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OECD CAPITAL SERVICES ESTIMATES: METHODOLOGY AND A FIRST SET OF RESULTS

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OECD CAPITAL SERVICES ESTIMATES: METHODOLOGY AND A FIRST SET OF RESULTS

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Abstract:

This document presents the concepts underlying capital services measures, describes estimation methods and produces a first set of results. It also raises a number of outstanding conceptual issues in relation to capital services measures.

Résumé :

Ce document présente les concepts employés dans les mesures des services du capital, décrit les méthodes d'estimation et fournit un premier ensemble de résultats. Il traite également d'un certain nombre de questions conceptuelles soulevées par la mesure des services du capital.

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1. Introduction

Measures of productivity are central to the assessment of growth patterns. Measures of multi-factor (total factor) productivity or of capital productivity rely on the availability of statistical series on the prices and quantities of capital services that enter the production process. Two OECD manuals, *Measuring Productivity* (2001) and *Measuring Capital* (2001) have described the concept and measurement of capital services and their relation to the better-known measures of gross and net capital stocks. Both manuals are very clear in their recommendation that volume indices of capital services are the appropriate measure of capital input for activity and production analysis. Unfortunately, to date only a small number of countries produce time series of capital services as part of their official statistics[1]. This document reports on an initiative by the OECD Secretariat to develop a set of capital service measures for a broader number of countries. The paper also raises a number of theoretical and practical issues that emerge in the context of capital measurement. Most of these issues concern the treatment of technical change, depreciation and obsolescence in capital service measures.

The following general conclusions have so far emerged from this work:

- Computation of capital services measures does not, in general, require a larger set of data or information than the computation of gross and net capital stock series. Indeed, the different capital measures are and should be all based on the same pieces of statistical information.

- The capital services approach not only offers a tool for productivity measurement but also leads to a consistent entity of measures of the gross stock, the net stock, prices and volumes of capital services and consumption of fixed capital. Sometimes, there is a dissociation of capital services measures for productivity analysis from depreciation and net stock measures in the national accounts. Where possible, these measures should be consistent and derived from the same model, as spelled out in the present paper.

- Methodology matters. Capital services estimates are sensitive to the choice of deflators, in particular for fast-evolving high-technology products. But assumptions about age-efficiency functions and the choice of the rate of returns also play a role. There is no unique best way to deal with some of these issues but it is obvious that more and better empirical information could settle a number of outstanding issues in capital service measurement.

1. This is the case for Australia (ABS), the United States (BLS) and Canada. Results will soon be forthcoming for Spain (Mas et al. 2002) and recently, work has been taken up in the United Kingdom.

- The present calculations raise questions about the level of detail at which OECD member countries publish investment data. In particular, there is an issue about the level of asset detail. From the perspective of capital services measurement, the separate recognition of certain investment goods (e.g. IT equipment) with large relative price changes would be desirable.

- Open questions remain, though. They are both of a conceptual nature (e.g., some questions regarding the treatment of obsolescence) and of an empirical nature (e.g., the form of age-efficiency functions, the choice of service lives, or the comparability of price indices). Some of these issues may merit a specific international effort to advance in a co-ordinated manner, others will require new empirical studies at the national level to put capital measures on a more solid empirical footing.

2. Framework

Capital services measures are based on the economic theory of production and have been described in OECD (2001a, 2001b). The present framework offers a more complete treatment, in particular with regard to measurement of depreciation, obsolescence, and expectations. It builds on the work by Jorgenson (1995), Hulten (1990), Triplett (1996, 1998), Hill (2000) and Diewert (2001).

In a production process, labour, capital and intermediate inputs are combined to produce one or several outputs. Conceptually, there are many facets of capital input that bear a direct analogy to measures of labour input (Table 1). Capital goods that are purchased or rented by a firm are seen as carriers of capital services that constitute the actual input in the production process. Similarly, employees hired for a certain period can be seen as carriers of stocks of human capital and therefore repositories of labour services. Differences between labour and capital arise because producers usually own capital goods. When the capital good ‘delivers’ services to its owner, no market transaction is recorded. The measurement of these implicit transactions – whose quantities are the services drawn from the capital stock during a period and whose prices are the user costs or rental prices of capital – is one of the challenges of capital measurement for the productivity analyst. We also note that there has been a longstanding academic debate about the fundamental nature of capital and its role in production. One approach, also adopted in this paper, is centred on prices and volumes of capital services. An other approach considers as fundamental the services not of the capital good, but of ‘waiting’, i.e., the act of foregoing today’s consumption in favour of building up capital goods and future consumption (see Rymes 1971 for a discussion).

Table 1. Labour and capital inputs

	Labour input	**Capital input**
Stock measures	Human capital	Physical capital
Services to production from input factors:		
Quantity	Labour services, measured as total person hours worked	Capital services, measured for example as total machine hours (typically, assumed to be in fixed proportion to capital stock)
Prices	Compensation per hour	User cost of capital per unit of capital service
Differentiation	By industry and by type of labour input	By industry and by type of capital asset
Factor cost or factor income	Compensation per hour*total hours	User costs*productive capital services
Aggregation weights	Industry-specific and labour quality-specific shares in total compensation	Industry-specific and asset specific shares of user costs of capital

2.1. Capital measures for a single homogenous asset

2.1.1. Capital services and the productive stock

For any given type of asset, there is a flow of productive services from the cumulative stock of past investments. This flow of productive services is called *capital services* of an asset type and is the appropriate measure of capital input for production and productivity analysis. Conceptually, capital services reflect a quantity, or physical concept, not to be confused with the value, or price concept of capital. To illustrate, take the example of an office building. Service flows of an office building are the protection against rain, the comfort and storage services that the building provides to personnel during a given period.

The price of capital services is measured as their rental price. If there were complete markets for capital services, rental prices could be directly observed. In the case of the office building, rental prices do indeed exist and are observable on the market. This is, however, not the case for many other capital goods that are owned and for which rental prices have to be imputed. The implicit rent that capital good owners ‘pay’ themselves gives rise to the terminology user costs of capital. Frequently, no conceptual distinction is made between rental prices and user costs. However, this requires that several added hypotheses (e.g., existence of complete and fully functioning markets for all types and vintages of capital goods) hold. For the purpose at hand, the distinction will be made: we define rental prices as market prices for the use of capital assets,

where market transactions actually take place. User costs of capital are the costs of using capital asset that arise for the owner-producer. A more extensive discussion of user costs can be found below.

Of course, the price for capital services will vary as a function of the age of the capital good. Typically, the user cost for an older piece of capital is lower than the user cost for a new capital good, reflecting the differences in productive efficiency of the two items. Total payments for capital services are then the product of the user costs for each asset and the quantity of capital services for each asset and vintage. Some notation is needed here for clarity. Call $uk_{t,s}^{i}$ the price of capital services that are derived from an s-year old capital good of type i in year t, and call $K_{t,s}^{i}$ the quantity of capital services associated with an s-year old asset. Total payments for capital services are given by expression (1). They are expressed in current prices but for convenience we assume that these current price payments can be broken up into a price component uk_t^i and a quantity component K_t^i.

$$uk_t^i K_t^i = uk_{t,0}^i K_{t,0}^i + uk_{t,1}^i K_{t,1}^i + uk_{t,2}^i K_{t,2}^i + uk_{t,3}^i K_{t,3}^i + \ldots \qquad (1)$$

Typically, neither the flow of capital services nor its market prices are directly observable. The assumption is thus made that the flow of capital services from an s-year old asset is in proportion to the volume of investment of that asset s years ago. Let λ_t^i be the proportionality factor by which capital service flows and vintage investment are linked. The quantity of investment of asset i in year t, I_t^i, is either measured in physical units if a truly homogenous asset can be observed or is obtained as the deflated value of current price investment. For this and other purposes, let $q_{t,s}^i$ be the price index for an s-year old asset of type i prevailing in year t.

Further, a retirement pattern is needed that describes how assets are withdrawn from service (scrapped, discarded). Typically, a retirement pattern is a distribution around the expected or mean service life. Each truck in a fleet of identical vehicles of the same age has the same expected service life. In practice, some of the trucks will be retired or scrapped before the expected service life, others later. This phenomenon is described by the retirement pattern. For the present purpose, we use a function F_s to describe the retirement pattern. F_s is non-negative and falling as s, the age of an asset, increases. For a new asset with s=0, F_0 takes a value of one.

It is also assumed that the investment goods purchased and installed in period t give rise to a flow of capital services in the following period. In the absence of specific empirical information about the length of lags between purchases of investment goods and their actual use in the production process, this seems like

a reasonable and simple assumption that is maintained for all types of assets. The flow of capital services is then approximated by:

$$K_{t,s}^{i} = \lambda_t^{i} F_s^{i} I_{t-s-1}^{i} \qquad (2)$$

Combining expressions (2) and (1) yields:

$$uk_t^{i} K_t^{i} = uk_{t,0}^{i} \lambda_t^{i} F_0^{i} I_{t-1}^{i} + uk_{t,1}^{i} \lambda_t^{i} F_1^{i} I_{t-2}^{i} + uk_{t,2}^{i} \lambda_t^{i} F_2^{i} I_{t-3}^{i} + uk_{t,3}^{i} \lambda_t^{i} F_3^{i} I_{t-4}^{i} + \ldots \qquad (3)$$

$\lambda_t^{i} uk_{t,s}^{i} F_s^{i} I_{t-s-1}^{i}$ represents the value of capital services in period t, derived from investment s periods ago. $uk_{t,s}^{i}$ has been defined as the price of one unit of capital services. More frequently, user cost expressions are defined in terms of the cost of using one unit of vintage investment. We call the so defined user cost term $u_{t,s}^{i}$ and compute it as $u_{t,s}^{i}=\lambda_t^{i} uk_{t,s}^{i}$. (3) is then re-written as:

$$uk_t^{i} K_t^{i} = u_{t,0}^{i} F_0^{i} I_{t-1}^{i} + u_{t,1}^{i} F_1^{i} I_{t-2}^{i} + u_{t,2}^{i} F_2^{i} I_{t-3}^{i} + u_{t,3}^{i} F_3^{i} I_{t-4}^{i} + \ldots \qquad (4)$$

Next, a behavioural relationship has to be introduced (Hulten 1990): a rational, cost-minimising producer will choose a vintage composition such that the relative productivity of different vintages is just equal to the relative user costs of the two vintages. The relative marginal productivity of two vintages of the same type of assets is captured by the ***age-efficiency function***. It reflects the loss in productive capacity of a capital good over time or the rate at which the physical contributions of a capital good to production decline over time, as a result of wear and tear, and technical obsolescence. For the purpose at hand, the age-efficiency function is called h_s^{i}, with non-negative values that decline with rising age s: $h_s^{i}=1$ for a new capital good (s=0) and $h_s^{i}=0$ for a capital good that has reached its maximum service life (s=T). In this general formulation, no other assumptions are made concerning the shape of h_s^{i}. For the empirical implementation, it will be assumed that the age-efficiency function is hyperbolically shaped. In a functioning market, the following relationship holds: $(h_s^{i}/h_0^{i})=(u_{t,s}^{i}/u_{t,0}^{i})$, or $u_{t,s}^{i}=u_{t,0}^{i} h_s^{i}/h_0^{i}$. When this term is inserted into (4), one obtains:

$$uk_t^{i} K_t^{i} = u_{t,0}^{i} (F_0^{i} I_{t-1}^{i} + h_1^{i} F_1^{i} I_{t-2}^{i} + h_2^{i} F_2^{i} I_{t-3}^{i} + h_3^{i} F_3^{i} I_{t-4}^{i} + h_4^{i} F_4^{i} I_{t-5}^{i} + \ldots) \qquad (5)$$

Box 1 How restrictive are age-efficiency functions?

It is common procedure, and also adopted in the present case, to assume that the relative user costs of different vintages of capital can be represented by a time-invariant age-efficiency function. This assumption has been challenged on the grounds that it is overly restrictive when it comes to capturing the effects of obsolescence of capital goods. To understand this point, it is useful to recall that in a well functioning market and with a rational producer, user costs of a particular vintage of capital will just equal the marginal revenues from employing this vintage in production. Thus, the assumption that relative user costs are captured by a time-invariant age-efficiency function implies that the ratio of marginal productivities of two vintages does not change over time.

This view has been challenged, for example by Harper (2002) who points out that cyclical effects and obsolescence typically affect different vintages in a disproportional way. For example, the introduction of a new computer model may have little impact on the marginal productivity of a one-year old model already in use but it may lead to discarding a five-year old model, thereby reducing its marginal productivity to zero. This is possible when quantities of computing power associated with different models are not perfect substitutes, e.g., because they require different combinations with labour, as is the case in Harper's model. Such an event implies disproportionate implications for marginal productivities and user costs of different vintages and is incompatible with a constant age-efficiency function.

Harper proposes a 'machine model' with vintage-specific production functions. Machines are aggregated to 'M-capital', using the property that the rents per unit of M-capital correspond to the price of output which is therefore identical across machines. This solves the aggregation problem but implies deflation of the value of capital services with a single deflator, the price of output, which does not really give rise to a meaningful volume measure of capital. For a more extensive discussion of Harper, see Diewert (2002).

Another issue[1] concerns the effects of enterprise demography and firm-specific investment on average age-efficiency functions. When firms exit, their productive capital often suffers a 'sudden death' as firm-specific assets are not directly or only at significant cost re-usable by other firms. As churning rates of enterprises are important, this form of obsolescence may affect the overall, average length of service lives and/or the form of the age-efficiency and age-price curve.

Thus, there is no easy way to reconcile current measurement approaches for capital with a more general treatment of obsolescence and other forces that may affect marginal productivity of vintages in a differential way. More research and a good empirical understanding of the effects of obsolescence will be needed in this area.

[1]This point was raised by John Baldwin (Statistics Canada) in a recent workshop on productivity measurement. Empirical studies carried out by Statistics Canada provide evidence for such an effect.

With expression (5), one is close to an operational expression for estimating a price and quantity component of capital services. As a last step, we define the productive stock of asset i at the end of period t-1 as:

$$S_{t-1}^{i} = F_0^{i} I_{t-1}^{i} + h_1^{i} F_1^{i} I_{t-2}^{i} + h_2^{i} F_2^{i} I_{t-3}^{i} + h_3^{i} F_3^{i} I_{t-4}^{i} + h_4^{i} F_4^{i} I_{t-5}^{i} \ldots \qquad (6)$$

The importance of measures of the productive stock in productivity analysis derives from the fact that they offer a practical tool to estimate flows of capital services – were the latter directly observable, there would be no need to measure capital stocks. Given information or assumptions about the age-efficiency function h_s^i, about the retirement pattern F_s^i and about the volume of vintage investment $I_{t,s}^i$, (6) is an expression of the perpetual inventory method that yields a measure of the productive stock of asset i. The productive stock of asset i is the sum of all vintage investment in this type of asset, corrected for the probability of retirement, and corrected for its loss in productive capacity, so that S_t is expressed in "new equivalent" units of year t. Such additive aggregation across vintages[2] implies perfect substitutability between investment goods of different vintages[3]. Inserting (6) into (5) yields:

$$uk_t^i K_t^i / u_{t,0}^i = F_0^i I_{t-1}^i + h_1^i F_1^i I_{t-2}^i + h_2^i F_2^i I_{t-3}^i + h_3^i F_3^i I_{t-4}^i + h_4^i F_4^i I_{t-5}^i + \ldots = S_{t-1}^i \qquad (7)$$

From (7), it is apparent that the productive stock of asset i at the end of period t in "new equivalent" units is equal to the deflated value of capital services, where the price index for deflation of $uk_t^i K_t^i$ is the user cost for a new asset in year t, $u_{t,0}^i$. Put differently, the value of capital services at current prices is equal to the volume of the productive stock in "new equivalent" units, valued at user costs of a new capital good:

$$uk_t^i K_t^i = u_{t,0}^i S_{t-1}^i \qquad (8)$$

For our empirical purpose of measuring the rate of change of the volume of capital services flowing from asset i, we simply form an index of the productive stock: S_t^i / S_{t-1}^i. This may seem straightforward but a number of qualifications are in place, spelled out in Box 2. Furthermore, for the aggregation procedure of capital service flows across assets we refer to the section on aggregation in this document.

2 . See Hulten (1990) for a discussion.

3 . Diewert (2001) showed how less restrictive forms of aggregation can be used to construct volume indices across vintages. However, for the case of time-invariant age-efficiency functions and constant proportionality factors λ, results are identical and the more restrictive additive formulation has been kept here for simplicity of exposition.

Box 2 What are the quantities in the value of capital services?

Expression (8) provides a breakdown of the nominal value of capital services into a price and into a volume component: the latter is the productive stock in 'new equivalent' units and in prices of a (fixed) base year. The former is the user cost for a new asset. While this seems like a natural way to go about things, there is no compelling reason to do so. An alternative way of presenting the value of capital services is to consider not the user cost per unit of investment, but the user cost per unit of capital services. In the present notation, this would amount to expressing the price component as $uk_{t,0}^{i}$ and the quantity component as $\lambda_t^i S_{t-1}^i$.

This switch is without any consequences for the *rate of change* of the volume of capital services as long as the proportionality factor λ_t^i is time invariant: $S_t^i/S_{t-1}^i = \lambda^i S_t^i / \lambda^i S_{t-1}^i$ for $\lambda_t^i = \lambda_{t-1}^i = \lambda^i$. However, if one maintains the more general formulation with a time-variant proportionality factor, the price-volume split will yield different results, as the volume index of capital services would be given by $\lambda_t^i S_t^i / \lambda_{t-1}^i S_{t-1}^i$. One obvious interpretation of $\lambda_t^i/\lambda_{t-1}^i$ is the rate of capital (or capacity) utilisation, so that the so computed capital input flow would be corrected for cyclical variations. Of course it is difficult to value $\lambda_t^i/\lambda_{t-1}^i$ empirically, and this is the principal reason why λ^i is either taken as time-invariant or simply relegated to the price component of the capital services expression.

But recognition of the fact that variations in the flow of capital services per unit of investment *should* be measured can be helpful. For example, an index of capital productivity would read as:

$$\text{'True' index of capital productivity} = [Q_t/Q_{t-1}]/[(\lambda_t^i/\lambda_{t-1}^i)\,(S_t^i/S_{t-1}^i)].$$

Without knowledge about $\lambda_t^i/\lambda_{t-1}^i$ we would measure capital productivity as:

$$\text{'Apparent' index of capital productivity} = [Q_t/Q_{t-1}]/[(S_t^i/S_{t-1}^i)].$$

A straightforward comparison of the two expressions shows that

$$\text{'Apparent' index of capital productivity} = (\text{'True' index of capital productivity})(\lambda_t^i/\lambda_{t-1}^i).$$

We are thus reminded that our empirical measure of capital productivity corresponds only to the true one if there are no variations in the intensity of the service flow. Otherwise, the empirical capital input measure will miss out on changes in $(\lambda_t^i/\lambda_{t-1}^i)$ – and under- or over-estimate true capital input and true capital productivity. Similar observations can be made for multi-factor productivity measures that often show pro-cyclical variations. The present set-up shows that such variations could be explained by capital input measures where variations in $(\lambda_t^i/\lambda_{t-1}^i)$ have been assumed away.

2.1.2. The wealth (net) and the gross capital stock

Whereas the productive stock is designed to capture the productive capacity of capital goods, and by implication the flow of capital services, the wealth (net) stock measures the market value of capital assets. Conceptually, the more familiar '***net capital stock***' is synonymous to the wealth capital stock. 'Wealth stock' is sometimes considered a more precise terminology, however, because there are other forms of 'net' stock, in particular the productive stock which is the gross stock 'net' of efficiency declines in productive assets.

The wealth (net) stock at prices of period t is called $q_t^i W_t^i$ and defined as in (9).

$$q_t^i W_t^i = q_{t,0}^i F_0^i I_t^i + q_{t,1}^i F_1^i I_{t-1}^i + q_{t,2}^i F_2^i I_{t-2}^i + q_{t,3}^i F_3^i I_{t-3}^i + \ldots \qquad (9)$$

Before moving on to the computation of user costs, a parenthesis is opened regarding the gross capital stock – a statistic frequently available in OECD countries. The ***'gross capital stock'*** is the cumulative flow of investments, corrected for the retirement pattern. It constitutes an intermediate step in the calculation of the productive stock that takes account of the withdrawal of assets but does not correct the assets in operation for their loss in productive capacity. Alternatively, gross capital stocks can be considered a special case of the productive stock, where the age-efficiency profile follows a pattern where an asset's productive capacity remains fully intact until the end of its service life (sometimes called 'one-hoss-shay')[4].

2.1.3. User costs

A fundamental relation in capital theory (Jorgenson, 1963) states that the market price of an asset equals the discounted value of the rentals that the asset is expected to generate in the future. In the absence of complete markets, the same relation can be adopted for the user-owner of capital goods by stating that the value of an asset equals the discounted marginal revenues from using the asset in production in the future. Expectations are formed under the information set Ω_t available at the beginning of period t. We adopt the convention that the marginal revenues (the rentals if there is a market transaction) generated by an asset arise at the end of each period and are discounted with the nominal rate r. The discount rate applies equally to all expected rentals but it may change over time as the information set changes. Marginal revenues of an s-year old asset are equal to its user costs, and called $u_{t,s}^i$ as before. $q_{t,s}^i$ is the purchase price of capital good i with age s, prevailing throughout period t. Note that all variables depend on the information set Ω_t. For notational simplicity, this is not explicitly stated but should be kept in mind.

$$q_{t,s}^i \,|\, \Omega t = u_{t+1,s}^i (1+r_t)^{-1} + u_{t+2,s+1}^i (1+r_{t+1})^{-2} + u_{t+3,s+2}^i (1+r_{t+2})^{-3} + u_{t+4,s+3}^i (1+r_{t+3})^{-4} + \ldots \qquad (10)$$

4. More formally, a gross capital stock of asset i in year t based on the perpetual inventory method is calculated as the sum $F_0^i I_{t-1}^i + F_1^i I_{t-2}^i + F_2^i I_{t-3}^i + F_3^i I_{t-4}^i + F_4^i I_{t-5}^i + \ldots$

A simplification is introduced here: we assume that the discount rate r that applies to different future time periods is constant for every information set Ω_t: $r_{t+s}=r_t=r(\Omega_t)$ for all s=0,1,..T. Expression (10) can be "solved" for u_t^i by shifting it by one period while keeping the information set Ω at period t, as in (11). This expression is then subtracted from (10) after multiplication by (1+r). The result can be found in (12).

$$q_{t+1,s+1}^{i} \mid_{\Omega t} = u_{t+2,s+1}^{i}(1+r)^{-1} + u_{t+3,s+2}^{i}(1+r)^{-2} + u_{t+4,s+3}^{i}(1+r)^{-3} + u_{t+5,s+4}^{i}(1+r)^{-4} + \ldots \qquad (11)$$

$$u_{t+1,s}^{i} \mid_{\Omega t} = q_{t,s}^{i}(1+r) - q_{t+1,s+1}^{i} \qquad (12)$$

As a final step, we shift the information set to the beginning of period t-1 and express the user costs of capital in period t for an s year-old asset u_{t+1}^{i} as:

$$u_{t,s}^{i} \mid_{\Omega t-1} = q_{t-1,s}^{i}(1+r) - q_{t,s+1}^{i} \qquad (13)$$

Box 3 Use of expected variables: a contradiction with the national accounts?

The variables on the right hand side of (14) are expected variables, given the information available at the beginning of period t-1. These expectations govern the rental price $u_{t,s}^{i} \mid_{\Omega t-1}$. The System of National Accounts, to which capital stock data should tie into, is based on ex-post prices, observed in the context of actual transactions. Would the use of user cost expressions such as the one above then be in contradiction with the principles of national accounts?

In our view, the answer is 'no'. Note that the presence of expectations does not make $u_{t,s}^{i} \mid_{\Omega t-1}$ less 'real': transactions are concluded at this price, even if with hindsight (ex post) the expectations underlying it may turn out to be wrong. This is most apparent when one thinks of a case where capital goods are actually rented: the observed rental price characterises the transaction and is the relevant market price, typically dependent on expectations on the side of the lessor and the lessee. Nobody would challenge using such observed prices in the national accounts. If rental prices are not observable, values have to be imputed, and equation (14) indicates how this can be done on the basis of economic theory. Imputations are numerous in the national accounts, and in this sense, the imputation of user costs would not constitute an exception.

Thus, it is not the presence of expected variable as such that is at issue. The real question from a capital and productivity measurement viewpoint is: is the realised but unobserved marginal productivity of fixed assets better approximated by an ex-ante or by an ex-post measure of user costs? This question is discussed in Box 4.

(13) constitutes a computable expression for user costs of capital, if a set of market prices for vintage investment goods and a discount rate are available. Vintage prices are observable, although not for all assets, and empirical studies are rare and often outdated. It will thus often be necessary to compute sets of

vintage prices, by invoking economic theory and a few additional assumptions. Before doing so, we transform (13) into a form frequently used in empirical work. To this end, define the (expected) rate of depreciation of asset i as $d_{t,s}^{i} \equiv 1 - q_{t,s+1}^{i}/q_{t,s}^{i}$ and the (expected) rate of price change of the same asset as $\zeta_t^{i} \equiv q_{t,s}^{i}/q_{t-1,s}^{i} - 1$. With these notations, the user cost term becomes:

$$u_{t,s}^{i} \mid_{\Omega t-1} = q_{t-1,s}^{i}(r + d_{t,s}^{i} - \zeta_t^{i} + d_{t,s}^{i}\zeta_t^{i}) \qquad (14)$$

(14) has, for example, been discussed by Hulten (1990) and shows that the user cost of capital for an s-year old asset is the product of the purchase price of this asset ($q_{t-1,s}^{i}$) multiplied by the gross rate of return on this asset where the gross rate of return is the sum of the discount rate (or net rate of return), plus the rate of depreciation (d_t^{i}) minus the rate of asset price change (ζ_t^{i}) plus an interaction term of depreciation and asset price change ($d_t^{i}\zeta_t^{i}$).

In the present set-up, rental contracts are concluded at the beginning of period t-1. The price specified in these rental contracts is the user cost, payable at the end of period t-1 (or at the beginning of the period t). When capital goods are owned and used in production by the same unit, the user cost term is implicit but the economic rationale remains the same: an asset will be used in production up to the point where its marginal revenues correspond to the expression on the right hand side of (14).

Box 4 User costs: ex-ante or ex-post?

The distinction between expected or ex-ante user costs has been discussed by Berndt and Fuss (1986) Harper et al. (1989), Diewert (2001) and by Berndt (1990) in his discussion of Hulten (1990). In Box 3, it was concluded that the importance of the distinction between ex-ante and ex-post measures lies in their capacity to approximate the realised marginal productivity of capital assets. On this matter, Berndt (1990) points out that: "…if one wants to use a measure of capital to calculate actual multifactor productivity growth, then theory tells us quite clearly that we should weight the various traditionally measured capital inputs by their *realised* marginal products, not their *expected* marginal products. This means that in choosing capital service price weights, on should employ shadow values or ex post rates of return, and not the ex ante rates of return that are appropriate in the investment context."

While we concur with Berndt's statement that for purposes of productivity measurement, realised marginal products are the appropriate weights, we wish to point out that this does not necessarily imply that ex post rates of return are always the preferred approximation to realised marginal productivity. Suppose that a capital asset is rented by a producer at a given, pre-agreed rental price to be paid by the end of the period. Independent of the ex-post rental price will the lessee of the asset use it in his production process as planned. Then, the marginal productivity of the asset in the production process would best be approximated by the *ex-ante* rental price which is the price at which the rental transaction took place.

Take another case of an owner/producer and suppose that there has been investment at the beginning of the period in line with the ex-ante user cost. Now let there be a change in market conditions that lead to a modification of expectations and of user costs. If capital is fully flexible and can be adjusted continuously, it will be done so in line with the new user cost term. But the user cost term remains one governed by expectations, even though expectations may have changed. Only when capital cannot be adjusted, the ex-post user cost term would furnish the preferred approximation to the realised marginal productivity of an asset. This is the case that Berndt (1990) and Berndt and Fuss (1986) have in mind and it relies on quasi-fixity of capital in the production process. In other words, there is no general conclusion that ex-post user cost measures should always be preferred to ex-ante one for purposes of measuring and aggregating capital input.

There is another conceptual difficulty with ex post user costs: the computation of the realised rates of return is commonly done by choosing a rate of return so that the ensuing user cost and total value of capital services just exhausts the measured gross operating surplus available from the national accounts. This computation relies, however, on the assumption that there be *only one* ex-post rate of return across all assets. While equalisation of rates of return across assets is a natural assumption in an ex-ante context, it is much harder to justify in an ex-post context, and a state of disequilibrium. Thus, we would be imposing an equilibrium condition to implement an (ex-post) measure that was specifically chosen on the grounds that it captures the nature of a situation of disequilibrium.

Diewert (2001) also points out that while the ex-post measure (of the nominal rate of return) is widely used in empirical research, it is subject to measurement error and it may not reflect the economic conditions facing producers at the beginning of the period.

Note a practical argument against the ex-post rate: its calculation requires information on the level of the productive capital stock at current prices (or alternatively on the wealth stock at current prices). But levels of capital stocks tend to be less reliable statistics than their rates of change, in particular when long historical investment series have to be estimated. This problem does not arise when user costs and nominal rates of return are of an ex-ante nature and therefore exogenous variables. On the other hand, ex-post rates of return are of interest as such, and straightforward to compute. In sum then, there is no clear conclusion on this matter. For the present work, however, we gave preference to an ex-ante approach – mainly because it allows us to develop capital service measures independently from measures of labour compensation, gross operating surplus and mixed income in the national accounts.

2.1.4. Depreciation

Depreciation measures the loss in *value* of a capital good as it ages. This definition follows the productivity literature and associates depreciation with the wealth or net capital stock. It has to be distinguished from ***decay*** or ***efficiency decline*** that reflects the loss of productive services that can be drawn from a capital good. Efficiency decline or decay is associated with the productive capital stock. Patterns of depreciation pertain to the age-price profile of an asset, and patterns of decay to its age-efficiency profile.

The loss in value of a capital good as it ages is shown in its age-price profile or the pattern of relative prices for different vintages of the same (homogenous) capital good[5]. How steeply the price of a capital good falls as it ages depends on several factors, including the rate of loss of productive capacity and the remaining service life. Obsolescence is another source for the loss of value of an old asset because a newly introduced asset of the same class contains improvements in productiveness or efficiency (Triplett (1998)). The market value of a five-year old truck is much lower than that of a new one, because the older truck has suffered from wear and tear and because its remaining service life is five years less than that of the new vehicle.

The age-price profile and age-efficiency profile of a specific type of capital good are not necessarily identical, but they are related. Thus, they cannot be defined independently of each other. A one-year old truck may have lost 20% of its market value but it has not necessarily lost 20% of its capacity to ship goods from one place to another. Indeed, the trucking services of a one-year old vehicle are probably nearly identical to those of a new one. Nonetheless, a change in service life or a different rate of efficiency loss will necessarily influence the value of existing assets. This illustrates the link between the age-price and age-efficiency patterns.

How, then, does one compute the rate of depreciation $d_{t,s}^{i}$? In those cases where a set of vintage prices is available, the answer is straightforward: $d_{t,s}^{i}=1-q_{t,s+1}^{i}/q_{t,s}^{i}$ by definition. More often than not, however, the set of vintage prices is incomplete. In fact, most of the time, only time series of new asset prices $q_{t,0}^{i}$ are readily available. In this case, use has to be made of the asset price equilibrium condition (10) to derive consistent estimates of the age-price profile. More precisely, the price of an s+1 year old asset relative to an asset that is s years old can be presented as:

5 . Depreciation is understood here to measure the value loss due to ageing for a capital good conditional on its survival. Thus, the effects of retirement are not reflected in this measure – they are picked up as a volume change (retirement effect) in the wealth stock. It is also possible to have a different set-up where

$$q_{t,s+1}^{i}/q_{t,s}^{i} \mid_{\Omega t} = \Sigma_{\tau=0}\, u_{t+\tau+1,s+\tau+1}^{i}\,(1+r)^{-(\tau+1)} / \Sigma_{\tau=0}\, u_{t+\tau+1,s+\tau}^{i}\,(1+r)^{-(\tau+1)} \qquad (15)$$

The vintage price ratio in (15) depends on expected user costs, and the discount rate prevailing at t, given the information available at the beginning of period t. To progress in this general case, one has to formulate expectations about future user costs of capital. Suppose that, given the information set Ω_t, users-owners expect user costs to change at a rate of ξ^i percent per period. In this case, one has $u_{t+\tau,s}^{i}=u_{t,s}^{i}(1+\xi^i)^{\tau}$. Note that although this has not been explicitly marked, ξ^i is dependent on the information set and may thus change over time. Then:

$$q_{t,s+1}^{i}/q_{t,s}^{i} \mid_{\Omega t} = \Sigma_{\tau=0}\, u_{t,s+\tau+1}^{i}\,(1+\xi^i)^{\tau+1}\,(1+r)^{-(\tau+1)} / \Sigma_{\tau=0}\, u_{t,s+\tau}^{i}\,(1+\xi^i)^{\tau+1}\,(1+r)^{-(\tau+1)} \qquad (16)$$

Next, invoke behavioural equation $(h_s^i/h_0^i)=(u_{t,s}^i/u_{t,0}^i)$, which links the ratio of user costs to the age-efficiency profile. We use it to present the numerator and denominator in (16) in terms of the user costs for new capital goods in period t only:

$$q_{t,s+1}^{i}/q_{t,s}^{i} \mid_{\Omega t} = \Sigma_{\tau=0}\, u_{t,0}^{i}\, h_{s+\tau+1}^{i}(1+\xi^i)^{\tau+1}\,(1+r)^{-(\tau+1)} / \Sigma_{\tau=0}\, u_{t,0}^{i}\, h_{s+\tau}^{i}\,(1+\xi^i)^{\tau+1}\,(1+r)^{-(\tau+1)} \qquad (17)$$

$u_{t,0}^i$ cancels out of expression (17) and one is left with the computable expression for vintage prices below. It depends on the age-efficiency profile, the discount rate and the expected rate of change of the asset price.

$$q_{t,s+1}^{i}/q_{t,s}^{i} \mid_{\Omega t} = \Sigma_{\tau=0}\, h_{s+\tau+1}^{i}\,[(1+r)/(1+\xi^i)]^{-(\tau+1)} / \Sigma_{\tau=0}\, h_{s+\tau}^{i}\,[(1+r)/(1+\xi^i)]^{-(\tau+1)} \qquad (18)$$

2.1.5. More on expected price changes

Some further remarks are called for regarding equation (18). First, in the special case where the age-efficiency profile is geometric, and declines at a constant rate δ^i independent of time t and vintage s, the expression simplifies to an age-price profile that is also geometric. Suppose that $h_{s+\tau}^{i}=h_{\tau}^{i}(1-\delta^i)^s$. This yields $q_{t,s+1}^{i}/q_{t,s}^{i} \mid_{\Omega t}=\Sigma_{\tau=0}\, h_{\tau}^{i}(1-\delta^i)^{s+1}\,[(1+r)/(1+\xi^i)]^{-(\tau+1)}/\Sigma_{\tau=0}\, h_{\tau}^{i}\,(1-\delta^i)^s\,[(1+r)/(1+\xi^i)]^{-(\tau+1)}=(1-\delta^i)$. Age-price and age-efficiency profiles coincide and significantly simplify computations. Geometric rates have been widely used in empirical research, in particular by Jorgenson (1995) and many of his co-authors. However,

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both the combined value loss due to the ageing of existing assets and the value loss due to retirement of assets enter the depreciation term.

geometric rates have also been criticised for several reasons (see OECD 2001b for a discussion) and the general approach that does not rely on geometric rates is further pursued in this paper.

The second remark about expression (18) concerns the term $[(1+r)/(1+\xi^i)]$. It is easy to see that a nominal discount rate divided by a rate of price change represents a real interest rate, albeit a somewhat special one, obtained not by applying a general price index but by applying an asset-specific price index. Of course, we could also say that the expression $[(1+r)/(1+\xi^i)]$ is the ratio of a real interest rate $[(1+r)/(1+p)]$ divided by a relative price change $[(1+\xi^i)/(1+p)]$ where p is some overall expected price index such as the GDP deflator or the consumer price index.

OECD (2001b) uses a special case where $[(1+r)/(1+\xi^i)]$ is taken as constant, at 1,04. This is justified on the grounds that a 4 % rate is a reasonable order of magnitude for a long-term real interest rate. For this reasoning to hold, however, the expected relative price change $[(1+\xi^i)/(1+p)]$ between user costs and some overall price index have to be assumed away so that the 4 % rate applies to the term $[(1+r)/(1+p)]$. For this term it presents a plausible value, independent of the specific asset under consideration.

The present work also uses a constant, but country-specific figure for the expected real interest rate $[(1+r)/(1+p)]$. In addition, we also formulate an empirical measure for the expected relative price change $[(1+\xi^i)/(1+p)]$. Together with values for the age-efficiency function, and based on the relationship (18), this provides us with a set of vintage asset prices for every time period under consideration.

A look at the user cost expression (14) recalls that all variables are based on an information set available at the beginning of period t-1, and this includes the rate of change of the purchase price of asset i, ζ_t^i. Thus, ζ_t^i is also an expected variable. This is apparent from its definition as $\zeta_t^i=q_{t,0}^i/q_{t-1,0}^i-1$ which includes $q_{t,0}^i$ – a variable not yet known with certainty at the beginning of period t-1. A consistent set-up for the user cost expression has to take the nature of ζ_t^i as an expected variable into account, in line with the expected variables underlying the estimate for the depreciation rate $d_{t,0}^i$ and the nominal discount rate r.

There is a direct link between the expected change in the purchase price of an asset, ζ_t^i, and the expected rate of change of its user costs, ξ^i, if one imposes consistency of these two terms in a situation of balanced growth. Suppose that ζ_t^i, ξ^i and r are constant and on some equilibrium path: $\zeta_t^i=\zeta^{i*}$, $\xi^i= \xi^{i*}$ and r=r*. By definition, $q_{t,s}^i/q_{t-1,s}^i=1+\zeta^{i*}$ and $u_{t,s}^i/u_{t-1,s}^i=1+\xi^{i*}$. But from (10) we also find that in this situation, $q_{t,s}^i/q_{t-1,s}^i=u_{t,s}^i/u_{t-1,s}^i$. Consequently, the long-run rate of asset price change has to be the same as the long-run rate of change of the user cost term, or $\zeta^{i*} = \xi^i$. We use this relation to simplify our empirical measurement of expected variables and set $\xi^i=\zeta^i$.

Yet another remark is in place here. In equation (8), it was shown that the value of capital services could also be presented as the productive capital stock multiplied by the user cost term for a *new* asset: $uk_t^iK_t^i = u_{t,0}^iS_{t-1}^i$. For the empirical calculations of capital services, only the productive stock S_{t-1}^i is needed as the quantity measure and the user cost expression $u_{t,0}^i$ as the price measure. From (14) it follows that $u_{t,0}^i= q_{t-1,0}^i(r + d_{t,0}^i - \zeta_t^i + d_{t,0}^i\zeta_t^i)$. Only the depreciation rate for a new asset enters the user cost term and all that is needed here is $d_{t,0}^i=q_{t,1}^i/q_{r,0}^0-1$.

2.2. Aggregation across different assets

Because many different types of capital goods are used in production, an aggregate measure of the capital stock or of capital services must be constructed. For net (wealth) stocks at current prices this is a straightforward matter of summing estimates for different types of assets. In so doing, market prices serve as aggregation weights. The situation is different in productivity analysis. Typically, each type of asset is associated with a specific flow of capital services and proportionality is assumed between capital services and capital stocks at the level of individual assets. This ratio is not the same, however, for different kinds of assets, so that the aggregate stock and the flows covering different kinds of assets must diverge. A single measure cannot serve both purposes except when there is only one single homogenous capital good (Hill 1999).

Jorgenson (1963) and Griliches and Jorgenson (1967) were the first to develop aggregate capital service measures that take the heterogeneity of assets into account. They defined the flow of quantities of capital services individually for each type of asset, and then applied asset-specific user costs as weights to aggregate across services from the different types of assets. User costs are prices for capital services and, under competitive markets and equilibrium conditions, these prices reflect the marginal productivity of the different assets. User cost weights thus provide a means to effectively incorporate differences in the productive contribution of heterogeneous investments as the composition of investment and capital changes.

An aggregate measure of the wealth (net) capital *stock*, on the other hand, uses *market prices* of individual assets to weight its components. Consequently, the difference between an aggregate index of capital services and an aggregate index of a capital stock can be seen in the sets of weights – the former is based on user costs, the latter on the market prices of the assets. In statistical practice, aggregate capital stock is often computed by summing up the stocks of individual assets, each measured at prices of a given base year. Over time, the quantity index of the capital stock will represent a Laspeyres-type index of aggregate capital, with market prices of a base year as weights.

2.2.1. Volume index of total capital services

To start out, define the total value of capital services as

$$uk_tK_t = u_tS_{t-1} = \Sigma_{i=1}\, u_t^iS_{t-1}^i \qquad (19)$$

where the productive stock per asset S_t^i and its associated user costs u_t^i as well as the flow of capital services from asset i, K_t^i, and its associated price uk_t^i have been defined and discussed earlier. In the total value of capital services, there is a quantity component that consists of the productive stocks of different assets S_t^i and a price component, the user costs. Thus, there is a price vector $\mathbf{u}_t \equiv[u_t^1, u_t^2, u_t^3,\ldots]$ and a quantity vector $\mathbf{S}_t\equiv[S_t^1, S_t^2, S_t^3,\ldots]$. The change in the value of capital services over time $u_tS_t/ u_{t-1}S_{t-1}$ has the following index number decomposition:

$$u_tS_{t-1}/u_{t-1}S_{t-2} = U(\mathbf{u}_t, \mathbf{u}_{t-1}, \mathbf{S}_{t-1}, \mathbf{S}_{t-2})\, S(\mathbf{u}_t, \mathbf{u}_{t-1}, \mathbf{S}_{t-1}, \mathbf{S}_{t-2}) \qquad (20)$$

where U and S are price and quantity indices respectively. For empirical implementation, we choose a Törnqvist index number and the volume index of depreciation of asset i is given by:

$$\ln(S_t/S_{t-1})= \Sigma_{i=1}\, 0.5[v_{t+1}^i+v_t^i]\, \ln(S_t^i/S_{t-1}^i) \text{ with } v_t^i\equiv u_t^iS_{t-1}^i/u_tS_{t-1} \qquad (21)$$

The price index for capital services is defined implicitly as $U_t/U_{t-1}=(u_tS_{t-1}/u_{t-1}S_{t-2})/(S_{t-1}/S_{t-2})$.

2.2.2. Net (Wealth) stock

The total wealth stock at current prices is computed by simple addition of the wealth stocks of individual assets, i.e., as $q_t\, W_t = \Sigma_{i=1}\, q_t^i\, W_t^i$. Proceeding the same way as for capital services, a volume index of the next stock can also be derived by identifying a price vector $\mathbf{q}_t \equiv[q_t^1, q_t^2, q_t^3,\ldots]$ and a quantity vector $\mathbf{W}_t\equiv[W_t^1, W_t^2, W_t^3,\ldots]$ so that the total value change of the wealth stock $q_t\, W_t/q_{t-1}W_{t-1}$ can be decomposed into a price and a volume component:

$$q_tW_t/q_{t-1}W_{t-1} = Q(\mathbf{q}_t, \mathbf{q}_{t-1}, \mathbf{W}_t, \mathbf{W}_{t-1})\, W(\mathbf{q}_t, \mathbf{q}_{t-1}, \mathbf{W}_t, \mathbf{W}_{t-1}) \qquad (22)$$

where Q and W are price and quantity indices respectively. For empirical implementation, a Törnqvist index number can be used and the volume index of the wealth stock is:

$$\ln(W_t/W_{t-1}) = \Sigma_{i=1}\, 0.5[v_{t,}^{W,i} + v_{t-1}^{W,i}]\, \ln(W_t^i/W_{t-1}^i) \text{ with } v_t^{W,i} \equiv q_t^i\, W_t^i/q_t W_t \qquad (23)$$

Box 5 International comparability of price indices

Price indices are key in measuring volume investment, capital services and user costs. Accurate price indices should be constant quality deflators that reflect price changes for a given performance of ICT investment goods. Thus, observed price changes of 'computer boxes' have to be quality-adjusted for comparison of different vintages. Wyckoff (1995) was one of the first to point out that the large differences that could be observed between computer price indices in OECD countries were likely much more a reflection of differences in statistical methodology than true differences in price changes. In particular, those countries that employ hedonic methods to construct ICT deflators tend to register a larger drop in ICT prices than countries that do not. Schreyer (2000) used a set of 'harmonised' deflators to control for some of the differences in methodology. We follow this approach and assume that the ratios between ICT and non-ICT asset prices evolve in a similar manner across countries, using the United States as the benchmark. Although no claim is made that the 'harmonised' deflator is necessarily the correct price index for a given country, we feel that the possible error due to using a harmonised price index is smaller than the bias arising from comparing capital services based on national deflators. However, for completeness and transparency, both sets of results are presented.

Note a difficulty with the harmonised deflator. From an accounting perspective, adjusting the price index for investment goods for any country implies an adjustment of the volume index of output. In most cases, such an adjustment would increase the measured rate of volume output change. At the same time, effects on the economy-wide rate of GDP growth appear to be contained (see Schreyer (2001) for a discussion).

Box 6: Wealth and capital services in the presence of technical change – a numerical example

The choice of aggregation weights becomes crucial when prices and quantities of different types of capital goods evolve at very different rates. This is, for example, the case when there is relatively rapid quality change of one type asset compared to others. Aggregation of assets by way of purchase prices will generate a serious bias in the capital input measures because purchase prices will inadequately approximate the marginal productivity of assets which constitute the appropriate weights for aggregation of capital services. User costs are designed to measure the marginal productivity of assets, and the difference between purchase prices (q) and user costs (uc) is the gross rate of return (GRR) that an asset must yield per year: marginal productivity (marginal revenue) = uc=q*GRR. The gross rate of return itself is composed of the net rate of return, the rate of depreciation and rate of revaluation or asset price change. Rapid negative price changes or large rates of depreciation therefore imply large gross rates of return and user costs. Thus, an aggregation based on user cost weights will give more weight to assets with relatively large GRRs as opposed to an aggregation based on purchase prices, q.

Consider the following example with two assets, A and B. In period t=0, the purchase price of both assets equals unit but declines by 30% in the case of A and rises by 10% in the case of B. Given the quantities of investment and the (geometric) rates of depreciation, a capital stock in period t=1 can easily be calculated. In the present case, wealth and productive stock coincide at the level of individual assets. Assume a net rate of return of 5%. The total user cost is then computed as 0.55 for Asset A and 0.15 for Asset B. This gives rise to a share of Asset A in total user costs in period t=0 of 79% and a share of Asset B of 21% - quite different from the 50% share for each asset when weights are based on purchase prices. Finally, construct a simple Laspeyres quantity index of capital services and the wealth stock and it is easy to see that the former rises much faster than the latter.

		Asset A	Asset B
Purchase price	t=0	1	1
	t=1	0.70	1.10
Quantity of investment	t=0	10	10
	t=1	15	8
Productive stock/Wealth stock	t=0	10	10
	t=1	23	16
User costs	Net rate of return	0.05	0.05
	Depreciation	0.20	0.20
	Revaluation	-0.30	0.10
	Total	0.55	0.15
Weights t=0	User cost based	0.79	0.21
	Purchase price based	0.50	0.50
Laspeyres quantity index	User cost based	2.15	
	Purchase-price based	1.95	

3. Results

The following section presents a first set of capital service measures[6] for the G-7 countries and Australia. These should be considered as preliminary, and further tests have to be carried out before data is used in production and productivity analysis. Nonetheless, this first set of results gives rise to several points of discussion. To start out with; Table 2 shows the volume changes of capital services, by type of asset or by type of product. One notes that at the level of *individual* assets, the rate of change of capital services is just equal to the evolution of the productive stock. The aggregate index of capital services (Table 2) corresponds to a weighted average of the each asset's index of capital services where nominal shares in total user costs constitute the relevant weights.

Rates of change of deflators can be found in Table 4. To account for some of the methodological differences between countries' deflators for information and communication technology products, the results presented here are based on 'harmonised' deflators (see Box 5).

6 . Value and volume measures for depreciation as well as the wealth stock have also been computed in the present exercise but no results are presented in the present document to keep it focused on capital services.

Table 2. Volume index of capital services by type of asset

Compound annual percentage changes, total economy, based on 'harmonised' deflators for ICT assets

		Total	Products of agriculture, metal products and machinery			Transport equipment	Non residential construction	Other products	
	Year		Hardware	Communi-cation Equipment	Other			Software	Other
Australia	1990-95	1.5%	19.9%	2.3%	-1.6%	0.2%	2.1%	11.0%	0.6%
	1995-99	2.5%	29.2%	5.8%	-2.6%	1.2%	2.3%	9.1%	0.9%
	1995-01	2.7%	28.9%	5.6%	-2.8%	1.5%	2.2%	6.8%	1.2%
Canada	1990-95	3.9%	16.8%	6.6%	1.7%	2.1%	3.6%	11.3%	n.a.
	1995-99	5.5%	35.6%	8.3%	1.9%	3.8%	3.3%	12.9%	n.a.
	1995-01	5.5%	34.9%	9.4%	1.9%	4.1%	3.3%	11.6%	n.a.
France	1990-95	2.8%	14.7%	4.5%	2.6%	2.1%	2.1%	6.5%	3.7%
	1995-99	2.4%	29.4%	6.3%	1.8%	2.9%	1.5%	20.6%	-0.1%
	1995-01	2.7%	32.6%	6.6%	2.0%	3.7%	1.6%	18.5%	0.6%
Germany	1990-95	3.0%	16.2%	4.5%	1.8%	3.8%	2.1%	8.1%	7.7%
	1995-99	2.5%	25.3%	3.4%	1.0%	2.0%	1.8%	9.4%	7.2%
	1995-01	2.6%	28.6%	4.0%	1.1%	2.3%	1.7%	9.3%	7.6%
Italy	1990-95	2.6%	8.3%	3.7%	2.8%	1.3%	2.1%	0.7%	2.7%
	1995-99	3.4%	26.3%	6.2%	2.9%	2.6%	1.8%	11.5%	1.8%
	1995-01	3.6%	28.5%	6.3%	3.1%	3.3%	1.8%	11.5%	2.1%
Japan	1990-95	4.6%	18.4%	7.5%	2.7%	4.4%	4.8%	7.2%	5.0%
	1995-99	4.1%	29.7%	10.7%	1.8%	2.4%	3.5%	15.6%	0.5%
	1995-00	4.0%	30.1%	10.6%	1.7%	2.1%	3.4%	15.2%	0.0%
United Kingdom	1990-95	2.5%	19.6%	7.6%	1.7%	-0.4%	3.1%	13.5%	-5.1%
	1995-99	4.3%	32.3%	13.8%	3.5%	1.6%	2.7%	13.3%	-1.9%
	1995-00	4.5%	32.2%	13.6%	3.7%	1.4%	2.7%	13.1%	-0.3%
United States	1990-95	3.0%	18.1%	4.3%	0.1%	2.1%	2.0%	12.3%	0.9%
	1995-99	5.5%	32.6%	7.1%	1.2%	4.9%	2.2%	16.0%	5.0%
	1995-01	5.3%	29.8%	7.8%	1.2%	4.8%	2.2%	14.1%	5.2%

Source: OECD capital services data base (Oct 2003)

Table 3. Volume index of capital services (all assets)
1980=100, total economy, based on 'harmonised' deflators for ICT assets

	Australia	Canada	France	Germany	Italy	Japan	United Kingdom	United States
1980	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1981	103.6	109.6	102.8	103.6	105.1	106.4	102.3	104.1
1982	107.6	117.6	105.9	106.7	109.7	112.5	104.9	107.7
1983	110.5	125.3	108.8	109.5	114.7	118.3	108.3	111.2
1984	113.5	133.5	111.9	112.3	123.1	124.2	113.1	115.6
1985	116.9	142.1	115.5	115.1	136.3	130.7	118.1	120.3
1986	120.1	150.8	119.4	118.1	150.5	137.4	122.2	124.7
1987	122.9	160.3	123.8	121.2	160.6	145.0	126.2	129.0
1988	126.2	171.1	129.0	124.6	169.7	153.7	131.0	133.3
1989	129.9	182.2	134.6	128.2	177.9	163.7	136.3	137.9
1990	133.2	192.1	140.7	132.2	185.7	174.1	141.4	142.2
1991	135.2	200.9	146.2	136.9	192.3	184.6	145.6	146.0
1992	136.6	208.5	151.1	142.0	198.2	194.4	148.7	149.9
1993	138.7	215.9	154.8	146.2	201.5	203.0	151.7	154.3
1994	141.2	224.7	158.4	149.7	205.4	210.4	155.7	159.3
1995	144.0	234.0	161.7	153.2	211.0	218.7	160.4	165.6
1996	146.4	244.1	165.1	156.8	217.3	229.0	165.8	173.2
1997	149.3	257.8	168.4	160.5	224.2	239.4	172.1	182.8
1998	153.3	274.0	172.7	164.6	232.3	248.7	181.2	194.1
1999	158.8	292.1	178.0	169.2	241.7	257.5	190.5	206.4
2000	164.4	309.8	184.2	174.2	252.3	266.8	200.7	218.5
2001	166.9	325.7	190.4	179.0	262.4	266.8	n.a.	227.5

Source: OECD capital services data base (Oct 2003)

Table 4. Price indices of capital goods by type of asset

Compound annual percentage changes, total economy, based on 'harmonised' ICT deflators

		Tota	Products of agriculture, metal products and machinery		Transport equipment	Non residential construction	Other products	
	Year	Hardware	Communi-cation Equipment	Other			Software	Other
Australia	1990-95	-12.8%	0.8%	8.0%	5.1%	0.7%	0.1%	-1.6%
	1995-99	-22.7%	-0.5%	17.1%	0.0%	2.4%	1.9%	6.8%
	1995-01	-20.9%	-0.8%	12.2%	-0.2%	2.5%	2.3%	9.7%
Canada	1990-95	-15.4%	-1.8%	3.0%	2.3%	0.8%	-2.5%	n.a.
	1995-99	-27.8%	-5.7%	2.4%	1.6%	2.4%	-3.3%	n.a.
	1995-01	-24.6%	-4.4%	2.4%	1.6%	2.5%	-1.3%	n.a.
France	1990-95	-15.0%	-1.4%	0.4%	0.5%	1.5%	-2.1%	2.1%
	1995-99	-27.8%	-5.6%	0.7%	-1.4%	1.7%	-3.2%	0.7%
	1995-01	-25.1%	-4.9%	0.7%	-0.8%	2.2%	-1.8%	0.6%
Germany	1990-95	-13.4%	0.2%	1.7%	2.6%	3.8%	-0.5%	-0.2%
	1995-99	-28.5%	-6.3%	0.6%	1.6%	-0.7%	-3.9%	-2.1%
	1995-01	-25.7%	-5.5%	0.8%	1.9%	-0.3%	-2.4%	-1.8%
Italy	1990-95	-9.4%	4.2%	2.8%	5.3%	4.5%	3.5%	4.0%
	1995-99	-26.6%	-4.4%	1.6%	2.6%	2.1%	-2.0%	2.2%
	1995-01	-24.2%	-4.0%	1.5%	2.2%	2.4%	-0.9%	1.6%
Japan	1990-95	-15.7%	-2.2%	0.1%	-0.6%	1.2%	-2.9%	0.4%
	1995-99	-28.6%	-6.4%	-0.9%	-0.4%	-0.2%	-4.0%	2.3%
	1995-00	-28.4%	-6.7%	-1.2%	-0.7%	-0.2%	-3.9%	1.4%
United Kingdom	1990-95	-15.3%	-1.7%	2.9%	3.3%	-2.5%	-2.4%	3.4%
	1995-99	-28.1%	-5.9%	-2.8%	1.5%	3.7%	-3.5%	3.2%
	1995-00	-27.3%	-5.6%	-2.0%	1.4%	3.5%	-2.8%	3.3%
United States	1990-95	-14.6%	-1.5%	3.5%	2.5%	2.5%	-1.4%	2.7%
	1995-99	-27.6%	-2.9%	3.4%	0.5%	3.0%	-1.5%	2.2%
	1995-01	-24.1%	-3.0%	2.8%	0.4%	3.4%	-0.5%	2.0%

Source: OECD capital services data base (Oct 2003)

A first way of assessing the set of capital services measures produced here is to compare them with similar data published at the national level. Today, this possibility for comparison exists only for a very few countries. Those are Australia (ABS publishes capital services data as part of its annual national accounts), the United States (capital services series are published by the Bureau of Labor Statistics as part of its multifactor productivity measurement programme) and the United Kingdom where work is underway at ONS and where a first set of capital services data has been published at the Bank of England (Oulton 2001). Statistics Canada has also compiled a set of capital services measures (Harchaoui and Tarkhani 2002) and work is underway in Spain (Mas et al. 2002).

A first comparison of our results for Australia and those published by the Australian Bureau of Statistics[7] reveals two points. First, the time profile of the OECD series follows that of the ABS series fairly closely. At the same time, and this is the second observation, there appears to be a systematic downward bias (5.1 versus 3.7 percent per year between 1980 and 1999) of our measures with regard to the official statistics. This is, however, due to the fact that the ABS series relates to the business sector whereas our results concern the entire economy. When only private sector data are used in the OECD model, a capital service measure with similar rates of change to those of the official ABS time series is found. Other small sources of differences in methodology persist (e.g., ABS chooses an endogenous rate of net return to capital, the OECD series is based on an exogenous rate, ABS equates actual and expected price changes in their user cost computations, OECD uses moving averages for price expectations etc.). Overall, however, the series fit closely when they relate to the same sector aggregate.

A second comparison relates to our capital services measures and those of the Bureau of Labor Statistics. Over the entire period 1981-2000, U.S. capital input grew by 3.8% per year according to BLS, and by 3.7% according to OECD estimates. This small difference over the entire period hides more significant differences over sub-periods that tend to offset on average. The OECD capital services series tend to show a smoother profile than the official BLS results. Partly, this may be explained by the fact that the BLS series relates to the private sector whereas OECD data covers the entire economy.

7 . Series 5402.0 *Australian System of National Accounts*.

The third comparison relates to the United Kingdom. Of the four comparisons, this is clearly the case where differences are largest. However, a good deal of the discrepancy between OECD measures and Oulton (2001) can be traced back to the fact that Oulton's estimates are based on United States price indices for ICT equipment goods, adjusted for exchange rate effects. Such exchange rate effects can be sizeable and have been discussed at greater length in Schreyer (2002). The OECD series here uses harmonised deflators: they are thus also based on U.S data but not exchange rate adjusted. This adjustment for exchange rate movements between the Pound and the US dollars introduced larger amplitude to the resulting volume series. Again, this comparison points to the crucial importance of the choice of price indices in producing capital services and capital stock data. Work is also underway in the U.K. Office of National Statistics to produce and release a series of capital services measures.

The fourth comparison concerns Canada. On the face of it, the capital services series released by Statistics Canada feature a profile that is significantly different from the one obtained by OECD. However, several important methodological differences account for such discrepancy: first, the OECD series relate to the economy as a whole whereas Statistics Canada's data covers the private sector. Secondly, the Canadian series are based on a geometric age-efficiency profile whereas OECD employs a hyperbolic pattern. Third, Canada's user cost measures are based on an endogenous rate of return, those computed by OECD on an exogenous rate. Fourth, there are significant differences in the service lives employed – in particular buildings and construction assets' service lives are significantly shorter in the official series than in those computed by OECD. A more detailed analysis can be found in Annex 2 where it is also shown that after correction for the methodological differences, the OECD model tracks the official data quite closely: over the period 1982-01, Statistics Canada evaluates capital services growth at 3.2 percent per year. The corresponding and comparable OECD result is at 3.3 percent.

The Canadian case clearly shows the trade-off between using symmetric and reproducible assumptions for all countries at the international level and thereby improving international comparability while foregoing potentially more accurate information for individual countries (such as service lives for Canadian assets). There is no short-term solution to this trade-off except careful documentation and explanation of differences in the release of data.

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ANNEX 1: ADDITIONAL METHODOLOGICAL REMARKS

Asset types. The estimation of capital service flows starts with identifying *R* different assets – for present purposes, these correspond to the asset breakdown current available from the OECD/Eurostat National Accounts questionnaire, augmented by information on information and communication technology assets where available. Only non-residential gross fixed capital formation is considered, and in particular, seven types of assets or products:

Type of product/asset	Collected in OECD/Eurostat questionnaire
Products of agriculture, metal products and machinery	Yes
Of which:	
IT Hardware	No
Communications equipment	No
Other	No
Transport equipment	Yes
Non-residential construction	Yes
Other products	Yes
Of which:	
Software	No
Other	No

Investment series. For each type of asset, a time series of current-price investment expenditure and a time series of corresponding price indices is established, starting with the year 1960. For many countries, this involves a certain amount of estimates, in particular for the period 1960-80. Such estimates are typically based on national accounts data prior to the introduction of SNA93, or on relationships between different types of assets that are established for recent periods and projected backwards. For purposes of exposition of the methodology, call current price investment series for asset type *i* in year t IN_t^i (i=1,2,..7*)* and the corresponding price index q_t^i. Price indices are normalised to the reference year 1995 where $q_t^i=1$.

Productive capital stocks for each asset type. For each of the (supposedly) homogenous asset types, a productive stock S_t^i is constructed following equation (6):

$$S_t^i = \sum_{\tau=0}^{Ti}[IN_{t-\tau}^i/q_{t-\tau,0}^i]h_\tau^i F_\tau^i \qquad \text{(A1)}$$

In this expression, the productive stock of asset *i* at the beginning of period *t* is the sum over all past investments in this asset, where current price investment in past periods, $IN_{t-\tau}^i$ is deflated with the purchase price index of new capital goods, $q_{t—\tau,0}^i$. Ti represents the maximum service life of asset type *i*.

Because past vintages of capital goods are less efficient than new ones, an *age efficiency function* h_τ^i has been applied. It describes the efficiency time profile of an asset, conditional on its survival and is defined as a hyperbolic[8] function of the form used by the United States Bureau of Labor Statistics (BLS 1983):

$$h_\tau^i=(T-\tau)/(T-\beta\tau).$$

Furthermore, capital goods of the same type purchased in the same year do not generally retire at the same moment. More likely, there is a retirement distribution around a mean service life. In the present calculations, a normal distribution with a standard deviation of 25% of the average service life is chosen to represent probability of retirement. The distribution was truncated at an assumed maximum service life of 1.5 time the average service life. The parameter F_τ^i is the cumulative value of this distribution, describing the probability of survival over the cohort's life span. The following average service lives are assumed for the different assets: 7 years for IT equipment, 15 years for communications equipment, other equipment and transport equipment, 60 years for non-residential structures, 3 years for software and 7 years for remaining other products. The parameter β in the age-efficiency function was set to 0.8.

Net rate of return. The present work uses a constant value rr for the expected real interest rate rr. The constant real rate is computed by taking a series of annual observed nominal rates (un-weighted average of interest rate with different maturities) and deflating them by the consumer price index. The resulting series of real interest rates is average over the period (1980-2000) to yield a constant value for rr. The expected nominal interest rate for every year is then computed as $r_t = rr(1+p_t)-1$ where p is the expected value of an overall deflator, the consumer price index..

To obtain a measure for p, the expected overall inflation, we construct a 5-year centred moving average of the rate of change of the consumer price index $MACPI_t = \sum_{s=1}^{5} CPI_{t-s}$ where CPI_t is the annual percentage change of the consumer price index. This yields the expected rate of overall price change and, by implication, the nominal net rate of return.

Rate of depreciation. The next variable to measure in the user cost of a new asset is the rate of depreciation. It is defined as the ratio of the purchase price of a one-year old asset over that of a new asset: $d_{t,0}=1-(q_{t,1}^i/q_{t,0}^i)$. To compute this ratio, as outlined in expression (16), one first needs to define the expected rate of change of nominal user costs, ξ^i, defined as $u_{t+\tau,0}^i=u_{t,0}^i(1+\xi^i)^\tau$. Empirically, ξ^i is measured as a 5-year centred moving average of rates of asset price change in the five years prior to t.

With the results for the expected asset price change and for the net rate of return, one gets an expression for $(1+r)/(1+\xi^i)$. Together with the age-efficiency profile, this is all that is needed to evaluate expression (18).

8. This is but one possible functional form of the age-efficiency profile. Often, a geometric form is chosen. For a discussion, see OECD (2001a,b).

ANNEX 2: DIFFERENCES BETWEEN CAPITAL SERVICES ESTIMATES BY STATISTICS CANADA AND BY THE OECD STATISTICS DIRECTORATE

The comparison of the OECD results for capital services for Canada and those produced by Statistics Canada reveals significant differences over the entire period 1982-2001 (Figure A1). Canadian capital services estimates grew by 3.3% per year according to Statistics Canada and by 5.3% according to OECD estimates. However, methodology and scope for the two series are different, and inhibit direct comparison. The present note aims at explaining and quantifying the sources of discrepancy.

Overall effect

There are four main differences between the capital series computed by Statistics Canada and OECD (Table A1): the sector coverage, the age-efficiency (or depreciation) profile, the average length of service lives of certain assets and the measurement of the nominal rate of return[9]. When the OECD estimate is modified so as to emulate as closely as possible the methodological choices made by Statistics Canada, a new series results, also shown in Figure A1. As it turns out, the profile of these 'OECD modified estimates' is very similar to those from Statistics Canada. The main remaining difference concerns the early 1980s and in all probability reflects weak source data used by OECD for its estimates[10].

The cumulative effect of the modification of all these four assumptions is an average decrease of 1.89 percentage points per year over the period 1982-2001. Thus, the modified OECD series features capital services growth of 3.4 percent per year as compared with 3.3 percent of Statistics Canada's series.

De-composition of overall effect

In addition to assessing the combined effect of modifying the capital services methodology it is of interest to quantify the relative importance of individual effects, for example moving from a hyperbolic to a geometric age-efficiency profile. This raises an interesting methodological issue – that of choosing the order in which to evaluate partial effects. To stick with the above example, the effect of changing between age-efficiency profiles may be different when one set of service lives is used as opposed to another set. In other words, the partial effects of changing parameters one-by-one is in general path-dependent, i.e., depends on the order by which effects are computed. Theory has little to recommend about a preferred ordering. One way to deal with this situation is to compute all possible paths and then average across partial effects. In the present case, with 4 sets of parameters to vary, there are 8 different paths, and assessing them all would have meant significant additional time spent on computations. The present simulations are therefore based on two of these paths only, and are reported in the tables 2 and 3 below.

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9 The capital services estimates published by Statistics Canada includes land and inventories but Statistics Canada provides OECD Statistics Directorate with results excluding land and inventories and as a consequence, the comparison is limited to the other assumptions.

10 A good deal of the investment series for the period 1960-81 broken down by asset type that flow into capital services measures had to be estimated by OECD in the absence of available official series.

Figure A1: Capital services

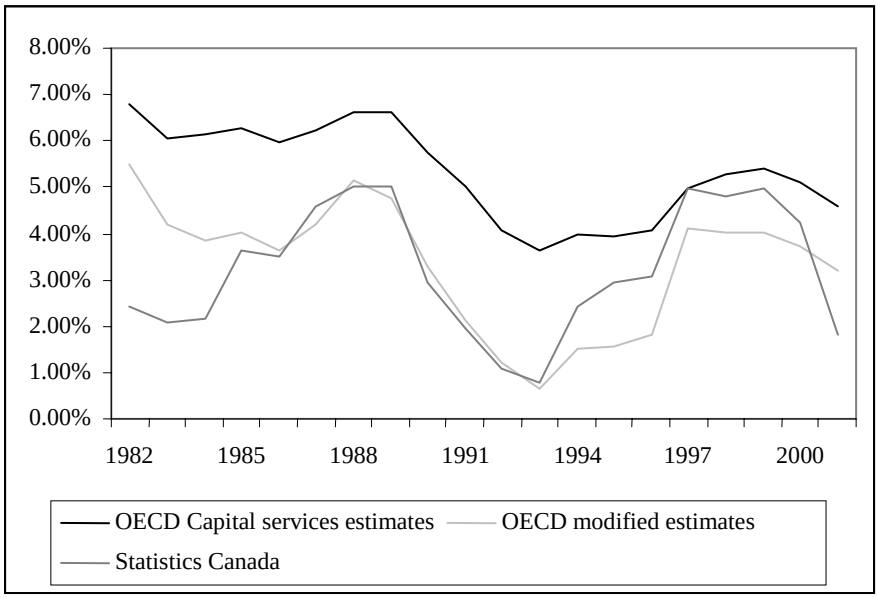

Table A1. Methodological choices

	OECD assumptions	OECD modified assumptions	Statistics Canada
Sector coverage	Total economy	Business sector	Business sector
Age-efficiency profile	Hyperbolic	Geometric	Geometric
Average service life[11] (years): • Transport equipment • Non residential buildings	 15 60	 7 30	 7 30
Measurement of the nominal rate of return	Exogenous	Endogenous	Endogenous

The first path (Table A2) is defined by the following consecutive modifications: Sector (business sector instead of total economy) – Measurement of the rate of return (endogenous instead of exogenous) – Age efficiency profile (geometric instead of hyperbolic) – Average service life (from 15 years to 7 for transport equipment and from 60 years to 30 for non residential buildings). The size of the effects of each modification given a certain constellation of other parameters is shown in Tables A2 and A3. For example, moving from OECD's assumptions on service lives to those used by Statistics Canada (the 'age effect') reduces the measured capital service growth by 0.16 percentage points over the period 1985-01 (Table A2), whereas the age effect turns out to be 0.05 percentage points in Table A3.

[11] OECD service life assumptions reflect current practices in OECD countries. The service life data for Canada refers to the tables 2.4 and 2.5 in GELLATLY Guy, Marc TANGUAY and Beiling YAN (2003) "An Alternative Methodology for Estimating Economic Depreciation: New Results Using a Survival Model"; *Productivity Growth in Canada – 2002*, Statistics Canada.

Table A2. Simple effects of the following successive modifications of assumptions on the capital services estimates: Sector – Rate – Profile – Age

Path 1	**Sector effect**			**Rate effect**		**Profile effect**		**Age effect**	
Sector	Total economy	**Business sector**	**Sector effect**	Business sector	**Rate effect**	Business sector	**Profile effect**	Business sector	**Age effect**
Age-efficiency profile	hyperbolic	hyperbolic		Hyperbolic		**geometric**		Geometric	
Average service life	OECD estimates	OECD estimates		OECD estimates		OECD estimates		**Statistics Canada estimates**	
Measurement of the Rate of return	exogenous	exogenous		**Endogenous**		endogenous		Endogenous	
1980-85	6.80%	6.69%	-0.11	6.26%	-0.42	5.21%	-1.05	5.41%	0.20
1985-90	6.24%	6.32%	0.09	5.42%	-0.90	4.35%	-1.07	4.20%	-0.15
1990-95	4.12%	3.79%	-0.34	3.39%	-0.39	2.13%	-1.26	1.41%	-0.72
1995-01	4.89%	4.76%	-0.13	3.91%	-0.85	3.44%	-0.47	3.49%	0.05
1980-01	5.51%	5.39%	-0.12	4.75%	-0.64	3.78%	-0.96	3.63%	-0.16

It is apparent from this table that each modification of assumptions generates a decrease of the capital services estimates over the entire period. Also, for the period as whole, the effect of the change in profiles is the most important one. For sub-periods (e.g. 1995-01) this is not necessarily the case.

An alternative path led to consider the following successive modifications: Sector – Measurement of the rate of return – Average service life - Age efficiency profile, where the two last modifications of assumptions are inverted compared to the first path (Table A3).

Table A3. Simple effects of the following successive modifications of assumptions on the capital services estimates: Sector – Rate- Age – Profile

Path 2	**Sector effect**			**Rate effect**		**Age effect**		**Profile effect**	
Sector	Total economy	**Business sector**	**Sector effect**	Business sector	**Rate effect**	Business sector	**Age effect**	Business sector	**Profile effect**
Age-efficiency profile	hyperbolic	Hyperbolic		Hyperbolic		hyperbolic		**geometric**	
Average service life	OECD estimates	OECD estimates		OECD estimates		**Statistics Canada estimates**		Statistics Canada estimates	
Measurement of the Rate of return	exogenous	Exogenous		**Endogenous**		endogenous		endogenous	
1980-85	6.80%	6.69%	-0.11	6.26%	-0.42	6.88%	0.62	5.41%	-1.47
1985-90	6.24%	6.32%	0.09	5.42%	-0.90	5.48%	0.05	4.20%	-1.28
1990-95	4.12%	3.79%	-0.34	3.39%	-0.39	2.80%	-0.59	1.41%	-1.39
1995-01	4.89%	4.76%	-0.13	3.91%	-0.85	3.63%	-0.28	3.49%	-0.14
Average	5.51%	5.39%	-0.12	4.75%	-0.64	4.70%	-0.05	3.63%	-1.07

It is again apparent that the impact of the profile effect is more important than those of other assumptions. However, this effect is more important for the second path (Table A3) than for the first one. Secondly, the hierarchy of the simple effects is different between the two paths: for the first one, the age effect is more important than the sector effect while in the second one the situation between these two effects is inverted. To approximate the average impact of each modification we calculate an arithmetic average of the single

effects for the two paths described above12: sector effect: -0.12 percentage points per year; rate effect: -0.64, age effect: -0.11; and profile effect: -1.02. The profile assumption has the most important effect, the rate effect is important and the age and sector effect are less significant. However, as could be seen above, only both assumptions together can explain the differences in the results from Statistics Canada and from the OECD.

Three principal conclusions arose from this analysis:

- First, the implementation of alternative methodological assumptions permits to explain the differences between the capital services estimates from Statistics Canada and from the OECD Statistics Directorate.

- Second, the definition of different paths can be useful to evaluate the partial effects of each modification in the methodological assumptions. The order of these changes influences the distribution of the partial effects even the global sensitivity of productivity estimates remains the same.

- Third all the modifications of methodological modifications have a negative effect on the capital services estimates. The age–efficiency profile (hyperbolic or geometric) has the most important impact. However, the differences between estimates from Statistics Canada and those from the OECD can only be explain by a combination of options.

[12] This approximation should be more accurate with a larger number of paths considered.