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On the measurement of Capital Services and Economic Efficiency

By

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Abstract

This article shows that the traditional assumption of proportionality between capital services and the capital stock made in the applications of production theory is generally not warranted. The article proposes a generalized measure of capital services which admits the traditional assumption only as a special case. Namely, it is argued that the proportionality factor between capital services and the capital stock is a function of both the real interest rate and the economic depreciation rate. Neglecting to take variations in either of these rates into account is shown to lead to paradoxical results. The common notion of economic efficiency is also extended to take the accumulation of wealth into account within a simplified dynamic framework. This sheds new light on the debated choice between the gross and the net of depreciation measure of aggregate output. The theoretical developments made in this article would support the net view.

1 - Introduction[1]

The reasonableness of the assumption of proportionality between capital services and the capital stock is certainly not amongst the most obvious ones in economic theory and yet that assumption is taken for granted by most economists of our time. It is certainly itself a by-product of the difficulty associated with the notion of capital. True, it is sometimes discussed, but most of the time it is only briefly so with occasional mentions to its potential limitations. This author has found no major proposals for alternative assumptions. Two examples will be given to illustrate and to introduce the subject.

Solow (1957, p.314), in his famous article in which he proposed the definition of technical progress, that has imposed as a standard in following writings on the subject, wrote:

> "ideally what one would like to measure is the annual flow of capital services. Instead one must be content with a less utopian estimate of the stock of capital goods in existence. All sorts of conceptual problems arise on this account. As a single example, if the capital stock consisted of a million identical machines and if each one as it wore out was replaced by a more durable machine of the same annual capacity, the stock of capital as measured would surely increase. But the maximal flow of capital services would be constant."

Although Solow clearly identifies that a changing rate of depreciation may introduce a non proportionality element between capital services and the capital stock, he does not propose any solution to the problem. He rather goes on to discuss the adjustment which must be brought to the capital stock for capacity utilization in order to obtain a sounder measure of the flow of capital services. Capital services are assumed to be proportional to capital in *use* rather than to the capital stock in *place*. Although this was introducing a

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1. The author wishes to thank Claude Simard who provided help in clarifying basic ideas and Joanne Johnson for her judicious comments on an earlier version of this paper. Conceptual errors remain, however, the sole responsibility of the author.

non-proportionality element between capital services and the capital stock in place, this did not, as such, question the basic assumption that capital services are a fixed proportion of some measure of the capital stock.

A more recent example is taken from Hulten (1986, p.38). In an article where he discusses the adjustment of capital stock for capacity utilization, Hulten wrote:

> "The theory outlined in the preceding section provides an enormously powerful analytical framework for estimating factors contributing to long-run economic growth. A key assumption of the framework, however, is that the flow of capital services is proportional with the stock of capital assets. This assumption is made necessary because the flow of services is not generally observable, and is justified by appealing to the long-run focus of the model. In the long-run, cyclical fluctuations in the flow of services average out, and one can take the ratio of the service flow to the quantity of capital to be constant."

Hulten's article was one of a series of articles dealing with the adjustment of capital for capacity utilization following the original proposal made by Berndt and Fuss (1986) on the issue. Berndt and Fuss showed that the most appropriate way of taking capacity utilization into account consists of measuring the share of capital in total factor cost in a residual manner by using the shadow (ex post or residual) price of capital services instead of the ex ante price[2]. It may be concluded from the Berndt and Fuss contribution that the traditional way of adjusting capital stock data with a capacity utilization index is less than adequate. Contrary to maintained views, their model supports the idea that, the total non-adjusted capital stock must be used in the estimation of productivity growth rather than some adjusted measure.

These important conceptual developments just brought back to the fore the assumption that capital services are proportional to the stock of capital in place in lieu of the stock in use[3]! Therefore, it may be taken for granted that conventional wisdom supports the view that the best approximation to the flow of capital services is provided by the estimate of the stock of capital. Hulten (1986, p.40) even goes as far as to suggest abandoning the concept of capital services in the first place and replacing capital services by the stock of capital in the production function[4]:

> "One way to clarify these issues is to abandon the notion of capital services altogether and to build a theory of productivity using capital stocks.[4]"

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2. It is intuitively simple to understand the Berndt and Fuss proposal when it is realized that the shadow price of capital is the price at which the existing quasi-fixed capital stock would be optimal under long-run equilibrium, and thus, using that residual price yields a long-run equilibrium set for all input prices and quantities. This set may thus be used to estimate productivity growth without bias.
3. This also coincides with the less formal view that capital costs are incurred whether capital is fully used or not. In fact, capital, in short-run equilibrium, is always fully used in a technical sense: no more production could be generated from the short-run combination of all inputs including capital.
4. See also Hulten (1990), p. 135.

This note begins with a brief reminder of Jorgenson's formulation of the user cost of capital which itself rests on the assumption that capital services are proportional to the stock of capital. The problems associated with Jorgenson's user cost of capital are illustrated successively for the cases when the path followed by (1) the depreciation rate or (2) the real interest rate are altered. Comparisons of the time path of productivity gains associated with the traditional, and the alternative measure proposed here, are made to put in perspective the advantages of the new approach. In particular, it is shown that the traditional measure leads to paradoxical conclusions which can only be resolved by resorting to the new measure. Empirical estimates of aggregate productivity gains for the Canadian business sector over the 1961-1992 period using both measures of capital services are presented next. This is all followed by a brief conclusion.

2 - Jorgenson's Measure of User Cost of Capital

We begin by recalling that the flows of capital services are spread over the many time periods of the life of the assets. Hence, the price of capital services is a *usage* or rental price, often called the capital "user" cost since its inception in the economic literature by Jorgenson (1963). In the absence of taxation, the price of capital services, r, is then given by:

$$r = p_k (i + \delta - \dot{p}_K) \qquad (1)$$

where p_k is the price of capital goods, i is the nominal rate of interest and δ is the rate of economic depreciation. The rate of economic depreciation is given, as is usual, by percentage change in the price of an asset which occurs at a given point in time and resulting only from aging[5]. The total price change of assets is given by the sum of their depreciation rate, δ, and the rate of inflation in new asset prices, $\dot{p}_K$. Hence, the cost of using capital goods per unit is given by the carrying interest charges (the charge for waiting) and the replacement or depreciation cost minus the capital gain resulting from the appreciation of the assets represented by the percentage time variation in the capital goods price deflator (noted with a doted symbol). We may consider $i - \dot{p}_K$ as the real interest rate in what follows and denote that real rate again by i to simplify the notation (or assume no inflation).

Equation (1) gives the price per period of acquiring the services of additional capital goods at the margin, given the prevailing real rate of interest. Note that the user cost is defined per unit of capital stock/per year rather than per unit of capital services. It also applies to service units only if the latter are proportional to the stock of capital. Total capital income, Y_k, can be computed as:

$$Y_K \equiv rK \qquad (2)$$

5. In discrete time, the rate of depreciation must be multiplied by $\left(1 + \frac{\Delta p_k}{p_k}\right)$,(see, for instance Hulten (1990), p.128).

The quantity of capital services used in any current period could be measured indirectly, similar to other inputs, as the cost of capital in that period, Y_k, divided by the user price of capital, *r*. In other words, this measure of capital services used into current production would be the total *real* user cost. The price *r* and the capital income Y_k may either be determined ex ante under long-run equilibrium assumptions or be determined residually ex post, as suggested by Berndt and Fuss, under short-run equilibrium conditions, while the stock of capital is assumed to be given.

According to identity (2), this amounts again, in both cases, to assuming that capital services are proportional to the stock of capital in place. Thus, on intuitive grounds, the traditional assumption of proportionality appears quite reasonable over the long term under balanced growth and given the definition of service prices. The more capital units are added to production, the more capital services are provided. But the assumption appears equally reasonable under short-run equilibrium conditions. As stated in the introduction, conventional wisdom, including recent theoretical developments, generally supports that assumption[6]. This assumption will be scrutinized and questioned in the following sections.

3 - Capital Services with a Varying Depreciation Rate

Coming back to Solow's example, it is important to note that Solow was explicitly referring to a change in the rate of depreciation of the capital stock as one of the problem of measuring capital services, although he did not correct his measure of capital services to take potential changes in that rate into account.

The depreciation rate of capital is falling in Solow's example as new, more durable, machines are replacing old machines. But in Solow's world, capital services do not change. Capital services are indeed assumed to be proportional to the fixed number of machines of equal capacity, that is to the gross stock of capital. Equivalently, we may say that Solow assumes a one-horse-shay type of physical depreciation.

This reminds us of Coen's (1980) light bulbs example. Their lighting capacity remains constant until they burn out. In modern production literature, the question of choice between different physical depreciation schedules has been a major issue that has remained largely unresolved. The problems arise because the schedule of economic depreciation generally follows a pattern which is different from the one of physical depreciation. Most authors, including Coen and Solow, adopt the view that, for the purpose of analyzing production, what matters is physical rather than economic depreciation. Capital goods are seen as physical devices which, combined with other inputs, sustain production activities. The production process is perceived as a pure engineering process in which the durability of capital goods does not play any particular

6. Bernd (1990, p.157) in his comments on Hulten's (1990) paper, however, recalling the Denison, Griliches and Jorgenson debate, opens the door to the introduction of the depreciation rate as a determinant of the measure of capital services: "Since nonresidential structures, for example, are longer lived on average than producers' durable equipment, the amount of service flow derived per year from a $1 stock of equipment is larger than that from a $1 stock of structures."

role. Indeed, the fact that the use of capital goods involves a process of waiting in the sense of postponing consumption into the future is certainly not part of the physical view of the production process.

But it will be shown below that the issue of the shape of the depreciation schedule is altogether largely a false issue which is tied to the inadequacy of the traditional assumption of proportionality between capital services and the capital stock and the inadequacy of the engineering view of the production process. It will also follow that what really matter is economic depreciation rather than physical depreciation.

Returning to Solow's example in which there is no changes in output, in the use of other inputs and in prices, this means that technical progress is nil in Solow's example. However, this is quite a strange result as intuition would lead us to think that the increased durability of the machines must come out of technical progress!

Note further that, in Solow's example, if one were to measure capital services as a function of the net rather than the gross stock of capital, then the growth path of productivity would actually fall in the transient period of renewal of the capital stock when compared to the alternative path on which the durability of the machines does not change. That is, a fall in the rate of depreciation induces a fall in productivity growth relative to a situation with no change[7].

Therefore, using the traditional approach, one would have to conclude that productivity growth is not affected by the use of the more durable machines (using the gross stock as a measure of capital services) or is even falling (using the growing net stock) despite that production costs are falling. Thus the technical innovation which lead to the production of more durable machine and a reduction in production costs would not show up as a positive productivity gain in the traditional set up.

But there is another deeper difficulty with the proportionality assumption which appears when one compares time paths of capital accumulation and productivity growth based on alternative (but otherwise fixed) depreciation rates. For two alternative growth scenarios with the same output path, the same allocation of output to gross investment and consumption, and the same initial stock of capital but different depreciation rates, the net stock of capital will grow faster in the scenario with the lowest depreciation rate than in the other scenario. The converse is exactly true for productivity growth if capital services are assumed to be proportional to the stock. Thus, in a one-sector-one-good model of economic growth, the economy having the largest net stock of capital goods at some terminal date, all other things being equal, would be considered the less efficient despite the fact that capital goods are identical to consumption goods and could be consumed at the terminal date. This appears, at face value, quite paradoxical[8]!

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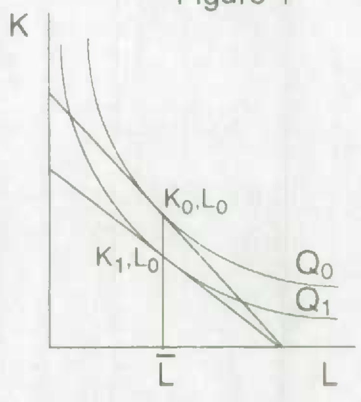
7. Note also that we are comparing here paths across time rather than levels at a point in time, i.e., we are doing comparative dynamic. It is only in that perspective that the weakness of the traditional assumption comes out clearly.

Similarly, if we let the depreciation rate gradually increase for some time starting at some date, then conventional wisdom would assert that productivity is accelerating (with a gradual fall in the growth rate of the capital stock). This is because the conventional view assumes that capital services are proportional to the stock of capital. Since at any future terminal date, the capital stock would be lower than under the initial scenario of fixed depreciation rate, and with everything else equal, then the conventional view would have to justify the contradiction between the assertion that productivity is growing faster and wealth accumulation is lower than in the alternative scenario.

However, were we to assume that capital services are, among other things, proportional to real economic depreciation, then a gradual increase in the depreciation rate would indicate an increasing use of capital services and a concomitant fall in productivity growth contrary to conventional wisdom. This would be more consistent with the fact that, despite the output path of the economy would remain the same, the consumption path would be shifting downward as well as the stock of wealth through time.

Hence, it appears that changes in the depreciation rate must be taken into account when measuring the flow of capital services in a form which will be made explicit below. As capital services would be proportional to the capital stock only when the depreciation rate would be constant, the traditional case would appear to be special case of a more general rule. But first, we show that the traditional approach also leads to paradoxical results by neglecting to take into account variations in the real interest rate.

Figure 1



4 - Capital Services with a Varying Real Rate of Interest

Now assume that the depreciation rate is constant but that the real interest rate gradually increases over a given time span, as a result of continuously changing time preferences. Assume further, without loss of generality that, as in Solow's example, the economy is initially in a stationary state of full employment equilibrium with no

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8. Such a paradox was drawn to our attention recently when the estimated growth path of the capital stock in Canada was revised downward from a maintained base year benchmark value. Following that revision, we had to revise Canadian estimates of multifactor productivity growth upward, without any further historical change in the output, investment and consumption growth path of the Canadian economy. Hence, we had to admit that the Canadian economy had been more efficient than we thought earlier because it had accumulated less wealth!

growth in its population nor its labour force. We compare the new growth path with a base case in which the rate of interest remains constant under the assumption that technical progress is nil in both cases.

In the alternative scenario, future consumption is discounted at increasingly higher real interest rates when compared to the base case scenario. The outcome of that change in the traditional framework will be a gradual reduction in the stock of capital so that the rate of return on capital (its marginal product) keeps in line with the rate of interest (see figure 1). There will be a fall in the capital-labour ratio with a relative fall in the marginal product of labour and the real wage rate. Taking the single output again as the numéraire with a fixed price of one, this means that all capital cost increases, if any, will be compensated by a reduction in the wage bill[9]. With a fixed labour supply and under long-run equilibrium conditions with full employment, this implies a reduction in input uses and a concomitant fall in output. Under the specified condition of no technical progress, the traditional approach should reveal no change in productivity. In the traditional static framework, this is as it should be.

Assume, on the contrary that if the proportionality constant between capital services and the stock of capital is a positive function of the rate of interest, as will be made precise shortly, then the gradual rise in the interest rate increases, other things equal, the rate of growth of real capital *services*. It surely does when compared to the traditional measure of capital services. Hence, we may conclude that input growth would be faster under the alternative model and productivity growth lower in all cases in which the interest rate increases and higher in the converse situation of a gradual fall in the interest rate[10].

The alternative model will yield estimates of productivity growth which are consistently lower than the traditional model in situation of rising real interest rates and conversely in situation of declining real interest rates. In the above example, the alternative model will indicate a fall in productivity even though there was no change in technical progress. Is it a lack of theoretical consistency of the new framework as was the case for the traditional model in a situation of a changing depreciation rate?

Internal consistency depends on how efficiency is defined. In the traditional set up, it is determined by the growth path of output and inputs irrespective of what happens to the stock of wealth and to consumption. In that perspective, production is seen as a pure physical process and productivity growth can, therefore, only be attributed to physical phenomena, that is to technological factors (technical progress and scale economies). In the alternative view proposed here, the stock of wealth has to be taken into account as exemplified in the above case of a rise in the depreciation rate. What counts, in fact, is the path of consumption which is itself a function of wealth. In the previous case of a gradual fall in the depreciation rate, indeed, productivity was shown to grow under the alternative model although output remained fixed. What happened is that, with a fall in the

9. The direction of change in factor income shares remains unknown unless some further assumption are made on technology. Assuming a Cobb-Douglas technology (with a unitary elasticity of substitution between inputs), factor income shares will remain fixed.

replacement rate of machines, less investment were required to maintained the existing stock of capital, thereby raising the level of the consumption growth path. Net wealth was also shown to increase. Under this enlarged notion of economic efficiency, productivity could be seen as improving and that improvement resulting from technical progress.

In the case of a rising interest rate, that increase does not per se change what can be produced with existing machines and labour force. There is no technical progress. It does affect the economy's growth path, however, through its action on the stock of capital. By lowering permanently the level of the stock of capital, a rise in the interest rate permanently lowers the growth path of output and consumption. At new higher interest rates, the capital stock is permanently lower. Combined with the same labour force and using the same technology, this means that output has to fall from a level, say Q_0, to a lower level Q_1, as depicted on figure 1, which shows the isoquant map of the economy in the traditional set up. The production possibility frontier of the economy has permanently shrunk as a result of the change in the time preferences despite no change in technology. That shift in the production possibilities came across through a reduction in the stock of wealth.

Note that there is a basic distinction in the two examples discussed above. In the case of the decline in the depreciation rate, that decline had to be associated with technical progress. In the case of the rise in the interest rate, no technical progress occurs. Nevertheless, efficiency deteriorates in some sense that is now further discussed.

The production activity is far from being a pure technical issue. It occurs as the result of humans' attempt to improve their living conditions. Those efforts require the sacrifice of leisure time and the sacrifice of present consumption for future consumption, what could be called waiting. The work effort and the waiting sacrifice are the only two primary inputs supplied in the economy[11]. These inputs, combined with technology, provide output, the benefit from the production activity. Inputs, that is costs, are valued in all societies against the benefits withdrawn from their supply in the production process. A rise in the waiting requirements, coming from a change in time preference, means a permanent loss of production and consumption possibility for a society to the same extent as a technical regression. In other words, it is equivalent to an increase in the human cost associated with the production activity. Cost increases means "efficiency" regress in a broad sense. The new model of capital services proposed in this note takes that phenomenon into

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10. Let $Q = \alpha K^{\beta} L^{(1-\beta)} e^{\gamma t}$ be a Cobb Douglas production function so that the rates of change of the variables through time, noted with dotted symbols, be related by $\dot{Q} - \beta \dot{K} - (1 - \beta) \dot{L} = \tau$ where τ is the traditional rate of technical progress (multifactor productivity growth). With no growth in labour and productivity, this implies that $\dot{Q} = \beta \dot{K}$ are equal and both smaller than zero. Assuming that capital services are proportional to the interest rate times the stock of capital would lead, maintaining the other assumptions, to $\dot{Q} = \beta (\dot{K} + \dot{i})$ where i is the real rate of interest. It follows that, if the *observed* traditional rate of technical progress is zero then, when the real interest rate is rising, the alternative rate of growth in economic efficiency is negative and, when the real interest rate is falling, the alternative rate of growth in economic efficiency is positive.

account. Assuming that the traditional model measures correctly zero growth in technical efficiency, the new model would show a decline in a broader measure of economic efficiency[12].

We may conclude that the productivity residual includes pure technical factors only when the interest rate is constant. Furthermore, in the traditional set up, the impact of the technical factors on productivity growth are properly assessed only when they have no incidence on the depreciation rate.

The new model provides a larger framework than the traditional model in explaining differences in productivity level and growth across countries. Technological knowledge alone cannot explain differences in income per capita. The broader framework suggests that welfare comparisons must be based not only on comparisons of consumption levels but also on associated costs. The assessment of economic performance in a broad sense must look at both costs and benefits withdrawn from production activities rather than, as traditionally done, at benefits only. Costs include not only work but also waiting. This brings us to the alternative model of capital services.

5 - The Alternative Formulation

We conclude from the above discussion that if capital services are assumed to be proportional to the stock of capital, that proportion must be related to the depreciation and the interest rate. The higher these rates, the higher the quantity of services used and the less *economically* efficient the production processes are[13]. We are now in a position to propose the following capital services flow measure, S:

$$S = (i + \delta) K \tag{3}$$

Equation (3) states that capital services are to be measured by the product of the physical stock of capital with the sum of the real interest and depreciation rates. Given that the interest and the depreciation rates are pure percentages, this product yields capital units used in the production process.

As the traditional user cost formula has always indicated, the costs of capital services are provided both by the quantity of capital destroyed in the production process (through wear and tear and obsolescence) and the sacrifice of waiting (carrying the whole stock of

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11. Even natural resources are primary production inputs only to the extent that they have a positive rental price associated with the *postponement* of their consumption into the future.
12. Note that technical efficiency does not imply economic efficiency in cases when, like in short-run equilibrium, some factors are quasi-fixed, i.e. in cases where short-run minimum costs are above long-run minimum costs. Long-run minimum costs are generally taken as the criterion for economic efficiency. Hence, despite no technical progress, productivity in the broader sense of economic efficiency may increase when the economy is converging toward long run equilibrium. Here, we further enlarge the notion of economic efficiency to include the stock of wealth into account. Since the growth path of consumption depends on the stock of wealth this adds a dynamic perspective to the concept.

capital one period into the future). What the new formula does is to give the quantity equivalent of the traditional formula. The quantity of capital services is asserted to be made of two components, depreciation and waiting.

In the new view, the price of capital services, therefore, reduces to the price of capital units, p_k according to identity (2) above. Indeed, the number of units of capital sacrificed in the production process whether through depreciation or through waiting must have the same price.

It is, therefore, the split between the quantity and the price components of the capital cost which is altered by the new formulation while the total cost is still given by identity (2) as should be. Note that, along any given path, depreciation (neglecting temporarily real interest) under a fix (geometric) rate and the stock of capital grow at the same rate so that it does not matter which is used as a proxy for the service flow. But the economy with the higher depreciation rate is the one consuming more capital services and which productivity *level* is lower. But it is also the one with the smallest stock of capital and, from the conventional perspective, the more efficient, again in terms of the level of productivity, contrary to the new view expressed here. Nevertheless, both would register the same productivity growth under fixed interest and depreciation rates.

Turning back once more to our first example in which the depreciation rate was falling as a result of a technical innovation which increases the life of assets, the new view, contrary to the traditional view, would assert that productivity is growing. This increased productivity translates into a gradual rise in the consumption possibilities of the economy since, given that output is fixed, gross investment is falling.

The flow of waiting services as input into the production process bears on the whole stock of capital units rather than the marginal units produced in any given year. *Waiting is the process of diverting the whole stock of capital inputs away from consumption to carry it over to the following year.* In that process, some units are lost in the form of interest foregone. Indeed, the real discounted value of the stock of capital carried into the future is less than its actual value at any positive real interest rate. The carrying over time of the stock of capital would not supply any waiting input (would have no opportunity cost) at all were the interest rate to equal zero. The sum of the depreciated units and interest units constitute the input flow of capital services charged against current year production.

Hence, looking at equation (3), the proportionality of stocks and services holds provided that both the interest and the depreciation rates remain fixed along a given time path. For instance, If the interest rate shifts to a higher level following a permanent change in time

13. Note that depreciation here is taken as the loss in the real value of capital assets or what has been termed economic depreciation. The latter may be associated with physical wear and tear or physical depreciation but it may as well be related to obsolescence. For instance, Hulten and Wykoff (1981, p.370) defines economic depreciation as "the rate of change of asset price with age at a point in time. In the absence of inflation, this definition corresponds to the widely accepted view that economic depreciation is the value of the capital stock which must be replaced in order to maintain initial investment".

preferences, this shift increases the waiting component of the capital service flow inputs into production. In other words, it becomes more costly in real terms to carry over the capital stock to the following year given the change in time preferences. The burden of supplying waiting has increased. Said differently again, the present discounted value of the waiting stock carried over one year into the future is lower at a higher interest rate so that more interest waiting units of capital have to be charged against current production.

6 - Some Further Interpretations of the New Measure

The new framework reinforces the idea proposed by Denison (1993) regarding deflating the capital stock by the price of consumption goods. It furthermore lends support to the idea that, as suggested by Solow (1957) and Denison (1962), what really matters is consumption, not production per se. It is true that, in order to sustain consumption, capital goods also have to be produced as argued, for instance, by Hulten (1992). This does not, however, of itself support the view that efficiency must be assessed in terms of gross value-added. In a dynamic framework in which wealth is taken explicitly into account, Denison's view that what matters is net rather than gross income receives much support[14]. The consumption path is indeed constrained by the discounted value of net national income and initial wealth, contrary to the discounted future labour income and initial wealth as asserted in Hulten (1992)[15].

Hulten equates value-added with the wage bill basically because he considers capital goods as intermediate goods rather than primary inputs as they were considered here. But this is denying that the use of capital goods involves a waiting sacrifice related to time preferences. Hulten's model would therefore result from our model only if the interest rate was set equal to zero. In such a case, time or waiting does not matter and capital goods can really be considered as intermediate goods consumed across the many time intervals. Net value-added then reduces to the wage bill. But at the same time, Hulten is denying that waiting is also productive. The economy's welfare (or consumption path) is independent of the investment path. However, this is clearly inconsistent with the welfare function being expressed as a function of the real interest rate. In particular, Hulten's correspondence between the static model emphasizing gross value added and the dynamic model emphasizing the consumption path breaks if the interest rate changes[16]. Indeed, capital services in the static framework are assumed to be proportional to the capital stock and unrelated to the interest rate. Hence, the static productivity measure is not affected by a change in the interest rate while the dynamic residual is. In other words, welfare falls with a rise in the path followed by the interest rate while the static gross output stream remains unchanged.

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14. In our example of a falling depreciation rate, consumption could be increased with a fixed output because of the fall in gross investment required to maintain the capital stock, suggesting that consumption rather than gross value added would be the appropriate concept of output. However, part of the additional income could also be used to increase gross investment and the capital stock thereby changing the future consumption path without any further change in efficiency. Thus value added net of depreciation or net national income would be preferable to consumption as a measure of output in the measurement of efficiency.

One must also note the important asymmetry between the interest and the depreciation components of capital costs. Technical progress can directly affect the depreciation rate as seen above because it can affect the production process of capital goods. Technical progress may reduces the life of assets through obsolescence, for instance, as it may increases their physical durability. Depreciation can therefore be considered as an intermediate input in the dynamic framework as it is, to follow Rymes, a produced input.

Technical progress cannot affect waiting in such a manner. Technical progress may perhaps have remote and indirect effects on the saving *behaviour* of households, by changing the set of choices open to them, but it has no incidence on the *measure* of waiting as such. Hence, only waiting should be considered as a primary (non produced) input into the production process. To conclude, if technical progress can change the cost-benefit ratio of production activities, the latter may also change for non-technical reasons channelled through changes in the real interest rate.

One has to note further that the waiting cost component of the capital service measure depends on the *value* of the capital stock net of depreciation. It is indeed the net rather than the gross stock which is carried over into the future after deducting the depreciation charges against current gross income[17].

Upward movements in either the depreciation or the real interest rate can be qualified as "technical" regress in a broad sense because they imply a downward shift in the consumption possibility frontier as the stock of existing knowledge cannot support the same level of output *and* level of wealth. An increase in the depreciation rate decreases the rate of growth of the capital stock and the discounted future stream of output, thereby decreasing the discounted value of the stock of capital. A similar reasoning applies to an increase in the real interest rate.

Again, the conclusion which can be drawn from a reading of equation (3) is that, since the quantity component of the capital cost equation includes both the depreciation and the interest rate, what is left in the price of capital services is the price of capital units, p_k. That is a new interpretation of Jorgenson's user cost of capital equation. However, it also seems far more reasonable from the price side as well, as change in the real depreciation and/or real interest rate could hardly be associated with pure inflation.

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15. More precisely, Hulten's equation (10) is erroneous: It should be $W_0 = p_0 K_0 + \frac{\sum w_t L_t + \sum p_t i_t K_t}{\prod_0^t (1 + i_s)}$ along a path which maintains initial wealth constant. In Hulten (1992), the future discounted interest income component is missing and the consumption path is constrained by initial wealth and the discounted future labour income. See, however, Hulten (1979).
16. More precisely, we refer to changes in the path of the interest rate. Interest rates may change along a given path in Hulten's model, but his model is inconsistent with a change from one path to another.

The traditional debate about the correct depreciation schedule is largely misplaced. What counts is economic depreciation, not physical depreciation as the new model of capital services suggests. Indeed, what counts is the number of capital units consumed into the production process whether the capital goods maintain their *physical* productive capacity constant or not throughout their life[18]. Stated differently, this is the consumption good units that have to be put aside to replace the deteriorated capital stock, through either physical tear and wear or obsolescence. Economic rather than physical depreciation is the proper notion of depreciation which enters the enlarged dynamic measurement framework of economic efficiency. Hence, the broader notion of economic efficiency incorporates the impact of technical progress on the life duration of assets while the traditional framework does not.

In addition, in a dynamic context, the notion of efficiency is itself extended to include the stock of capital in addition to current output or what could alternatively be called the maximum sustainable consumption growth path over an infinite time horizon. The new framework takes into account the fact that the outcome of the production process is not only the current output but a one year older capital stock available for consumption only at the end of the production period.[19]

The following question is: Does it really matter from an empirical point of view? This is discussed next for the Canadian case.

7 - Some empirical estimates

The new view on capital services presents an interesting advantage compared to the traditional view when combined with the Berndt-Fuss (1986) proposal to solve the capacity utilization issue. Indeed, from identity (2) and definition (3), one obtains

$$S = \frac{Y_K}{p_K} \tag{4}$$

where Y_K is the residual observed gross capital income. It follows that estimates of the capital stock are not necessary to obtain estimates of the flow of capital services. Estimates of capital income are more readily available than estimates of the capital stock at detailed industry level. In addition, capital income data are available on a quarterly basis in Canada at the economy's aggregate level, opening the possibility to estimate multifactor productivity growth on a quarterly basis.

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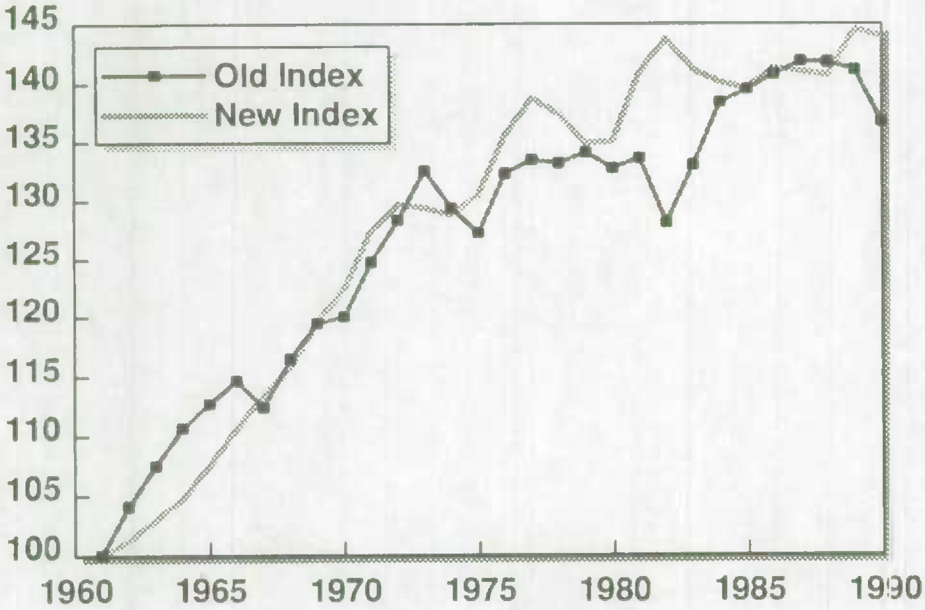
17. One should, although this has not been done here, extend the reasoning to the real capital stock by taking into account the fact that the net capital stock measure incorporates productivity gains associated with the production of capital goods in the past. The correct measure of the waiting input would be a function of the real interest rate and the stock of capital net of past cumulative depreciation *and* productivity gains as suggested by Rymes.
18. Physical depreciation will nevertheless impact on the shape of the economic depreciation schedule through time and the corresponding rental price of assets.

Figure 2:

Business Sector Multifactor Productivity

computed with the capital stock (old index) and with the new measures of capital services (new index)



Annual estimates of productivity growth for the business sector of the Canadian economy over the period 1961 to 1990 were produced by aggregating results of estimates established at the most detailed industrial level at which multifactor productivity estimates are currently produced in the Canadian Systems of National Accounts[20]. Estimates of the net-end-year capital stock based on the geometric depreciation schedule was used to generate the conventional estimates as currently published by Statistics Canada[21].

Alternative estimates of productivity growth for the Canadian business sector were obtained using formula (4) and using the resulting capital service flow estimates in place of the capital stock in the productivity formula[22]. Figure 2 reports the alternative index levels of productivity obtained by cumulating their rates of growth from an arbitrary value of 100 in the base year. In both cases, output is measured by gross domestic product so that the estimates differ only with respect to the measure of capital input.

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19. To return to Coen's example of the production of light, it is true that, neglecting to take into account the capital stock as an outcome of the production process, the correct concept of depreciation to use in production analysis would appear to be the one of physical depreciation or loss-of-productive-efficiency. As long as "capacity" remains the same, output may be maintained for whatever rate of economic depreciation of the light bulb associated with its falling life expectancy as time passes. However, it is equally true that consumption or net output is related to economic depreciation alone, whatever the pattern of physical depreciation, even though, as clearly shown by Coen, economic depreciation is related to physical depreciation.
20. Which presently consists of 111 industries.
21. See Statistics Canada, *Aggregate Productivity Measures*, annual, cat. no. 15-204.

As the figure indicates, both measures of productivity exhibit the same trend. The traditional estimates, however, generally show more sensitivity to the business cycles than the alternative, despite the Berndt-Fuss correction for capacity utilization. The new estimates are corrected twice for capacity utilization in that the residual capital income is used to compute both the capital income share and the quantity of capital services. They exhibit almost no or slightly counter cyclical fluctuations except for the 1982 recession where they exhibit stronger counter cyclical fluctuations. This may be due to the second energy shock which immediately preceded that recession and which is likely to be responsible for the dip in the productivity index around 1979, 1980.

The slight counter cyclical fluctuations of the new index may be due to labour hoarding. Capital is not, indeed, the only quasi-fixed input in the short-run. Labour is also quasi-fixed over the short-run. However, labour income is not affected by labour hoarding the same way as capital income is. The latter income is the one supporting the brunt of labour hoarding, while the wage rate is not immediately affected by the phenomena. This may explain why the correction made with Bernd-Fuss technique may be overdone.

The impact of the energy shocks of 1973 and 1979 is clearly visible for both estimates but more so for the new measure. This could be associated with the increased implicit depreciation of the capital stock which followed the energy shocks as capital use is complementary to the use of energy over the short-run. The impact of the 1979 energy shock on the new measure combined with its counter cyclical variation may have contributed to the observed 1982 peak. In general, however, the new measure shows less dispersion around its trend than the traditional measure. The trend in productivity growth is thus easier to identify.

One may also note that the changing productivity growth path associated with the energy shocks is more consistent with the new than the old view. These shocks induced a fall in the real value of wealth associated with existing capital goods as these were not initially designed according to energy saving technologies. The latter could only be gradually developed and implemented through time. The observed slowdown in productivity growth is therefore easier to interpret with the broader concept of economic efficiency than it is with the traditional concept of technical progress.

8 - Conclusion

This note has proposed a new measure of capital services defined as the number of capital units per period used in the production process either in the form of depreciation or in the form of interest charges. That new measure was shown to be consistent with the concept of technical progress in cases in which technical progress changes the depreciation rate while the traditional measure was not.

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22. All estimates are produced using the chained Törnqvist index number formula.

Introducing interest into the measure required an extension of the traditional concept of efficiency generally associated with a static production framework. The new framework provides an explanation for the fall in value of the stock of capital as an input which follows a rise in the rate of interest. This view is perfectly consistent with the view that the future consumption stream associated with that stock has a lower present discounted value. That reconciles perfectly the notion of capital as a stock of wealth with the notion of capital as an input into the production process. In the enlarged dynamic framework, we no longer need distinct concepts and theories of capital.

According to the traditional view, nothing happens to the level of productivity at the time of an upward movement in the depreciation or the real interest rate since capital services do not depend directly on depreciation or time preferences. The potential of the economy remains the same despite the loss of real wealth.

The new framework includes the burden of waiting as a major factor explaining economic growth besides technical progress as in the traditional framework. Changing time preferences may permanently affect the growth path of the economy. This extends to changing preferences between leisure and income. The benefits of production activities, therefore, have to be balanced against their real input costs. Productive efficiency can be defined as the ratio of these benefits, measured by the consumption path possibility frontier (delimited by the real net national income), to the real primary input costs. That ratio changes through time as a result of technical progress but not only as a result of technical progress.

Again, this is contrary to the traditional framework in which wealth (and welfare) is associated with the discounted future consumption stream. In the framework proposed in this note, wealth or welfare is not necessarily maximized by maximizing the discounted future consumption stream as the value of that consumption stream has to be assessed against its leisure and waiting costs. True, the consumption set may be enlarged, in the traditional model, to include leisure; that is, the labour supply may be considered as endogenous. However, the traditional framework does not and cannot incorporate an endogenous real interest rate similar to the new framework. It therefore provides only a limited view of economic efficiency.

Empirically, the traditional and the new measures of efficiency exhibit a similar path over the long-run. Over the short-run, the new measure appears to be less sensitive to cyclical variations although labour hoarding may seem to introduce slightly counter cyclical movements. It is, however, less stable in periods of structural changes which affect the real value of the stock of wealth channeled either through changes in the depreciation or the interest rate.

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