the base period value for the aggregate approaches 0.
[67] The ABS presently has livestock as a capital asset and as an inventory item. We do not think that the distinction is meaningful and the two stocks should just be treated as an inventory item. In our view, the essence of an inventory stock item is that it can be measured in homogeneous units at balance sheet dates. A capital stock item on the other hand undergoes change as it is used during the period; i.e., a one period old machine is not equivalent to a newly purchased machine of the same type.
[68] Diewert (1980; 498-503) also has a few observations on the reservation price technique.
[69] Quality adjustment techniques are systematically reviewed in recent surveys by Triplett (2004) and Silver (2004a) (2004b). For a good introduction to hedonic regression techniques, see Griliches (1971) and chapter 4 of Berndt (1991).

There is little doubt that the use of the traditional statistical agency matched model pricing methodology leads to a substantial understatement of economic growth.[70] Our recommendation here is that the ABS have a systematic program in order to quality adjust the prices of commodities where there has been rapid technological change.

8. Problems with How We Collect our Statistics

In this section, we discuss some of the difficulties in measuring productivity when *information on outputs and inputs is collected in different surveys*.

Eric Bartelsman (2004a) in his presentation noted that the best way to collect data for the purpose of measuring productivity is to collect data on output and input prices and quantities by firm or establishment in one big comprehensive survey. Before the information technology revolution, this suggestion would have been impractical, due to respondent burden issues. But increasingly, firms are collecting very detailed data on the prices and quantities of their outputs sold and their inputs used for their own internal management purposes. This means that these firms could simply pass on their data files to the statistical agency with virtually no respondent burden.[71] It may be thought that this "one big survey" methodology is impractical but it is being adopted in Iceland on an experimental basis as they introduce a program for measuring producer prices. However, it may be that the relatively small scale of the Icelandic economy makes such a program practical there but not in a larger economy.[72]

The problem with the existing business survey methodology is this: labour input by industry is collected in two separate surveys, capital input by industry in another survey, and information on the prices and values of outputs and intermediate inputs is collected in two additional surveys. This means that the estimated production statistics for any (small) firm and any industry are *synthetic constructs* which can contain a considerable amount of measurement error. This also means that the statistics on productivity for the entire economy will be much more accurate than for any particular industry, since aggregate output, imports, labour and capital input are much more accurately estimated at the national level.[73]

As mentioned above, the most promising approach to improving industry productivity measurement will be to convince firms to share their internal data on prices and quantities with the national statistical agency.

9. Problems with the Input Output Framework

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[70] Nordhaus (1997) gives an excellent example of this understatement in his analysis of the price of light (in lumens) over the years. Note that this understatement of growth adds another source of bias in the regressions that attempt to measure the effects of investments in R&D on economic growth.
[71] However, there would be considerable burdens placed on the statistical agency to sort out the data!
[72] It may also be the case that Icelandic producers are more willing to cooperate with the central statistical agency.
[73] Lawrence and Diewert (1999) discuss this problem at much greater length. They urged readers to use their industry statistics with a great deal of caution!

Simon Zheng (2004) in his presentation at this conference raised the following issue: under what conditions will industry growth contributions add up to overall GDP growth? This question was also raised by Moyer, Reinsdorf and Yuskavage (2004) in a recent contribution. The answer to this question is complicated by the fact that overall GDP is measured at final demand prices whereas the productivity literature recommends that industry outputs be measured at prices that exclude indirect taxes that are paid for by final demanders and industry intermediate inputs should be measured at prices that include indirect taxes; see Jorgenson and Griliches (1972; 85). However, recently Diewert (2004c) showed that industry growth contributions could be made to add up to overall GDP growth at final demand prices provided that a certain treatment of indirect taxes was followed and provided that either the Laspeyres, Paasche or Fisher index number formula is used in the aggregation.[74]

The analysis in Diewert (2004c) also has implications for constant dollar input output tables produced by statistical agencies.[75]

10. Firm Dynamics

Bartelsman (2004b) in his second presentation at the conference reported on some of his research on how entering and exiting firms contribute to the overall productivity growth of a country.[76] This is an exciting new area of research in productivity analysis that is only a bit over 10 years old; see the pioneering contributions of Baldwin and Gorecki (1991) and Baily, Hulten and Campbell (1992).[77] Not only is this area of research of interest from a theoretical point of view, it appears to be extremely important empirically; see Haltiwanger (1997) (2000) and Bartelsman, Haltiwanger and Scarpetta (2004).

An open question in this area is the influence of the regulatory and institutional environment on firm dynamics. No doubt, many interesting papers on this topic will be written in the future.[78]

An unresolved issue in this literature on the contributions to productivity growth of entering and exiting firms is *how exactly should we measure these contributions*. Various

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[74] Diewert (2004c) generalized the earlier results of Diewert (2004d; 479-484) and Moyer, Reinsdorf and Yuskavage (2004) where each sector was assumed to face the same vector of commodity prices (across sectors) except possibly for commodity tax distortions. Diewert (2004c) also generalized Diewert (2004e) by introducing commodity taxes into the model.

[75] Diewert (2004c) showed that it will generally be fruitless to construct constant dollar supply and use tables that value each commodity at the same price across industries; i.e., he showed that constant dollar input output tables should not be expected to add up along each row of the table due to aggregation bias. Diewert also showed how transportation and selling margins can be derived from first principles in the input output tables.

[76] See Bartelsman, Haltiwanger and Scarpetta (2004) for a review of the evidence on the productivity effects of entry and exit over 24 countries using micro data sets over the past decade. Other reviews of the literature on this topic can be found in Haltiwanger (1997) (2000), Ahn (2001) and Balk (2003; 25-31).

[77] Most of the ideas on how to measure productivity are at least 30 years old. The problem is that it is not all that easy for statistical agencies to implement these old suggestions on how to measure productivity; see Diewert (2001) on this topic.

[78] See Bartelsman, Haltiwanger and Scarpetta (2004).

answers to this question have been proposed by Baldwin and Gorecki (1991), Baily, Hulten and Campbell (1992), Griliches and Regev (1995), Olley and Pakes (1996), Bartelsman and Doms (2000), Foster, Haltiwanger and Krizan (2001), Fox (2002), Balk (2003; 25-31) and Baldwin and Gu (2003). No doubt future contributions on this topic will resolve this question.[79]

The following section concludes with some suggestions for the ABS that might improve the measurement of productivity in Australia. These suggestions follow from the discussion in the previous sections of this paper.

11. Future Directions

I have five suggestions for the ABS to improve its measurement of Australia's Total Factor Productivity performance:

- Institute a systematic program to measure the prices of service sector outputs. This program will be required in order to provide measures of real output for the new service sector industries that will emerge from the new classification of industries for Australia and New Zealand.
- Improve the measurement of labour input by dealing with the self employment problem and disaggregating labour input into reasonably homogeneous types of labour.
- Put additional resources into the measurement of capital input. For reproducible capital components, institute a capital retirements survey.[80] Improve the measurement of the contribution of inventories and land. Implement several user cost concepts and make them available to users, with full documentation of methods used.[81] With respect to intangible assets, it might be wise to wait until some of the methodological problems mentioned in section 2 above have been solved before the ABS provides official estimates for stocks of intangible assets.
- Experiment with computer intensive methods for collecting price and quantity data from firms in a cost effective manner.
- Institute a systematic program for the quality adjustment of prices for goods and services that are subject to rapid technological progress. Cooperate with other countries that have done hedonic regressions to profit from their experience.

The above suggestions for improving economic measurement apply to many countries and not just Australia!

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[79] Diewert and Fox (2005) provide their own answer to this question.
[80] Ask businesses the following questions: (1) What assets were retired or sold over the last reference period and if an asset was sold, at what price was it sold? (2) What was the age of the asset when retired or sold and what was its purchase price? Using this survey information, much more accurate estimates of depreciation rates could be obtained.
[81] One of the user cost variants would be chosen as the "official" estimate and the other series would be made available to users as supplementary or experimental series.

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