CAPITAL STOCKS, CAPITAL SERVICES AND MULTI-FACTOR PRODUCTIVITY MEASURES

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INTRODUCTION

Measures of productivity are central to the assessment of economic growth. 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 stock. 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] The OECD has thus developed a set of capital service measures for a broader number of countries. This paper provides an overview of the concepts and methods underlying capital services measures, reports results for the G-7 countries and discusses some of the consequences for measured rates of multi-factor productivity growth.

CAPITAL SERVICES – CONCEPTUAL FRAMEWORK

Capital services measures are based on the economic theory of production. The concept relates back to the work of Jorgenson and Griliches (1967) with further developments mainly in the productivity literature such as 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. 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 productivity analysis.[2]

Production function

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.

Capital services are an integral part of a durable goods model of production, itself characterised by a production function, say G that is separable in the services of different vintages of different types of capital goods:

$$Q_t = G(K_t[K_t^1, K_t^2, ..., K_t^N], L_t, t) \qquad [1]$$

In (1), $K_t[K_t^1, K_t^2, ..., K_t^N]$ is an aggregator of capital services from N different types of assets, Q_t is an aggregate measure of the volume of output, and L_t are labour inputs in the production process. The capital service measure for each type of asset – say a particular type of machine or building – is itself an aggregator across different vintages of this asset: $K_t^i = K_t^i[K_{t,0}^i, K_{t,1}^i, ... K_{t,T}^i]$ where $K_{t,\tau}^i$ is the capital service flow at time t from a τ-year old asset of type i. The assumed separability of K_t from other elements in the production function implies that the marginal rate of substitution between any pair of vintages of a particular type of asset is independent of other inputs. This is important insofar as it allows constructing the capital services measure from the "bottom up" and independently of other inputs in the production process. The purpose of the empirical work presented here is therefore to measure capital services aggregates for each asset and to derive a total aggregate of capital services, notably for its rate of change, K_t / K_{t-1}.

Even though there is little new about (1), there are important differences to more common representations of capital in the production process. Many textbooks and empirical work start from a production function $G(K_t^G, L_t, t)$ where K_t^G is the gross (or sometimes the net) *stock* of "capital". This presents in fact a special case of (1) – when there is only one homogenous type of asset or in the absence of any substitution possibilities between different types of assets. The rate of change of K_t^G would then equal the rate of change of capital services, K_t. In the more general context discussed here, the respective rates of change will be different between these measures, causing potential biases in production and productivity analysis if measures of gross or net stocks are used instead of capital services.

Productive stock and capital services with geometric profiles

For expositional purposes, and to relate the capital services approach to other capital measures, a simplifying but widely-used assumption will be made here, namely that of geometric age-efficiency and age-price profiles. An age-efficiency profile describes how the productive efficiency of an otherwise homogenous asset evolves as the asset ages. An age-price profile describes the relative price of different vintages of the same asset at a given point in time. The geometric age-price profile postulates that the efficiency of asset type i declines at a constant rate, say δ^i. Let I^i_{t-1} be the quantity of investment in new assets of type i in year t – 1. Then, $(1-\delta^i)I^i_{t-1}$ will be the volume that remains productively efficient in year t. More generally, the productive stock of asset i at time t is given by:

$$S^i_t = \sum_{\tau=0}^{\infty}(1-\delta^i)^{\tau} I^i_{t-\tau} \qquad [2]$$

Implicit in the additive presentation of the productive stock is an assumption about the perfect substitutability between different vintages.[3] Thus, the productive stock is expressed in "new equivalent" units of the capital good i. It is further assumed that the flow of capital services K^i_t is proportional to the productive stock at the end of the previous period:

$$K^i_t = \lambda^i S^i_{t-1} \qquad [3]$$

With little loss of generality, the proportionality factor λ is set to unity for all asset types.[4] The next issue is to consider the price of renting one unit of the productive stock for one period. If there were complete markets for capital services, rental prices could be directly observed. In the case of the office building, rental prices exist and are observable in 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" that is used synonymously with "rental price" in this paper.[5] To determine the rental price, we use the hypothesis that in a functioning asset market, the purchase price of a capital good equals the discounted value of its expected rentals (Box 1). The rental price/user cost for a new asset at time t turns out to be $uc^i_{t,0} = q^i_{t-1,0}\left(r+\delta^i-\zeta^i_t\right)$.

The term in brackets constitutes the gross rate of return that one dollar invested in the purchase of capital good i must yield in a competitive market. The gross rate of return itself comprises three terms:

- A rate of depreciation δ^i: depreciation is the loss in market value of a capital good due to ageing. In the general case, depreciation may vary over time and depend on the vintage. In the present case of geometrically declining efficiency, the price turns out to decline at the same geometric rate. This facilitates computations significantly and implies that the price ratio of a one-year

Box 1. **Deriving the user costs of capital**

In a fully functioning asset market, the purchase price of an asset will equal the discounted flow of the value of services that the asset is expected to generate in the future. This equilibrium condition is used to derive the rental price or user cost expression for assets. Let $q_{t,0}^i$ denote the purchase price in year t of a new (zero-year old) asset of type i, and let $u_{t+\tau,\tau}^i$ be the rental price that this asset is expected to fetch τ periods later (first subscript to the right) when the asset will be of age τ (second subscript to the right). With r as the nominal discount rate valid at time t, the asset market equilibrium condition for a new asset (age zero) becomes:

$$q_{t,0}^i = \sum_{\tau=0}^{\infty} u_{t+\tau+1,\tau}^i (1+r)^{-(\tau+1)}$$

This formulation implies that rentals are paid at the end of each period. To solve this expression for the rental price, the price for a one year old asset in the period t + 1 is computed as $q_{t+1,1}^i = \sum_{\tau=0}^{\infty} u_{t+\tau+2,\tau+1}^i (1+r)^{-(\tau+1)}$ and then subtracted from the expression above to obtain $u_{t+1,0}^i = q_{t,0}^i(1+r) - q_{t+1,1}^i$ or $u_{t,0}^i = q_{t-1,0}^i(1+r) - q_{t,1}^i$ which can be transformed into $u_{t,0}^i = q_{t-1,0}^i \left(r + \delta^i - \zeta_t^i + \delta^i\zeta_t^i \right)$. As in the main text, the shorthand notation for depreciation, δ^i, and for asset price changes, ζ_t^i, are used. The result is the user cost expression shown in the text although the interaction term $\delta^i\zeta_t^i$ that arises in a discrete time formulation has been left out there for expositional simplicity. Jorgenson and Yun (2001) show how tax considerations enter the user cost of capital and how they affect measured economic performance. Due to a lack of available data, such fiscal parameters could at present not be considered in the OECD set of user costs and capital measures.

old asset over a new asset is constant and equal to the price ratio of an s-year old asset of an s+1-year old asset: $\frac{q_{t,s}^i}{q_{t,k}^i} = (1-\delta^i)^{s-k}$ where s and k are any two points in the service life of asset i.
- A revaluation or capital gains term ζ_t^i, defined as the expected asset price change between the beginning and the end of the period: $\zeta_t^i \equiv q_{t,0}^i / q_{t-1,0}^i - 1$. Because the revaluation term enters into the user cost expression with a negative sign, a fall in asset prices raises user costs. For example, rental prices for personal computers have to factor in the fall in market prices and the ensuing loss in value of the computers that are in use.
- A net rate of return r – the expected remaining remuneration for the capital owner once depreciation and asset price changes have been taken into

account. The choice of r is a matter of importance: the value of the user cost term determines the value of capital services of asset i as well as the overall remuneration of capital. One way to choose r is by setting it so that the re-sulting value of capital services exactly exhausts the value of non-labour in-come (gross operating surplus) that is computed in the national accounts. While computationally convenient, this procedure requires additional re-strictive assumptions. Another possibility is to choose an external net rate of return. While no extra assumptions are needed here, the resulting value of capital services does not necessarily add up to gross operating surplus and this complicates growth accounting exercises. Also, a choice has to be made as to the exact measurement of the exogenous rate. Despite this complica-tion, the exogenous approach has been put forward as the preferred one in the present exercise.

As the price of capital services is given by the user cost of capital, the product of this price and the quantity of services yields the value of capital services for asset type i: $uc_{t,0}^i K_t^i = uc_{t,0}^i S_{t-1}^i$. By aggregating across all asset types, one obtains the overall value of capital services $uc_t K_t = \sum_i uc_{t,0}^i K_t^i$.

Jorgenson (1963) and Jorgenson and Griliches (1967) were the first to develop these 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 cost shares as weights to aggregate across services from the different types of assets. Because user costs shares reflect the relative marginal productivity of the different assets, these weights provide a means to effectively incorporate differences in the productive contribution of heterogeneous investments into the overall measure of capital input. A customary and theoretically recommended index number formula to construct a volume index of capital services is the Törnqvist index that applies average user cost weights to each asset's rate of change in capital services:

$$\ln(K_{t+1}/K_t) = \sum_i 0.5(v_{t+1}^i + v_t^i)\ln(K_{t+1}^i/K_t^i)$$

where:

$$v_t^i \equiv \frac{uc_t^i K_t^i}{\sum_i uc_t^i K_t^i} \qquad [4]$$

Net (wealth) stock

It is instructive to compare the volume index of capital services and the total value of capital services with the more familiar net capital stock and its rate of change at current and constant prices.[6] 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. "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 a stock "net" of efficiency declines in productive assets. In the present setting, the net stock at current prices is obtained by valuing each asset's productive stock by the market price of the corresponding new asset. The total value of the net stock is obtained by adding the individual values of each asset: $q_t W_t = \sum_i q_t^i S_{t-1}^i = \sum_i q_t^i K_t^i$.

The rate of change of the net stock at constant prices depends again on the index number formula chosen for aggregation across assets. One obvious possibility is to employ again a Törnqvist-type formula to obtain:

$$\ln(W_{t+1}/W_t) = \sum_i 0.5(w_{t+1}^i + w_t^i)\ln(W_{t+1}^i/W_t^i)$$

where

$$w_t^i \equiv \frac{q_{t,0}^i K_t^i}{\sum_i q_{t,0}^i K_t^i} \tag{5}$$

Because the net stock is a concept that is well anchored in the system of national accounts, most OECD countries publish data for a net stock of fixed assets. However, these series are not normally aggregated through Törnqvist indices: the majority of countries use a Laspeyres-type volume index[7] which introduces an additional difference between measures of capital stocks available from the national accounts and measures of capital services for productivity analysis.

To conclude, there are two key features that distinguish the rate of change of the capital services measure from that of the net capital stock: the weighting scheme and in many cases the index number formula used. In periods of rapid change of relative prices and volumes both elements contribute to potentially significant differences between the time profiles of the two measures. Usage of the net stock in productivity computations instead of the capital services measure can then give rise to a biased statistic of multi-factor productivity. To illustrate, Figure 1 below compares the two measures for the United States and for France and Box 2 provides a numerical example.

Productive stock and capital services with hyperbolic profiles

The use of geometric patterns to describe the efficiency and price profiles of assets is computationally convenient. Also, there is empirical evidence for price profiles that resemble geometric patterns. Everyday experience suggests that the prices of assets decline by relatively large absolute amounts in the first years after their purchase – a 20 per cent drop in the value of a new car during its first year of

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Figure 1. **Capital services and net capital stock[1]**
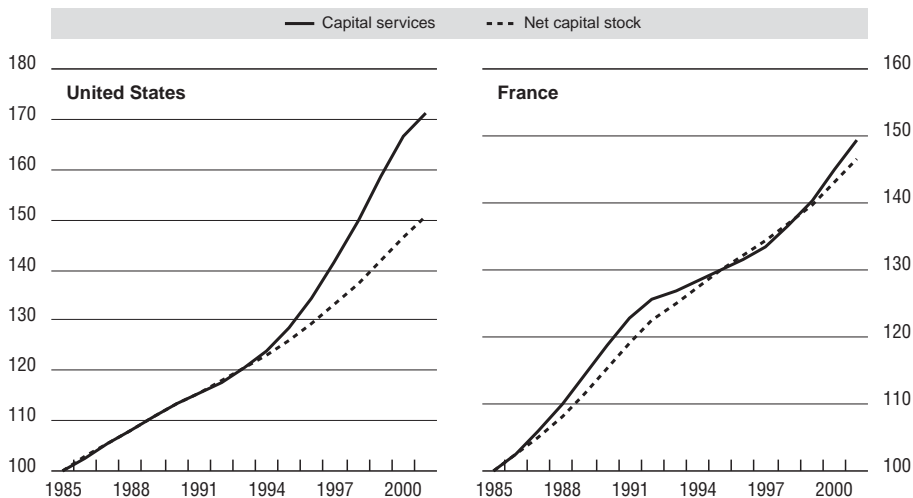
1. Based on geometric age-efficiency and age-price profile and "harmonised" ICT deflators. Aggregation through Törnqvist indices.
Source: Derived from OECD Capital Services Database (October 2003).

usage is a well-know empirical phenomenon. However, is the same pattern plausible when it comes to describing the relative efficiency of a vintage product? For example, does a car loose one fifth of its capacity to generate transport services during its first year of usage? Based on a single capital item, the answer to this question will often be "no" and this suggests adopting an approach that allows for differences in the efficiency and in the price profiles of assets while keeping the two profilesconsistent.

The OECD capital services measure is based on a hyperbolic pattern for its efficiency profile and derives a consistent price profile. A hyperbolic pattern assumes a slow loss in productive efficiency over the first years of an asset's service life and a more rapid decline towards the end of the service life. This is shown in Figure 2. It reproduces the age-efficiency profile for transport equipment – an asset whose average service life is taken to be 15 years. Neither the hyperbolic nor the geometric pattern breaks off at the 15 years. In the case of the hyperbolic curve, an assumption has been made that retirement of a cohort is distributed around the median service life of 15 years. In the case of the geometric pattern, no explicit retirement function is formulated. It is assumed that the geometric decline captures both the effects of wear and tear and retirement.

Box 2. **Wealth stock 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 of asset compared with 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 reflect the marginal productivity of assets: capital goods are employed until their marginal revenue (itself dependent on marginal productivity) equals marginal cost (the user cost or rental price) of an asset. The difference between purchase prices (q) and user costs (uc) is the gross rate of return (GRR) that an asset must yield per year: 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 per cent in the case of A and rises by 10 per cent 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 per cent. 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 per cent and a share of Asset B of 21 per cent – quite different from the 50 per cent 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

Figure 2. **Hyperbolic and geometric age-efficiency pattern**
Average service life 15 years
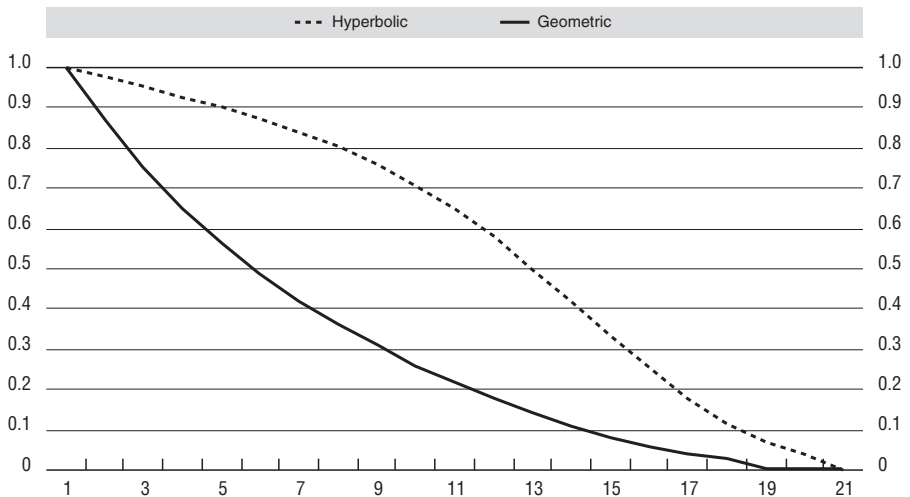
Capital services measures are sensitive to the choice of the age-efficiency profile. For example, capital services measures based on geometric age-efficiency profiles rise by 1.5 per cent per year on average in Australia over the period 1985-01. The same variable based on hyperbolic profiles grows at 2.2 per cent per year. Similarly, the geometrically-based series for the United States exhibits a 3.4 per cent growth rate over the same period whereas the hyperbolic pattern produces a growth rate close to 4 per cent. In France, the figures are 2.5 per cent per year (geometric) and 3.1 per cent per year (hyperbolic).

CAPITAL SERVICES – RESULTS

The following section presents a set of capital service measures for the G-7 countries and Australia. The results presented are based on a more general model than the one set out in the second section of this paper. In particular, efficiency profiles were not assumed to be geometric. Results based on geometric profiles are also available from the database but as a special case. To start out, Table 1 shows the volume changes of capital services, by type of asset or by type of product. 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

Table 1. **Volume growth of capital services by type of asset**[1]

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

			Products of agriculture metal products and machinery			Transport equip-ment	Non-residential construc-tion	Other products	
		Total	Hardware	Communi-cation equip-ment	Other			Software	Other
					Percentages				
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	25.3	3.4	1.0	2.0	1.8	9.4	7.2
	1995-99	2.5	28.6	4.0	1.1	2.3	1.7	9.3	7.6
	1995-01	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
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

1. Using a hyperbolic age-efficiency profile.
Source: OECD capital services data base (October 2003).

capital services where nominal shares in total user costs constitute the relevant weights.

Rates of change of deflators can be found in Table 3. 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 3).

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 few countries. These are Australia (ABS publishes capital services data as part of its annual national accounts), the United

Table 2. **Volume index of capital services (all assets)**[1]

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

1. Using a hyperbolic age-efficiency profile.
Source: OECD capital services data base (October 2003).

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[8] 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 per cent per year between 1980 and 1999) of the OECD 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

Table 3. **Price indices of capital goods by type of asset**[1]
Compound annual percentage changes, total economy, based on "harmonised' ICT deflators

		Products of agriculture, metal products and machinery			Transport equipment	Non-residential construction	Other products	
		Hardware	Communi-cation Equipment	Other			Software	Other
					Percentages			
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

1. Using a hyperbolic age-efficiency profile.
Source: OECD capital services data base (October 2003).

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 the OECD capital services measures and those the Bureau of Labor Statistics. Over the entire period 1981-2000, US capital input grew by 3.8 per cent per year according to BLS, and by 3.7 per cent 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

Box 3. **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 investment goods. For example, 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, 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 available from the capital services database.

There is a difficulty with the harmonised deflator that should be noted. 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 small (see Schreyer, 2001 for a discussion).

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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.

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 US 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 US data but not exchange rate adjusted. This adjustment for exchange rate movements between the UK pound and the US dollar introduces larger fluctuations in the resulting volume series. This comparison thus points to the crucial importance of price indices in producing capital services and capital stock data. Work is currently underway in the UK 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 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 Schreyer *et al.* (2003) who show that after correction for the methodological differences, the OECD model tracks the official data quite closely: over the period 1982-01, Statistics Canada shows growth of capital services at 3.2 per cent per year. The corresponding and comparable OECD result is at 3.3 per cent annual growth.

The Canadian case clearly shows the trade-off between using symmetric and reproducible assumptions for all countries at the international level, which helps to improve international comparability and the 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.

CAPITAL SERVICES AND MFP MEASURES

The most important usage of capital services measures is to assess multi-factor productivity (MFP) growth. It is, therefore, of interest to examine how the use of capital services series instead of net capital stock measures impacts on the MFP residual. A complete empirical analysis would exceed the scope of this paper[9] but results will be presented for three countries by way of illustration.

To derive an MFP measure,[10] assume that the production function (1) has the form: $Q_t = a_t F(K_t[K_t^1, K_t^2, ..., K_t^N], L_t)$ where a_t is a technology parameter that shifts the production function over time. Diewert (1976) showed that if the input aggregator function F has a translog form, and when producers are profit maximising, the rate of technical change between periods t + 1 and t is given by the ratio of a volume index of output and a Törnqvist index of aggregate inputs. In logarithmic form this yields:

$$\ln\left(\frac{a_{t+1}}{a_t}\right) = \ln\left(\frac{Q_{t+1}}{Q_t}\right) - \sum_{i=1}^{N} \tfrac{1}{2}\left(v_{t+1}^{Ki} + v_t^{Ki}\right)\ln\left(\frac{K_{t+1}^i}{K_t^i}\right) + \tfrac{1}{2}\left(v_{t+1}^L + v_t^L\right)\ln\left(\frac{L_{t+1}}{L_t}\right) \qquad [6]$$

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where $v_t^{Ki} \equiv \dfrac{uc_t^i K_t^i}{\sum_{i=1}^{N} uc_t^i K_t^i + w_t L_t}$, and $v_t^{L} \equiv \dfrac{w_t L_t}{\sum_{i=1}^{N} uc_t^i K_t^i + w_t L_t}$ are each input's share in total cost.

To assess the importance of choosing capital services measures over measures of gross or net capital stock, we compute (5) in its current configuration and with a net capital stock measure. For the countries and periods under consideration, the capital services measure rises more rapidly than the net stock measure (Table 4). This reflects the compositional change in the productive capital stock where rapidly-growing asset types such as ICT equipment receive larger weights than in the net stock measure. This effect is particularly visible for the United States and Australia (Table 4). Consequently, the MFP residual is lower in the first case than in the second. Put differently, using the net capital stock as a measure of capital input would lead to over-estimating MFP growth and under-estimating the contribution of capital assets to economic growth.

Table 4. **MFP growth, total economy**
Percentage change at annual rates

		Australia	United States	France
Output	1984-90	3.2	3.3	2.9
	1990-95	3.2	2.4	1.1
	1995-01	3.8	3.4	2.5
Capital services[1]	1984-90	2.0	2.7	3.3
	1990-95	0.6	2.5	1.8
	1995-01	1.8	4.8	2.3
Net capital stock[1]	1984-90	1.7	1.8	2.1
	1990-95	0.4	1.5	1.5
	1995-01	0.6	2.4	1.3
MFP based on capital services	1984-90	0.9	1.0	1.9
	1990-95	2.2	0.8	1.0
	1995-01	2.2	1.1	1.4
MFP based on net capital stock	1984-90	1.0	1.2	2.2
	1990-95	2.3	1.1	1.1
	1995-01	2.6	1.7	1.7

1. Based on geometric age-efficiency and age-price profile and "harmonised" ICT deflators. Aggregation through Törnqvist indices.
Source: Derived from OECD Capital Services and Productivity Databases (October 2003).

CONCLUSIONS

The following conclusions have emerged from the work on capital services:

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 consistently derived from the same model.

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 return 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 services measurement.

The present calculations raise questions about the level of detail at which OECD member countries publish investment data. In particular, there is a question about the level of asset detail that is available. 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.

Certain open questions also remain: they are both of a conceptual nature (*e.g.* the treatment of obsolescence, exogenous and endogenous rates of return) 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.

NOTES

1. This is the case for Australia (ABS), the United States (BLS) and Canada (Statistics Canada). Results are forthcoming for Spain (Mas *et al.* 2002). Recently, work has also been taken up in the United Kingdom.

2. There has been a longstanding academic debate about the nature of capital and its role in production. One approach, also adopted in this paper, concentrates on prices and volumes of capital services. Another approach does not consider the services of the capital good as fundamental, but "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).

3. Weaker assumptions than perfect substitutability are possible (Diewert 2001) but will not be presented here for ease of exposition.

4. See Schreyer *et al.* (2003) for a treatment that does not make this assumption.

5. This is for simplicity only. In principle, a distinction should be made between rental prices and user costs unless one assumes the added hypotheses of the existence of complete and fully functioning markets for all types and vintages of capital goods.

6. The gross capital stock is another statistic frequently available in OECD countries. It represents the cumulative flow of investments, corrected for a retirement pattern. In the case of geometric depreciation/efficiency profiles, such a retirement function is absent because the geometric pattern extends to infinity, implying that capital goods never retire even though their productive efficiency and value become infinitely small. Consequently, the gross stock does not exist in this case. Where it exists, it constitutes an intermediate step in the calculation of a 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").

7. A Laspeyres-type aggregation implies $W_{t+1}/W_t = \sum_i w_{t0}^i (W_{t+1}^i/W_t^i)$ where $w_{t0}^i \equiv \dfrac{q_{t0,0}^i K_t^i}{\sum_i q_{t0,0}^i K_t^i}$ and t0 is the weight reference period.

8. Series 5402.0, *Australian System of National Accounts*.

9. See Wölfl (forthcoming) for a sensitivity analysis of MFP measures with regard to the choice of capital input measures.

10. There is also a conceptual issue that will be left aside here as to exactly *which* MFP measure should be chosen in the presence of exogenous rates of return.

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Annex 1

OECD METHODOLOGY

Asset types. The estimation of capital service flows starts with identifying N different assets – for present purposes, these correspond to the asset breakdown currently 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 *of which*:	Yes
IT Hardware	No
Communications equipment	No
Other	No
Transport equipment	Yes
Non-residential construction	Yes
Other products *of which*:	Yes
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 are 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 as follows:

$$S_t^i = \sum_{\tau=1}^{T^i} \left(IN_{t-\tau}^i / q_{t-\tau,0}^i \right) h_\tau^i F_\tau^i \qquad \text{[A1]}$$

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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, $q_{t-\tau,0}^{i}$. T^{i} 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 function of the form used by the United States Bureau of Labor Statistics (BLS 1983):

$$h_{\tau}^{i} = \left(T^{i} - \tau\right)\left(T^{i} - \beta\tau\right)$$

Alternatively, a geometric profile can be assumed, along the lines described in the body of the paper. In the non-geometric case, it has to be taken into account that 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 per cent 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 times 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: seven years for IT equipment, 15 years for communications equipment, other equipment and transport equipment, 60 years for non-residential structures, three years for software and seven years for remaining other products. The parameter β in the age-efficiency function was set to 0.8. Service lives and parameter values follow BLS practice.

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 $r_t = (1 + rr)(1 + p_t) - 1$ 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 five-year centred moving average of the rate of change of the consumer price index $MACPI_t = \sum_{s=-2}^{+2} CPI_{t+s} / 5$ 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. In the case of geometric profiles, the rates of depreciation are given by the method of double-declining balances: given the average service life $\overline{T}^{i}$, the rate of depreciation is computed as $\delta^{i} = 1/2\overline{T}^{i}$. For the case of non-geometric profiles, see Schreyer *et al*. (2003) for a detailed description.