Productivity Measures and Sustainable Prosperity

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The government of Korea is striving to achieve more rapid, and sustainable, increases in economic output. We begin by reviewing measures national governments can use to monitor progress toward achieving sustainable prosperity. The various indexes each involve a comparison of some measure of total output volume with a measure of the total volume for specified input factors.

The total output measure most used by national statistical agencies is gross domestic product (GDP). We recommend other output measures that would better capture exchange rate effects, efficiency gains in intermediate product use, and the depreciation of durable assets. The recommendations concerning the treatment of durables are of special relevance for monitoring progress toward sustainable prosperity. We also report on progress toward accounting for the use of natural resource assets and human environmental impacts. We conclude with some thoughts on the meaning of sustainable prosperity and options for achieving this.

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I. Introduction

The government of Korea is urgently interested in finding ways to achieve more rapid, and sustainable, increases in national economic output. Years of exceptionally rapid economic growth, prior to the 1997 financial crisis, fuelled public expectations that the Korean standard of living would soon catch up with the U.S. standard. The past successes have now become an uncomfortably high standard of comparison for subsequent Korean administrations, especially as the date of the 1997 financial crisis recedes further into the past.[1] Secondly, the proportion of dependent older people is rising in Korea, and increasing amounts of resources will be needed for their care. Of course, many nations are facing this need for raising output. A third reason is special to Korea. Many in the Republic of Korea hold out hopes for reunification with North Korea, but recognize that this will lead to immediate needs for aid to help bring the standard of living of those in the North more in line with what it is in the South. So, there are projected needs for more output.

Unfortunately, shortfalls are predicted for labour and other inputs needed to achieve the desired increases in output. The average hours of labour supplied per worker has been falling rather than rising, and the proportion of the population in the prime working years has been falling and is likely to continue to fall. Also, since 2000, the rate of domestic investment in machinery and equipment (M&E) has been low (see Pyo 2006). Many are arguing that input led economic growth is not an option for Korea now. Interest in finding ways to increase total factor productivity (TFP) is inevitable in the present circumstances that Korea faces.

We begin by briefly considering measures that national governments can use to try to monitor progress toward achieving

[1] What is now widely known as the Asian financial crisis started with the July 2, 1997 devaluation of the Thai Baht. As the crisis spread, the currencies of several Asian countries including Korea were sharply devalued. Some U.S. producers probably benefited from the 1997 Asian crisis. Many of the countries with large depreciations of their currencies exported substantial amounts of information and communications technology (ICT) products to the United States. Some U.S. producers responded by greatly increasing their demand for Asian ICT products. Feenstra *et al.* (2005) report that by 2000, the combined ICT trade deficit of the United States was $57 billion, which was 17 percent of the entire non-oil U.S. trade deficit.

sustainable prosperity.

At a national level, the various productivity indexes produced by official statistics agencies each involve a comparison of some measure of total output volume with a measure of the total volume for specified input factors. The main measures used for estimating productivity are examined in Section II. Throughout this section, the precise definition of total output is left unstated.

The total output measure usually used by national statistical agencies is gross domestic product (GDP). In Section III, we argue for changes in this practice. We recommend measures of national output that would more adequately capture exchange rate effects, efficiency gains in the utilization of intermediate products, and the depreciation of durable assets including buildings, equipment and intellectual property. The recommendations concerning the treatment of durables are of special relevance for monitoring progress toward *sustainable* prosperity.

Section IV reports on steps being taken internationally and in Canada to account for the use of natural resource assets and human impacts on the environment. Section V concludes with some thoughts on the meaning of sustainable prosperity and options for achieving this.

II. Measures of Productivity and the Standard of Living

We begin our examination of productivity measures by considering the definitions of different types that are in common use.[2] The ratio

[2] Although useful analogies can be drawn and there are methodological commonalities, the measurement of productivity for nations is a fundamentally different undertaking from the sorts of productivity measurement dealt with by engineers for specific machines and production lines, and by accountants and business analysts and economists working with micro level data for individual production units. At the national level of aggregation, the data available are limited to fairly short time series, putting bounds on the scope for econometric estimation. Also feedback effects among the measured inputs and outputs cannot be ruled out a priori. Index number methods (including growth accounting) are the mainstay methodology. Estimates of relative productivity or productivity growth do not, by themselves, provide causal insights. However, many aspects of federal government and other economic planning are affected by reported productivity measures. Also, causal research on productivity depends as well on having measures of productivity. See Diewert (1976, 1987) and Diewert and Nakamura (2003, 2007).

for a given nation and time period of the output volume produced to the volume of one or more specified input factors used in producing the output is referred to as the productivity level, or simply as productivity. Different types of measures result from considering different selections of the input factors. Here we look at how the commonly mentioned measures relate to each other and to output *per capita*.

Output *per capita* is defined as the product of output per hour of work, and can be represented as follows:

$$\frac{\text{Output}}{\text{POP}} \equiv \frac{\text{Output}}{\left[\begin{array}{c}\text{Total}\\ \text{input}\end{array}\right]} \times \frac{\left[\begin{array}{c}\text{Total}\\ \text{input}\end{array}\right]}{\left[\begin{array}{c}\text{Total}\\ \text{measured}\\ \text{input}\end{array}\right]} \times \frac{\left[\begin{array}{c}\text{Total}\\ \text{measured}\\ \text{input}\end{array}\right]}{\left[\begin{array}{c}\text{Total}\\ \text{labour}\\ \text{input}\end{array}\right]} \qquad (1)$$

$$= \quad (A) \quad \times \quad (B) \quad \times \quad (C)$$

$$\times \frac{\left[\begin{array}{c}\text{Total}\\ \text{labour}\\ \text{input}\end{array}\right]}{\left[\begin{array}{c}\text{Total}\\ \text{work}\\ \text{hours}\end{array}\right]} \times \frac{\left[\begin{array}{c}\text{Total}\\ \text{work}\\ \text{hours}\end{array}\right]}{\left[\begin{array}{c}\text{Number}\\ \text{of}\\ \text{workers}\end{array}\right]} \times \frac{\left[\begin{array}{c}\text{Number}\\ \text{of}\\ \text{workers}\end{array}\right]}{\left[\begin{array}{c}\text{Potential}\\ \text{labour}\\ \text{force}\end{array}\right]} \times \frac{\left[\begin{array}{c}\text{Potential}\\ \text{labour}\\ \text{force}\end{array}\right]}{\text{POP}}$$

$$\times \quad (D) \quad \times \quad (E) \quad \times \quad (F) \quad \times \quad (G).$$

For expositional convenience, we denote the terms on the right-hand side by (A)-(G), respectively. In term (G), POP denotes the size of the total population, and the potential labour force is the number of persons who are old enough to legally work.

Economists tend to prefer the most comprehensive of the productivity statistics that can be defined: total factor productivity — TFP — given by term (A). This is the productivity statistic that fits naturally into the growth accounting models of economists. Of course, national statistical agencies cannot measure the *total* input used in producing the output of a nation. However, as an approximation to TFP, many official statistics agencies also produce a multifactor productivity measure (MFP) that takes account of machinery and equipment and other capital inputs as well as labour.[3]

Economic growth strategies can focus on raising various combinations of the terms on the right-hand side of the above expression for output per person. For example, providing daycare so that women can more easily work or increasing or removing the age for mandatory retirement for older workers might increase term (F). When the average hours of work per worker rises, this raises term (E). Reducing personal income taxes is a measure often recommended for governments interested in raising term (E). Total labour input per hour worked, which is term (D), will tend to rise if, for example, the educational level of the workforce is increased. More rapid investment in machinery and equipment and other non-labour input factors will tend to increase term (C), and tax measures are sometimes recommended for achieving this objective as well. Term (B) rises with increases in factors of production *other* than those being accounted for in the MFP measure produced by a national statistical program. Unmeasured inputs typically include intellectual capital such as new business processes.

Lacking workable strategies for raising terms (B)-(F) above, attention naturally shifts to term (A) and the importance of raising TFP.

In addition to producing estimates for MFP, the statistical agencies in many countries also produce one or more of three sorts of labour productivity measures. In this paper we refer to these using the designations of per worker labour productivity (LP), per hour labour productivity (HLP), and weighted hour labour productivity (WHLP).

In Figure 1 we show how the various labour productivity measures (LP, HLP, and WHLP) as well as the multi factor MFP and TFP measures relate to each other and to the components of output *per capita* designated in (1). From the decomposition of output *per capita* shown in (1) and the definitions in Figure 1 below, we see that it is *not* true that labour productivity relates more directly or naturally to output *per capita* than a TFP or MFP measure, as is sometimes claimed. It can be seen too that TFP, and also MFP, are components of all the labour productivity measures. Hence raising TFP or MFP will tend to raise measured labour productivity as well.

Also, if all of the productivity measures defined in Figure 1 were evaluated for the same production scenario (*i.e.*, the same country

[3] For more on the definition and measurement of MFP see Schreyer (2001).

Total Factor Productivity:
$$\text{TFP} \equiv \frac{\text{Output}}{\left[\text{Total input}\right]} = (\text{A})$$

Multi Factor Productivity:
$$\text{MFP} \equiv \frac{\text{Output}}{\left[\text{Measured input}\right]} = \text{TFP} \times (\text{B})$$

Wage Weighted Hours Productivity:
$$\text{WHLP} \equiv \frac{\text{Output}}{\left[\text{Total labor input}\right]} = \text{TFP} \times (\text{B}) \times (\text{C}) = \text{MFP} \times (\text{C})$$

Hours Labour Productivity:
$$\text{HLP} \equiv \frac{\text{Output}}{\left[\text{Total work hours}\right]} = \text{TFP} \times (\text{B}) \times (\text{C}) \times (\text{D})$$
$$= \text{MFP} \times (\text{C}) \times (\text{D}) = \text{WHLP} \times (\text{D})$$

Worker Labour Productivity:
$$\text{LP} \equiv \frac{\text{Output}}{\left[\text{Number of workers}\right]} = \text{TFP} \times (\text{B}) \times (\text{C}) \times (\text{D}) \times (\text{E})$$
$$= \text{MFP} \times (\text{C}) \times (\text{D}) \times (\text{E}) = \text{WHLP} \times (\text{D}) \times (\text{E}) = \text{HLP} \times (\text{E})$$

FIGURE 1
THE RELATIONSHIP OF DIFFERENT PRODUCTIVITY MEASURES TO TOTAL OUTPUT

and time period), the values for the MFP and labour productivity measures would always be greater than the value for TFP. The smaller the measured input that a statistical agency accounts for in their MFP measure compared with the actual total input, the greater the factor will be by which the measured MFP exceeds the true TFP. The value for a simple worker labour productivity measure (LP) will also always exceed the hours labour productivity (HLP) and the wage weighted hours productivity (WHLP) measures. Thus, being clear in empirical studies and policy analyses about the measures used is important.

To be meaningfully interpreted, productivity measures must usually be placed in a comparative context. The two most common contexts are (1) comparisons of productivity for two different time periods for the same productive unit — *e.g.*, for the same nation — and (2) for two nations such as for Korea and the United States or Japan. To carry out such a comparison, usually a ratio is formed of the chosen productivity index for the two time periods, or for the two production units: a productivity comparison measure. Depending on the nature of the comparison, productivity comparison measures are often referred to as productivity growth, or as relative productivity, measures.

Historically, national statistical agencies focused on producing measures of productivity growth for their own nations. An advantage of this focus is that factors that are omitted, and measurement error distortions, that tend to be stable from year to year over time for a given nation may largely cancel out of a productivity growth index. However, these days statistical agencies need to also produce measures comparing the productivity of nations.

Both growth and relative productivity indexes can be defined in terms of comparisons between two designated production scenarios, denoted, say, by s and t. A ratio of output to input can be thought of as the rate of transformation of input into output. It is natural to consider how this rate of transformation compares for two nations in a given time period, or for one nation over time.

III. How Should National Output Be Measured?

The numerator of all the productivity measures presented in the previous section is stated simply as total output. What a productivity index actually picks up will depend, of course, on how the output measure is defined. The most commonly used measure of national output is gross domestic product (GDP). GDP can be presented as an aggregate of four categories delineated by the final purchaser of the products:

$$\text{GDP} = \text{Consumer Spending (C)} + \text{Business and Residential Investment (I)} + \text{Government Spending, not including transfer payments (G)} + \text{the Trade Balance.} \quad (2)$$

TABLE 1

GDP *PER CAPITA* AND OTHER INDICATORS OF LIVING STANDARDS

Country	Population as of 2006	GDP *per capita*, (2005 $PPPs)	GNI *per capita*, 2004[1] (2005$, Atlas)	Infant Deaths/ 1,000 Live Births (for 2006)	Life Expectancy at Birth (for 2006)	Unemployment Rate (for 2005)
	(1)	(2)	(3)	(4)	(5)	(6)
U.S.	298,444,215 [1]	41,600 [1][1]	43,740 [2]	6.43 [7]	77.85 [6]	5.1 [6]
Iceland	299,388 [7]	35,700 [2]	46,320 [1]	3.29 [2]	80.31 [3]	2.1 [1]
Canada	33,098,932 [4]	33,900 [3]	32,600 [4]	4.69 [4]	80.22 [4]	6.8 [7]
Australia	20,264,082 [5]	31,600 [4-5]	32,220 [5]	4.63 [3]	80.50 [2]	5.1 [5]
Japan	127,463,611 [2]	31,600 [4-5]	38,980 [3]	3.24 [1]	81.25 [1]	4.4 [4]
New Zealand	4,076,140 [6]	25,300 [6]	25,960 [6]	5.76 [5]	78.81 [5]	3.7 [3]
South Korea	48,846,823 [3]	22,600 [7]	NA	6.16 [6]	77.04 [7]	3.7 [2]

Source: See U.S. World Fact Book figures for 2005 for all columns except for the GNI figures that are taken from the World Bank (2005).
Note: 1) Ranks from 1 to 7 are given in square brackets, with number 1 being highest or best.

A. Allowing for Changes in the Terms of Trade

The terms of trade are determined by the prices obtained for exports relative to the prices paid for imports. Trade is important for the Korean economy, and it is sensitive to the terms of trade.

Extending and applying methods proposed by Diewert and Morrison (1986), Kohli (1990, 2004), and Feenstra, Reinsdorf, Slaughter, and Harper (2005) argue and show empirically for the United States that it is important to allow for the effects of import and export price movements in studies of productivity and economic growth.

Instead of GDP, gross national income (GNI) might be used as a measure of the size of an economy. GNI is equal to GDP less net taxes on production and imports, less compensation of employees and property income payable to the rest of the world plus the corresponding items received from the rest of the world. For example, when company profits are transferred abroad, this tends to lower GNI relative to GDP. Conversely, when foreign affiliates or domestic firms or residents abroad make payments to the domestic economy, this will tend to raise GNI relative to GDP.

The World Bank uses GNI *per capita* converted to equivalent U.S. dollars using the Atlas method[4] to classify countries for analytical purposes and to determine borrowing eligibility. GDP *per capita* at purchasing power parity (PPP) and GNI *per capita* expressed in U.S. dollars using the Atlas method lead to different pictures of the relative standard of living even if attention is confined to developed countries. This point is demonstrated in Table 1. For example, Canada is ranked ahead of Japan according to GDP *per capita* at purchasing power parity, but behind Japan in terms of GNI *per capita* expressed in U.S. dollars using the Atlas method. The value for GNI for Korea is missing in the source for column 3 of Table 1; it would be interesting to have that value.

B. Value Added or Gross Output?

Output can be measured as value added, or as gross output. GNP and GDP are both value added measures, despite the fact that these terms begin with the word "gross." GNP and GDP are value added measures because they exclude intermediate inputs (*i.e.*, they exclude both produced and purchased energy and goods and services used for the production of final demand products). In contrast, a gross output measure includes the intermediate products. The KLEMS (capital, labour, energy, materials, and services) approach involves an explicit treatment of intermediate products and makes use of gross output measures.[5]

Modern business processes aim to improve the efficiency with which both intermediate and primary inputs are used. For example, just-in-time (JIT) production, statistical process control, and computer-aided design and manufacturing serve to reduce error rates

[4] The Atlas conversion method involves using a three-year average of exchange rates.

[5] Jorgenson, Gollop, and Fraumeni (1987) were the first scholars to work out and apply the basic KLEM methodology for a detailed industry analysis of productivity growth in the post-war U.S. economy. The primary aim of the European KLEMS (EU KLEMS) project is to arrive at an internationally comparable dataset for a KLEMS-type analysis of productivity growth for eight European countries: Denmark, Finland, France, Germany, Italy, Netherlands, Spain, and the United Kingdom. The World KLEMS project, of which EU KLEMS is the first component, represents an international platform for national level research and data collection efforts with a clear emphasis on the need for international comparability. For more on the development of the KLEM approach in the United States, see Dean and Harper (2000), Gullickson (1995), and Gullickson and Harper (1999). Pyo (2005) explains that they have constructed a Korean database of gross output, GDP, and input series for the period of 1984-2002 in the framework of KLEM Model.

and cut down on sub-standard production. These approaches reduce the wastage of materials as well as worker time.[6] Such efficiencies may be an important potential margin of improvement for countries struggling to increase output with little or no input augmentation.

All of the productivity measures introduced in this paper can be recast in a KLEMS formulation. TFP or MFP growth as measured by the value added method will systematically exceed the index values based on gross output by a factor equal to the ratio of gross output to value added.[7] Productivity in the gross output formulation is $Y/(E+M+L+K)$ where Y is gross output, E is energy, M is materials, L is labour input, and K is capital input. Productivity in the real value added framework is roughly $(Y-E-M)/(L+K)$. Given a productivity improvement of ΔY with all inputs remaining constant, the gross output productivity growth rate is

$$[(Y+\Delta Y)/(K+L+E+M)]/[Y/(K+L+E+M)]=(Y+\Delta Y)/Y=1+(\Delta Y/Y), \quad (3)$$

which is less than the real value added productivity growth rate of

$$[(Y+\Delta Y-E-M)/(K+L)]/[(Y-E-M)/(K+L)]=1+[\Delta Y/(Y-E-M)]. \quad (4)$$

Thus, the smaller denominator in the value added productivity measure translates into a larger productivity growth measure.[8] Several studies have found that productivity growth measured according to a value added model is greater than that derived from a model that also takes intermediate inputs into account.[9]

Pyo, Rhee, and Ha (2006) present preliminary estimates of labour productivity and total factor productivity for Korea at a reasonably detailed industry level. They use a 72-sector industrial classification, following the guidelines of the EU KLEMS and World KLEMS initiatives. A KLEMS model can be thought of as a gross output growth accounting framework in which output is decomposed into

[6] This is demonstrated, for instance, by Gullickson and Harper (1999).

[7] See Diewert (2002, p. 46, endnote 21).

[8] See also Schreyer (2001, p. 26).

[9] For example, Oulton and O'Mahony (1994) show that the value-added method produces estimates of MFP growth for manufacturing in the United Kingdom that are roughly twice those given by the gross output method. It is to be expected, of course, that sub-national level studies will be more affected by the choice of a value added or gross output measure.

components attributed to capital (K), labour (L), energy (E), materials (M), and services (S) inputs. Intermediate inputs are allowed for explicitly.

Many firms sell some or all of their output to other firms as intermediate inputs. For example, increasing numbers of firms are outsourcing business services such as call center and accounting operations. Some of the outsourcing takes place with other firms in the same nation, but increasing amounts are with firms in other nations (the so-called “off shoring”).

In countries such as the United States and Japan, there has been widespread fear that outsourcing, and especially off shoring, would lead to job loss at home. As Hyunbae Chun brought to our attention in his commentary, some researchers including Amiti and Wei (2006) have studied this issue empirically.[10]

Amiti and Wei (2006) argue that off shoring can affect labour demand through three channels. First, there is a substitution effect through the input price of materials or services. A fall in the price of imported services would lead to a fall in the demand for labour when labour and services are substitutes. Second, if off shoring leads to productivity improvements then firms can produce the same amounts of output with smaller amounts of input. Hence, conditional on a given level of output, off shoring is expected to reduce the demand for labour. Third, off shoring can affect labour demand through a scale effect. An increase in off shoring can make the firm more efficient and competitive, increasing the demand for its output and hence labour.

C. Taking Account of Depreciation

Currently, the most widely reported and used concept of national economic output is gross domestic product (GDP). However, economists have long argued that net domestic product (NDP) or, equivalently, its income counterpart, net domestic income (NDI), are more appropriate measures of the total output of a nation.[11]

[10] Related studies include Feenstra and Hanson (1999). They report that material off shoring explained over 40 percent of the increase in nonproduction wages in the 1980s!

[11] For example, Denison (1985) used net output in his studies of economic growth, Hulten (1990, 1992) argues for using net output for welfare analysis, and Landefeld and Fraumeni (2001) call attention to the significance of NDP as a measure of sustainable growth.

Moreover, Diewert and Fox (2005) argue that certain features of the "new economy" make it more important than ever that a switch is made from using GDP to NDP or NDI as the measure of total output to be monitored by governments striving to achieve sustainable prosperity and used in national productivity measures.

Spant (2003) argues that because of the increase in the share of capital investment that is made up of rapidly depreciating high technology products, the use of GDP as opposed to NDP has lead to an overstatement of the real rate of economic growth and productivity increase.

In order to calculate net investment, an appropriate depreciation charge must be calculated for each period. Lack of professional consensus on how to determine this charge is perhaps the main reason why GDP is used instead of NDP or NDI.[12] However, even a very imperfect estimate of depreciation might result in economic analyses that better capture reality.

Diewert (2007) explains that each definition of net product gives rise to a corresponding definition of "income." In the economics literature, most of the discussion of alternative measures of net output has been conducted in terms of alternative "income" measures, so here we also discuss alternative "income" rather than "net product" measures. The key ideas can be understood by considering alternative income concepts in a very simple two period (t=0, 1) economy with only two goods: consumption C^t with unit price p_C^t and a durable capital input K^t. Net investment, I^t, is defined as the difference between the end and the beginning of period capital stocks: *i.e.*, $I^t \equiv K^t - K^{t-1}$.

Samuelson (1961, p. 45) used the Marshall (1890)-Haig (1921/1959) definition of income as consumption plus the consumption equivalent of the increase in net wealth over the period, and Diewert (2007) follows this same practice. Nominal income in period 1 can be represented as $p_C^1 C^1 + p_I^1 I^1$ where I^1 is net investment in period 1. If we substitute this representation of net investment into Samuelson's definition of period 1 nominal income, we obtain the following expression for *period 1 nominal income*:

[12] See, Diewert (1996, 2005), Diewert and Schreyer (2006a, 2006b), Diewert and Wykoff (2006), and Hotelling (1925) for more on this model of depreciation. Different countries make quite different assumptions about service lives.

$$\text{Income A} \equiv p_C^1 C^1 + p_I^1 I^1 = p_C^1 C^1 + p_I^1 (K^1 - K^0) = p_C^1 C^1 + p_I^1 K^1 - p_I^1 K^0. \quad (5)$$

Suppose depreciation partially consumed the capital stock in the current period t and there was no new investment to offset this. Then the term $I^t \equiv K^t - K^{t-1}$ would be negative and this term would tend to pull down the value of Income A. We see Income A as an improvement over income measures that take no account of a reduction in capital stocks.

However, Income A is not wholly satisfactory. Here, the beginning and end of period capital stocks are valued at the same price, p_I^1. On conceptual grounds, it would probably be better to value the beginning of period capital stock at the beginning of period opportunity cost of capital, p_K^0, and the end of period capital stock at the end of period expected opportunity cost of capital, p_K^1. That is, perhaps we should replace p_I^1 in (6) by p_K^1 for the K^1 portion of $I^1 \equiv K^1 - K^0$, and by p_K^0, adjusted for the effects of inflation over the duration of period 1, for the K^0 portion.[13] This price of capital could surely change over a period as long as a year. To adjust p_K^0 for inflation we could use either a capital *specific price index*, denoted here by $1+i^0$, or a *general price index* that is based on the movement of consumer prices, denoted by $1+\rho^0$. That is, we could use:

$$1+i^0 \equiv p_K^1 / p_K^0, \text{ or} \quad (6)$$

$$1+\rho^0 \equiv p_C^1 / p_C^0. \quad (7)$$

These alternative adjustment factors lead to different *measures of income from the perspective of the level of prices prevailing at the end of period 1*:

$$\text{Income B} \equiv p_C^1 C^1 + p_K^1 K^1 - (1+i^0) p_K^0 K^0. \quad (8)$$

$$\text{Income C} \equiv p_C^1 C^1 + p_K^1 K^1 - (1+\rho^0) p_K^0 K^0. \quad (9)$$

Comparing (8) and (5), it is easily seen that Income B equals Income A. Thus, for a measure of output, we are left with the

[13] Here the assumption is made that it is not necessary to adjust p_C^1 into an end of period 1 price.

options of choosing between Income A, which is adjusted for (*i.e.*, net of) wear and tear,[14] and Income C, which is adjusted for wear and tear and also anticipated revaluation,[15] or of sticking with a gross output measure.

The "traditional" user cost of capital (which approximates a market rental rate for the services of a capital input for the accounting period), u^1, consists of three additive terms:

$$u^1 = U^1 + D^1 + R^1, \tag{10}$$

where U^1 denotes the reward for waiting (an interest rate term), D^1 denotes the cross sectional depreciation term (the wear and tear depreciation term), and R^1 is the anticipated revaluation term which can be interpreted as an obsolescence charge if the asset is anticipated to fall in price over the accounting period. The gross output income concept corresponds to the traditional user cost term u^1. This gross income measure can be used as an approximate indicator of short run production potential, but it is not suitable for use as an indicator of sustainable consumption. For an indicator of sustainable consumption, income concept A or C is more appropriate.

Expressed in words, for Income A, we take the wear and tear component of the traditional user cost, D^1, times the beginning of period corresponding capital stock, K^0, out of the primary input category and treat this as a negative offset to the period's gross investment. Diewert (2007) suggests that the Income A concept can be interpreted as a *maintenance of physical capital approach* to income measurement. In terms of the Austrian production model favoured by Hicks (1961) and by Edwards and Bell (1961), capital at the beginning and also at the end of the period (K^0 and K^1 respectively) should both be valued at the end of period stock price for a unit of capital, p_K^1, and the contribution of capital accumulation to current period income is the difference between the end of period value of the capital stock and the beginning of the period value (at end of period prices), $p_K^1 K^1 - p_K^0 K^0$. This difference

[14] We can associate this income concept with Marshall (1890), Haig (1921/1959), Pigou (1941), and Samuelson (1961). On machine replacement issues, see, for example, Cooper and Haltiwanger (1993).

[15] We can associate this income concept with Hayek (1941), Sterling (1975), and Hill (2000).

between the end and beginning of period values for the capital stock converted into consumption equivalents can be added to actual period 1 consumption in order to obtain Income A.

Income C can be computed by subtracting from gross output both wear and tear depreciation, D^1K^0, and the revaluation term, R^1K^0, and treating both of these terms as negative offsets to the period's gross investment.[16] Diewert (2007) terms this *a maintenance of real financial capital approach* to income measurement.

In the Austrian production model tradition followed by Hicks (1961) and Edwards and Bell (1961), capital stocks at the beginning and end of the period should be valued at the prices prevailing at the beginning and the end of the period,[17] p_K^0 and p_K^1 respectively, and then these values of the capital stock should be converted into consumption equivalents (at the prices prevailing at the beginning and end of the period). Thus the end of the period value of the capital stock is $p_K^1K^1$ and this value can be converted into consumption equivalents at the consumption prices prevailing at the end of the period. The beginning of the period value of the capital stock is $p_K^0K^0$. To convert this value into consumption equivalents at end of period prices, we must multiply this value by $(1+\rho^0)$, which is one plus the rate of consumer price inflation over the period. This price level adjusted difference between the end and beginning of period values for the capital stock, $p_K^1K^1-(1+\rho^0)p_K^0K^0$, can be converted into consumption equivalents and then can be added to actual period 1 consumption in order to obtain Income C.

The difference between Income A and Income C can be viewed as follows. Income A (asymmetrically) uses the end of period stock price of capital to value both the beginning and end of period capital stocks and then converts the resulting difference in values into consumption equivalents at the prices prevailing at the end of the period. In contrast, Income C symmetrically values beginning and end of period capital stocks at the stock prices prevailing at the beginning and end of the period and *directly* converts these values into consumption equivalents and then adds the difference in these consumption equivalents to actual consumption.

[16] The resulting Income 3 can be interpreted to be consistent with the position of Hayek (1941), Sterling (1975), and Hill (2000).

[17] Strictly speaking, the end of period price is an expected end of period price.

In symbols, the difference between income concepts A and C is as follows:

$$\begin{aligned}\text{Income A}-\text{Income C} &= p_C^1 C^1 + p_I^1 K^1 - p_I^1 K^0 \\ &\quad -[p_C^1 C^1 + p_K^1 K^1 - (1+\rho^0) p_K^0 K^0] \\ &= (\rho^0 - i^0) p_K^0 K^0.\end{aligned} \tag{11}$$

If ρ^0 (the general consumer price inflation rate) is greater than i^0 (the asset inflation rate) over the course of the period, then there is a negative real revaluation effect (so that obsolescence effects dominate). In this case, Income C will be less than Income A, reflecting the fact that capital stocks have become less valuable (in terms of consumption equivalents) over the course of the period. If ρ^0 is less than i^0 over the course of the period, then the real revaluation effect is positive (so that capital stocks have become more valuable over the period). In this case, Income C exceeds Income A, reflecting the fact that capital stocks have become more valuable over the course of the period and this real increase in value contributes to an increase in the period's income which is not reflected in Income A.

Both Income A and Income C have reasonable justifications. However, Income C seems preferable for three reasons: (i) It seems to us that (expected) obsolescence charges are entirely similar to normal depreciation charges and Income C reflects this similarity. (ii) In contrast to Income C, Income A does not value the beginning and end of period value of the capital stock in an asymmetric manner. And (iii) it seems to us that waiting services (U^1K^0) along with labour services and land rents are natural primary inputs whereas depreciation and revaluation services (D^1K^0 and R^1K^0 respectively) are more naturally regarded as intermediate input charges.[18]

As Professor Pyo points out in his commentary, our decompostion of output *per capita* in expression (1) does not allow us to represent the depreciation issues considered in this section, but he does this in his comment on our paper.

[18] Income B is based on the Austrian model of production that has its roots in the work of Böhm-Bawerk (1891), von Neumann (1937), and Malinvaud (1953) but these authors did not develop the user cost implications of the model. On the user cost implications of the Austrian model, see Hicks (1973, pp. 27-35) and Diewert (1977, pp. 108-11; 1980, pp. 472-4).

IV. Accounting for Natural Resource and Environmental Assets

"Environmental economists are still working towards an agreed definition of sustainable income, but central to it is the point recognised by Hicks that if assets are consumed without replacement one is worse off at the end of the period than at the start and consumption in the period has covered not just income, but also an element of wealth. So far, however, no precise formulation of sustainable income has been agreed."

(Anne Harrison 1989, p. 386)

"A sustainable economy includes economic stability and competitiveness, employment and education, a healthy environment, and sound environmental practices."

(Government of Canada 2005)

The above definition of a sustainable economy is included in the official 2005 Government of Canada statement of economic objectives. It echoes the spirit of the definition of sustainable economic growth provided by the World Commission on Environment and Development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[19] The phrases used to describe the objectives of environmentally sustainable economic development, and the need for measures to monitor progress in this regard, might seem at first to be similar to the discussion in the previous section on the need to take account of asset depreciation in measuring the economic and productivity growth of a nation. However, with the environmental assets, the price weights needed to evaluate a Marshall-Haig concept of income are missing. Canada has thus opted to account for natural resource and environmental assets in an external satellite account, rather than directly integrating these with the measures for the market part of the economy.

In Canada, the relationship between environmental accounts and the economy has been structured *via* the development of the Canadian System of Environmental and Resource Accounts (CSERA),[20] relying in particular on the Material and Energy Accounts (MEFA) and the input-output (I/O) tables of the Canadian SNA (System of

[19] See Harrison (2001).

[20] It should be noted that much of the statistical information in the CSERA is in physical rather than monetary units.

National Accounts).[21] The link to the SNA is important. The accounts, when complete, will record all resources and wastes that flow across the environment-economy border. They will record the quantities of natural resource based products produced by industries, households and government, and then show how the same agents consume the products. The planned benefits of MEFA, using the level of disaggregation of the I/O accounts, include the ability to analyse changes within specific industries. The I/O accounts show flows and many of the same concepts of the I/O accounts can be transferred to the MEFA.

The priorities that have been decided on in developing environmental accounts for Canada are water, energy, and green house gases. These accounts closely follow the recommendations of the international System of Environmental and Economic Accounts (SEEA), and are consistent as well with the basic approach adopted by the United States.[22] SEEA 2000 includes tables in purely physical terms, with links between the use of produced goods, natural resources taken from the environment and residuals released back into the environment.[23]

The SEEA 2000 introduces the concept of hybrid accounts. These include conventional national accounts, consistent with the 1993 SNA as well as physical measures for residual outputs and resource inputs. The analytical power of the hybrid tables comes from the use of classifications of environmental activities and products that are consistent with the classifications used in the SNA.

By now, the Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003, referred to as SEEA 2003, is available.[24] This lays out the guidelines for construction of a satellite system of the System of National Accounts that brings together economic and environmental information in a common framework to measure the contribution of the environment to the

[21] One difference between the I/O and MEFA is that the MEFA include the production of resources that are traded, as well as those that are self-consumed. The MEFA attempt to account for all material and energy flows. The I/O considers flows among the economic agents.

[22] See Smith (2005) for more on the Canadian approach, and Landefeld (1999) for material on the U.S. approach.

[23] The word residual is used to cover emissions to both air and water and also solid waste.

[24] This Handbook is available online at http://unstats.un.org/unsd/envAccounting/seea.htm.

economy and the impact of the economy on the environment. It seeks to provide policy-makers with indicators and descriptive statistics to monitor these interactions as well as a database for strategic planning and policy analysis to identify more sustainable paths of development.[25]

The SEEA 2003 covers four categories of accounts. The first category is the flow accounts for pollution, energy and materials. These accounts provide information at the industry level about the use of energy and materials as inputs to production and the generation of pollutants and solid waste. The second category is environmental protection and resource management expenditure accounts. These accounts identify expenditures incurred by industry, government and households to protect the environment or to manage natural resources. They take those elements of the existing SNA that are relevant to the management of the environment and show how the environment-related transactions can be made more explicit. The third category is the natural resource asset accounts. These accounts record stocks and changes in stocks of natural resources such as land, fish, forest, water, and minerals. And the fourth category is the valuation of nonmarket flow and environmentally adjusted aggregates. This component presents nonmarket valuation techniques and their applicability in answering specific policy questions. It discusses the calculation of several macroeconomic aggregates adjusted for depletion and degradation costs and their advantages and disadvantages. It also considers adjustments concerning the so-called defensive expenditures.

V. Concluding Remarks

We set out to discuss measures that national governments can use

[25] The revision of the SEEA 2003 was undertaken under the joint responsibility of the United Nations, Eurostat, IMF, OECD, and the World Bank. Much of the work was done by the London Group on Environmental Accounting. The SEEA 2003 is a satellite system of the System of National Accounts. It brings together economic and environmental information in a common framework to measure the contribution of the environment to the economy and the impact of the economy on the environment. It provides policy-makers with indicators and descriptive statistics to monitor these interactions as well as a database for strategic planning and policy analysis to identify more sustainable paths of development. See also the *OECD Environmental Data Compendium* (1993, 1997, 1999).

to try to monitor progress toward achieving sustained economic growth. Multiple aspects of sustainable economic growth are implicit in the issues covered.

We noted that shifts in the terms of trade can affect *per capita* income in much the same way as changes in economic efficiency. However, nations often have little control over terms of trade changes. Thus we have argued for the use of measures of national output such as GNI rather than GDP, and for approaches to decomposing economic growth that allow for terms of trade effects (*e.g.*, the Diewert-Kohli-Morrison approach).[26]

New efficiencies can be introduced through product and process innovation for intermediate as well as final demand products. We argued for a gross output/KLEMS approach that explicitly allows for intermediate products, including international trade in intermediates.

We argued also that societies must be on guard not to consume so much, period to period, that they eat into the capital investments carried forward from previous periods. And we argued that societies must take care as well to save enough to cover the depreciation of existing capital and protect the environment. We argued that proper national accounting procedures, including measures of national economic output that allow for depreciation, could help in these respects.

However, to be in a position to save and make replacement and environmental protection as well as new capital investments, economic growth is required.[27] Where do the process and product innovations that fuel economic growth come from? This brings us back to the underlying question that stimulated interest in the

[26] See Diewert and Morrison (1986) and Kohli (1990, 2004).

[27] In the political realm, of course, the meaning of sustainable prosperity is more than a matter of just achieving some relative level of *per capita* income without running down assets. If output grows on target, but unemployment and poverty rates rise, the leaders of a country will be unlikely to view this as sustainable. Governments attempting to lead their nations to higher levels of sustainable prosperity need a *portfolio of accounts* including measures of profit rates, firm births and failures, consumer saving and credit behaviour, the distribution of employment and income for different segments of the population, access to education, socio-political participation, the environment, and many aspects of human health. This situation is analogous to the use of diagnostic measures by doctors. Different measures are needed for, say, heart function *versus* blood sugar, since the proper responses to unsatisfactory results are so different.

national income accounting measurement issues: How can a nation like Korea achieve more rapid, and sustainable, growth of economic output?

Three basic strategies for raising TFP and, more importantly, for raising output *per capita* figure prominently in the literature. We will refer to these as the eureka, the coattails, and the super-size-it approaches.

The eureka approach. Sometimes people really do come up with totally new products or processes.[28] Discovery and invention can deliver sustainable TFP and *per capita* output growth only to the extent that a nation comes up with reliably successful ways of fostering and also commercializing product and process discoveries and inventions. Institutional innovations such as research universities, national laboratories, and the Japanese private sector research consortiums are attempts at making the eureka approach a sustainable source of economic growth.

The coattails approach focuses on identifying and adopting commercially promising inventions of others. The sustainability of this approach depends on finding reliable strategies for noticing and adapting and adopting the inventions of others. Many nations sponsor scientists and entrepreneurs to scour the academic journals and newly filed patent applications for promising new inventions, and also sponsor students to study at research institutions like Harvard university, in the hopes of learning about new product and process inventions in early phases of their development, thereby facilitating efforts to find, vet, adapt and adopt commercially valuable inventions. This approach can deliver sustainable TFP and *per capita* output growth to the extent that a nation can come up with reliable ways of fostering the access to the new discoveries in other nations and the commercial adaptation and adoption processes.

The super-size-it approach focuses on finding ways to help firms headquartered in, or anyway operating within, a nation to grow so they can eventually reap economies of scale in production. Firms that succeed in growing large enough will come to dominate the markets they buy and sell in, and this market power can also help them survive longer. Moreover, firms that become very large also tend to develop political clout, and this too may help these firms

[28] See, for example, Feenstra, Markusen, and Zeile (1992) on economic growth associated with new inputs.

survive longer.

But do large, dominant, long-lived firms reliably bring sustainable economic and productivity growth? “No” is the tentative verdict on that question of Morck, Chun, and their collaborators.[29] Indeed the economic growth lessons we take away from the research of Morck *et al.* (2005) and Chun *et al.* (2007) is that market mechanisms that reward new invention, as well as adaptations and adoptions of the product and process inventions of others, and that weed out and reallocate the resources of producers who fail to provide products that customers prefer, are the only means that societies have discovered so far for reliably stimulating and maintaining a flow of new product and process ideas.[30]

The market mechanisms to which the research of Morck and Chun and their colleagues point *are not of the hands off, minimal government sort*. Rather, they require the infrastructure of effective laws and enforcement mechanisms, accounting conventions and corporate governance, and financial market regulations aimed at protecting the operation of free markets. Morck, Chun, and their collaborators argue that threats to the functioning of free markets can grow from *within* market economies, and indeed are probably an inevitable consequence of the growth of successful large firms and other vested economic interests. This is not a “manna from heaven” view of economic and productivity growth. This is a perspective on economic development that links sustained long run success to investments in institutions that protect the functioning of free markets, so that the economic contestants are competing on level fields, with referees adequate to the task of insuring that the stronger competitors end up with the gold medals, reliably, year after year. Morck and his collaborators argue that these are the conditions that help ensure that each new generation of individuals who are born into the world with the raw talent that could allow them, one

[29] See Feenstra, Hamilton, and Lim (2002), for example, on the nature of large, long-lived corporate groups in Korea.

[30] The empirical productivity literature has demonstrated that increases in the productivity of the economy can be obtained by reallocating resources away from low productivity firms in an industry to the higher productivity firms. However, different investigators have chosen different methods for measuring the contributions to industry productivity growth of entering and exiting firms and Diewert and Fox (2007) propose yet another method for accomplishing this decomposition, and also critique methods proposed and used by others.

day, to create valuable new products and processes will be motivated to strive hard, and their families will be motivated to back up their efforts to put in the gruelling effort it takes, to realize the benefits of the capacities they were born with, for themselves, their families and for their nations.

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References

Amiti, M., and Wei, S.-J. Does Service Offshoring Lead to Job Losses? Evidence from the United States. NBER Working Paper No. 11926, http://www.nber.org/books/criws06/amiti-wei12-5-06.pdf, 2006.

Böhm-Bawerk, E. V. *The Positive Theory of Capital*. W. Smart (Translator of the original German book published in 1888), New York: G. E. Stechert, 1891.

Chun, Hyunbae, Kim, Jung-Wook, Morck, Randall, and Yeung, Bernard. Creative Destruction and Firm-Specific Performance Heterogeneity. University of Alberta Working Paper, 2007.

Cooper, R., and Haltiwanger, J. "The Aggregate Implications of Machine Replacement: Theory and Evidence." *American Economic Review* 83 (No. 3 1993): 360-82.

Dean, E. R., and Harper, M. J. The BLS Productivity Measurement Program. U.S. Bureau of Labor Statistics, Washington, 2000.

Denison, E. *Trends in American Economic Growth, 1929-1982*. Washington, D.C.: Brookings Institution, 1985.

Diewert, W. E. "Exact and Superlative Index Numbers." *Journal of Econometrics* 4 (No. 2 1976): 115-46 (Reprinted as Chapter 8 in Diewert and Nakamura, pp. 223-52, 1993).

__________. "Walras' Theory of Capital Formation and the Existence of a Temporary Equilibrium." In G. Schwödiauer (ed.), *Equilibrium and Disequilibrium in Economic Theory*. Dordrecht: D. Reidel, pp. 73-126, 1977.

__________. "Aggregation Problems in the Measurement of Capital." In D. Usher (ed.), *The Measurement of Capital*. Chicago: University of Chicago Press, pp. 433-528, 1980.

__________. "Index Numbers." In J. Eatwell, M. Milgate, and P. Newman (eds.), *The New Palgrave: A Dictionary of Economics*. Vol. 2, London: Macmillan, pp. 767-80, 1987 (Reprinted as

Chapter 5 in Diewert and Nakamura, pp. 71-104, 1993).

__________. The Measurement of Business Capital, Income and Performance. Background Paper for the Canberra Group on Capital Stock Statistics, http://www.oecd.org/dataoecd/9/28/2666968.pdf, 1996.

__________. "Productivity Trends and Determinants in Canada." In S. Rao and A. Sharpe (eds.), *Productivity Issues in Canada*. University of Calgary Press, pp. 31-58, 2002.

__________. "Issues in the Measurement of Capital Services, Depreciation, Asset Price Changes and Interest Rates." Forthcoming in C. Corrado, J. Haltiwanger, and D. Sichel (eds.), *Measuring Capital in the New Economy*. NBER Studies in Income and Wealth, Chicago: University of Chicago Press, 2005. (Available as Discussion Paper 04-11, Department of Economics, University of British Columbia (http://www.econ.ubc.ca/diewert/disc.htm).

__________. "The Measurement of National Income." In W. E. Diewert *et al.* (eds.), 2007.

Diewert, W. E., Balk, B. M., Fixler, D., Fox, K. J., and Nakamura, A. O. (eds.) *Price and Productivity Measurement*. Trafford Press. 2007, Also Available for Free Download (After June 1 2007 from http://www.ipeer.ca/study.htm).

Diewert, W. E., and Fox, K. J. The New Economy and an Old Problem: Net *versus* Gross Output. Working Paper, Centre for Applied Economic Research, The University of New South Wales, 2005 (http://www.econ.ubc.ca/diewert/caer0502.pdf).

__________. "On Measuring the Contribution of Entering and Exiting Firms to Aggregate Productivity Growth." In W. E. Diewert *et al.* (eds.), 2007.

Diewert, W. E., and Morrison, C. J. "Adjusting Output and Productivity Indexes for Changes in the Terms of Trade." *Economic Journal* 96 (No. 383 1986): 659-79.

Diewert, W. E., and Nakamura, A. O. *Essays in Index Number Theory. Vol. I*, Amsterdam: North-Holland, 1993.

__________. "Index Number Concepts, Measures and Decompositions of Productivity Growth." *Journal of Productivity Analysis* 19 (Nos. 2-3 2003): 127-60.

__________. "The Measurement of Productivity for Nations." In J. J. Heckman and E. E. Leamer (eds.), *Handbook of Econometrics Volume 6*. Elsevier Science, 2007.

Diewert, W. E., and Schreyer, P. *The Measurement of Capital.* Forthcoming in the *New Palgrave Dictionary of Economics*, 2006a.

__________. Does Capitalized Net Product Equal Discounted Optimal Consumption in Discrete Time? Working Paper, Department of Economics, University of British Columbia, 2006b (http://www.econ.ubc.ca/discpapers/dp0601.pdf).

Diewert, W. E., and Wykoff, F. C. "Depreciation, Deterioration, and Obsolescence When There Is Embodied or Disembodied Technical Change." In W. E. Diewert *et al.* (eds.), 2007.

Edwards, E. O., and Bell, P. W. *The Theory and Measurement of Business Income*. Berkeley: University of California Press, 1961.

Feenstra, R. C., Hamilton, G. H., and Lim, E. M. "Chaebols and Catastrophe: A New View of the Korean Business Groups and Their Role in the Financial Crisis." *Asian Economic Papers* 1 (No. 2 2002): 1-45.

Feenstra, R. C., and Hanson, G. H. "The Impact of Outsourcing and High Technology Capital on Wages: Estimates for the United States, 1979-1990." *Quarterly Journal of Economics* 114 (No. 3 1999): 907-40.

Feenstra, R. C., Markusen, J. R., Zeile, W. "Accounting for Growth with New Inputs: Theory and Evidence." *The American Economic Review* 82 (No. 2 1992): 415-21.

Feenstra, R. C., Reinsdorf, M. B., Slaughter, M. J., and Harper, M. Terms of Trade Gains and U.S. Productivity Growth. Working Paper, http://mba.tuck.dartmouth.edu/pages/faculty/matthew.slaughter/High-Tech-Feenstra-Reinsdorf-Slaughter-Harper.doc, 2005.

Government of Canada. Canada's Performance 2005: The Government of Canada's Contribution. Published on the Canadian Treasury Board Secretariat Website (http://www.tbs-sct.gc.ca/report/govrev/05/cp-rc03_e.asp), 2005.

Gullickson, W. "Measurement of Productivity Growth in U.S. Manufacturing." *Monthly Labor Review* Vol. 118 (No. 7 1995): 13-28.

Gullickson, W., and Harper, M. J. *Production Functions, Input-Output Tables, and the Relationship between Industry and Aggregate Productivity Measures*. Bureau of Labor Statistics, Washington, February, 1999.

Haig, R. M. "The Concept of Income: Economic and Legal Aspects." In R. A. Musgrave and C. S. Shoup (eds.), *Readings in the Economics of Taxation*. Homewood, Illinois: Richard D. Irwin, pp. 54-76, 1959 (Haig's chapter was originally published in 1921).

Harrison, A. "Environmental Issues and the SNA." *Review of Income and Wealth* 35 (No. 4 1989): 377-88.

__________. Revised Handbook on Environmental Accounting (the SEEA 2000). SNA News and Notes, Issue 13, Oct. (http://unstats.un.org/unsd/nationalaccount/sna/sna13-en.htm#txt4), 2001.

Hayek, F. A. V. "Maintaining Capital Intact: A Reply." *Economica* 8 (No. 31 1941): 276-80.

Hicks, J. R. "The Measurement of Capital in Relation to the Measurement of Other Economic Aggregates." In F. A. Lutz and D. C. Hague (eds.), *The Theory of Capital*. London: Macmillan, pp. 18-31, 1961.

Hicks, J. R. *Capital and Time: A Neo-Austrian Theory*. Oxford: Clarendon Press, 1973.

Hill, T. P. Economic Depreciation and the SNA. Presented at the 26*th* Conference of the International Association for Research on Income and Wealth, Cracow, Poland, 2000.

Hotelling, H. "A General Mathematical Theory of Depreciation." *Journal of the American Statistical Association* 20 (No. 151 1925): 340-53.

Hulten, C. R. "The Measurement of Capital." In E. R. Berndt and J. E. Triplett (eds.), *Fifty Years of Economic Measurement, Studies in Income and Wealth*. Volume 54, The National Bureau of Economic Research, Chicago: The University of Chicago Press, 1990.

__________. "Accounting for the Wealth of Nations: The Net *versus* Gross Output Controversy and Its Ramifications." *Scandinavian Journal of Economics* 94 (No. 0 1992): S9-24.

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

Kohli, U. "Growth Accounting in the Open Economy: Parametric and Nonparametric Estimates." *Journal of Economic and Social Measurement* 16 (No. 3 1990): 125-36.

__________. "Real GDP, Real Domestic Income and Terms of Trade

Changes." *Journal of International Economics* 62 (No. 1 2004): 83-106.

Landefeld, J. S. "Assessing BEA's Prototype Integrated Economic and Environmental Satellite Accounts." *Survey of Current Business* (November 1999): 44.

Landefeld, S. J., and Fraumeni, B. M. "Measuring the New Economy." *Survey of Current Business* (March 2001): 23-40.

Malinvaud, E. "Capital Accumulation and the Efficient Allocation of Resources." *Econometrica* 21 (No. 3 1953): 233-68.

Marshall, A. *Principles of Economics*. London: Macmillan, 1890.

Morck, R., Wolfenzon, D., and Yeung, B. "Corporate Governance, Economic Entrenchment and Growth." *Journal of Economic Literature* 43 (No. 3 2005): 655-720.

Oulton, N., and O'Mahony, M. *Productivity and Growth*. Cambridge: Cambridge University Press, 1994.

Organisation for Economic Co-operation and Development. *OECD Environmental Data Compendium*. Paris: OECD, 1993, 1997, 1999.

Pigou, A. C. "Maintaining Capital Intact." *Economica* 8 (August 1941): 271-5.

Pyo, Hak. K. Investment Stagnation in East Asia and Policy Implications for Sustainable Growth. Final Report Paper for Korea Institute for International Economic Policy. http://www.kiep.go.kr/inc/download.asp?fnm=(2005-07-21-00332646677348)%20KIEP_Report_final.pdf, 2005.

___________. Investment Stagnation in East Asia and Policy Implications for Sustainable Growth. Working Paper 06-01, Korea Institute for International Economic Policy, 2006.

Pyo, Hak. K., Rhee, K. H., and Ha, B. Estimates of Labor and Total Factor Productivity by 72 Industries in Korea (1970-2003). Paper to Be Presented at OECD Workshop on "Productivity Analysis and Measurement." Bern, 16-18 October 2006. http://www.oecd.org/dataoecd/48/44/37537395.pdf, 2006.

Samuelson, P. A. "The Evaluation of 'Social Income': Capital Formation and Wealth." In F. A. Lutz and D. C. Hague (eds.), *The Theory of Capital*. London: Macmillan, pp. 32-57, 1961.

Schreyer, P. *OECD Productivity Manual: A Guide to the Measurement of Industry-Level and Aggregate Productivity Growth*. Paris: OECD, Available for Download in Unabridged Form at http://www.oecd.org/subject/growth/prod-manual. pdf, 2001.

Smith, P. "Broadening the Scope of Canada's National Accounts." Horizons, *Policy Research Initiative* 8 (No. 1 2005).

Spant, R. "Why Net Domestic Product Should Replace Gross Domestic Product as a Measure of Economic Growth." *International Productivity Monitor* 7 (Fall 2003): 39-43.

Sterling, R. R. "Relevant Financial Reporting in an Age of Price Changes." *The Journal of Accountancy* 139 (February 1975): 42-51.

U.S. Central Intelligence Agency (CIA). *World Fact Book*. http://www.cia.gov/cia/publications/factbook/index.html.

von Neumann, J. "Über Öein konomisches Gleichungssystem und eine Verallgemeinerung des Brouwerschen Fixpunktsatzes." *Ergebnisse eines Mathematische Kolloquiums* 8 (1937): 73-83 (Translated as "A Model of General Economic Equilibrium." *Review of Economic Studies* 13 (1945-6): 1-9).

World Bank. *World Development Indicators*. http://devdata.worldbank.org/data-query/.

Comments and Discussion

*Comments by Hak K. Pyo**

The *Seoul Journal of Economics* paper by Diewert and Nakamura is more than a review paper, though it provides an overview of some of the material covered in their forthcoming Heckman-Leamer Handbook chapter. In addition, however, their *Seoul Journal of Economics* paper attempts to reformulate the relationship of different productivity measures to total output and brings about two related important issues in productivity measurement: accounting for depreciation and environmental assets.

The paper argues that allowing properly for capital inputs requires adjustments to the numerator as well as the denominator of conventional productivity measures. In addition, since many sorts of capital equipment are commonly bought from foreign suppliers or may be assembled from intermediate parts purchased in international markets, they argue that it is important as well to use productivity measures that properly allow for both shifts in exchange rates and imported intermediate parts and equipment. The authors recommend measures of national output that would more adequately capture exchange rate effects, efficiency gains in the utilization of intermediate products, and the depreciation of durable assets including buildings, equipment and intellectual property. They argue that recommendations concerning the treatment of durables are of special relevance for monitoring progress toward sustainable prosperity.

The paper also revisits the issue of separability of value added from gross output production function and demonstrates that the growth rate of total factor productivity (TFP) from gross output growth accounting cannot be greater than that from value-added growth accounting following Denny and Fuss (1977) and Diewert (1980). Pyo and Ha (2006) has demonstrated it also empirically by

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using 33-sector KLEM model and has rejected the separability of value-added from gross output.

The authors also correctly point out that the values for the multifactor productivity (MFP) and labour productivity measures would always be greater than the value for TFP and that the value for simple worker labour productivity measure (LP) should be greater than the hours labour productivity (HLP) and the wage weighted hours productivity (WHLP) measures. This is an important useful reminder to estimators of productivities particularly when they are engaged in international comparison of productivities.

My comment and suggestion centers on the formula where output *per capita* is defined as the product of output per hour of work, and can be represented as follows:

$$\frac{\text{Output}}{\text{POP}} \equiv \frac{\text{Output}}{\left[\text{Total input}\right]} \times \frac{\left[\text{Total input}\right]}{\left[\text{Total measured input}\right]} \times \frac{\left[\text{Total measured input}\right]}{\left[\text{Total labour input}\right]} \qquad (1)$$

$$= \quad (A) \quad \times \quad (B) \quad \times \quad (C)$$

$$\times \frac{\left[\text{Total labour input}\right]}{\left[\text{Total work hours}\right]} \times \frac{\left[\text{Total work hours}\right]}{\left[\text{Number of workers}\right]} \times \frac{\left[\text{Number of workers}\right]}{\left[\text{Potential labour force}\right]} \times \frac{\left[\text{Potential labour force}\right]}{\text{POP}}$$

$$\times \quad (D) \quad \times \quad (E) \quad \times \quad (F) \quad \times \quad (G).$$

In Figure 1 the authors have shown how the various productivity measures (LP, HLP, and WHLP as well as MFP and TFP) relate to each other and to the components of output *per capita* designated in (1). From the decomposition of output *per capita* shown in (1) and the definitions in Figure 1, they point out that it is *not* true that labour productivity relates more directly or naturally to output *per capita* than a TFP or MFP measure, as is sometimes claimed. This observation is helpful.

Total Factor Productivity: $$\text{TFP} \equiv \frac{\text{Output}}{\left[\text{Total input}\right]} = \text{(A)}$$

Multi Factor Productivity: $$\text{MFP} \equiv \frac{\text{Output}}{\left[\text{Measured input}\right]} = \text{TFP} \times \text{(B)}$$

Wage Weighted Hours Productivity: $$\text{WHLP} \equiv \frac{\text{Output}}{\left[\text{Total labor input}\right]} = \text{TFP} \times \text{(B)} \times \text{(C)} = \text{MFP} \times \text{(C)}$$

Hours Labour Productivity: $$\text{HLP} \equiv \frac{\text{Output}}{\left[\text{Total work hours}\right]} = \text{TFP} \times \text{(B)} \times \text{(C)} \times \text{(D)}$$

$$= \text{MFP} \times \text{(C)} \times \text{(D)} = \text{WHLP} \times \text{(D)}$$

Worker Labour Productivity: $$\text{LP} \equiv \frac{\text{Output}}{\left[\text{Number of workers}\right]} = \text{TFP} \times \text{(B)} \times \text{(C)} \times \text{(D)} \times \text{(E)}$$

$$= \text{MFP} \times \text{(C)} \times \text{(D)} \times \text{(E)} = \text{WHLP} \times \text{(D)} \times \text{(E)} = \text{HLP} \times \text{(E)}$$

FIGURE 1

THE RELATIONSHIP OF DIFFERENT PRODUCTIVITY MEASURES TO TOTAL OUTPUT

However their formula (1), shown also above, does not account for capital input and therefore, cannot reflect the authors' emphasis on the appropriate accounting for depreciation (Section III-*C*). I suggest the following alternative formula to be considered:

$$\frac{\text{Output}}{\text{POP}} \equiv \frac{\text{Output}}{\left[\text{Total input}\right]} \times \frac{\left[\text{Total input}\right]}{\left[\text{Total measured input}\right]} \times \frac{\left[\text{Total measured input}\right]}{\left[\text{Total capital input}\right]} \qquad (1')$$

$$= \text{(A)} \times \text{(B)} \times \text{(C)}$$

$$\times \underbrace{\frac{\left[\text{Total capital input}\right]}{\left[\text{Total capital stock}\right]}}_{(D)} \times \underbrace{\frac{\left[\text{Total capital stock}\right]}{\left[\text{Total labour input}\right]}}_{(E)} \times \underbrace{\frac{\left[\text{Total labour input}\right]}{\left[\text{Total work hours}\right]}}_{(F)} \times \underbrace{\frac{\left[\text{Total work hours}\right]}{\left[\text{Number of workers}\right]}}_{(G)}$$

$$\times \underbrace{\frac{\left[\text{Number of workers}\right]}{\left[\text{Potential labour force}\right]}}_{(H)} \times \underbrace{\frac{\left[\text{Potential labour force}\right]}{\text{POP}}}_{(I)}$$

where total capital input and total capital stock are added to formula (1).

The advantage of formula (1′) lies in that the ratio, (D), of total capital input (flow) and total capital stock can represent the utilization rate of capital stock and therefore, can reflect efficiency profile based on the concept of productive capital stocks (Schreyer 2004). In addition, the usual concept of capital labour ratio (capital intensity) can be accounted for by two ratios, (E) and (F). The alternative formula suggested above can be applied to sector-level data as applied to Korean data of 72 industrial sectors following EU-KLEMS guidelines in Pyo, Rhee, and Ha (2006). It can also be applied to decomposing *per capita* gross output (*Gross Output*/POP) by changing total capital input to an aggregator function of multiple inputs including intermediate input, for example four inputs of capital, labour, energy and material in case of a KLEM model.

References

Denny, M., and Fuss, M. “The Use of Approximation Analysis to Test for Separability and the Existence of Consistent Aggregates.” *American Economic Review* 67 (No. 3 1977): 404-18.

Diewert, W. Erwin. “Hicks’ Aggregation Theorem and the Existence of a Real Value Added Function." In M. Fuss and D. McFadden (eds.), *Production Economics: A Dual Approach to Theory and Applications*. Vol. 2, Amsterdam: North Holland, pp. 17-51, 1980.

Diewert, W. Erwin, and Nakamura, Alice O. "Productivity Measures and Sustainable Prosperity." Forthcoming in *Seoul Journal of Economics* (2007a).

__________. "The Measurement of Productivity for Nations." In J. J. Heckman and E. E. Leamer (eds.), *Handbook of Econometrics*. Volume 6, Elsevier Science, 2007b.

Pyo, Hak K., Rhee, Keun Hee, and Ha, Bongchan. Estimates of Labor and Total Factor Productivity by 72 Industries in Korea (1970-2003). Paper Presented at OECD Workshop on Productivity Analysis and Measurement, Bern, 16-18 October 2006.

Schreyer, Paul. "Capital Stocks, Capital Services and Multi-Factor Productivity Measures." *OECD Economic Studies*, No. 37, 2003/2, OECD 2004.

*Comments by Hyunbae Chun**

In monitoring progress toward sustainable prosperity, national governments use a productivity measure that is a ratio of output produced to weighted sum of inputs. The paper by Diewert and Nakamura provides several recommendations concerning adequate measures of national output (a numerator of the productivity measure). These include terms of trade effects, the depreciation of durable assets, and so on.

In this discussion, I will focus on the depreciation of durable goods related to output measurement. The depreciation rate has rapidly risen during the last few decades. This rising depreciation rate is mainly due to the increasing share of short-lived assets; namely, information and communication technology (ICT) assets. From the early 1970s to now in the U.S., the share of ICT investment in total investment has risen from 10% to 30%. The pattern of ICT investment in the U.S. is well documented in Jorgenson (2001).

Using data from the U.S. Bureau of Economic Analysis, I calculate the depreciation rate (δ) as: $\delta=\{I(t)/K(t-1)\}-[\{K(t)-K(t-1)\}/K(t-1)]$ where $I(t)$ and $K(t)$ are investment and capital stock at time t, respectively. Figure 1 clearly shows the rising trend in the depreciation rate of private fixed assets in the U.S. The rising depreciation rate is not confined to the U.S., but is also observed in most OECD countries (see Spant 2003).

If the growth rate of an economy is measured by Gross Domestic Product (GDP), the rising depreciation rate may overestimate the rate of economic growth. This increase in current production through a higher depreciation rate will decrease future production. In this respect, Net Domestic Product (NDP), GDP minus capital depreciation, is more appropriate because NDP measures general welfare or income. However, GDP is still a better measure for analyzing productivity and production structure. Thus, the two measures are not substitutes, but are complements. In the period of divergence in GDP and NDP, national governments need to monitor economic growth rates based on the two measures. In Denmark, Iceland,

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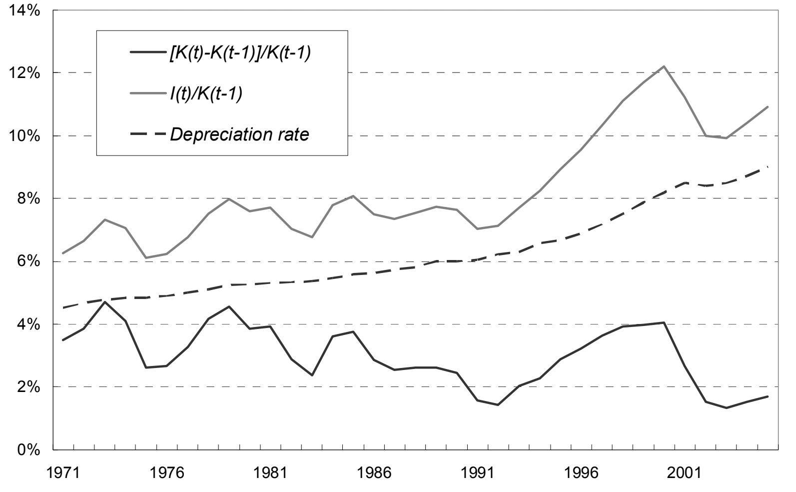

FIGURE 1

RISING DEPRECIATION RATE IN THE UNITED STATES, 1971-2005.

and the U.S. in the period of 1995-2001, the difference between GDP and NDP based annual average growth rates are above 0.4% (Spant 2003).

Furthermore, the rising depreciation rates cannot be considered as a simple substitution between two types of capital goods such as substituting cars with trucks. This rise due to ICT investment reflects a phenomenon of the New Economy. Why does the ICT capital stock depreciate so rapidly? Main source of this fall in the value of ICT assets is not physical deterioration, but is lower replacement costs or obsolescence. The latter is mainly due to faster technological changes in new ICT capital. In addition to the difference between GDP and NDP based growth rates, the rising depreciation rate should be monitored as a sign of technological changes by national governments.

Along with faster technological changes, international factors such as changes in the terms of trade and rising globalization in production make it more difficult to measure national output. In addition to traditional trades of goods, the production of services has become more global. For example, Amiti and Wei (2006) find the rising trend in off-shoring shares in U.S. manufacturing industries in the 1990s. In particular, the share of imported services has increased faster than that of imported materials.

In monitoring sustainable prosperity, Diewert and Nakamura provide several insightful suggestions on difficulty in measuring national output. Among their suggestions, I added recent evidence on technological changes and globalization. I also emphasize that these factors can affect not only the measurement of output but also directly productivity, which implies that researchers should pay attention on these factors' effects on productivity growth.

References

Amiti, Mary, and Wei, Shang-Jin. Service Offshoring and Productivity: Evidence from the United States. NBER Working Paper No. 11926, January 2006.

Bureau of Economic Analysis. Standard Fixed Assets Tables. Available at http://www.bea.gov/national/FA2004/index.asp, 2007.

Jorgenson, Dale W. "Information Technology and the U.S. Economy." *American Economic Review* 91 (No. 1 2001): 1-32.

Spant, Ronald. "Why Net Product Should Replace Gross Domestic Product as a Measure of Economic Growth." *International Productivity Monitor* 7 (Fall 2003): 39-43.