# Measuring capital services in the United Kingdom

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*For many macroeconomic purposes, such as the study of productivity or the assessment of capacity utilisation, we need measures of the level and growth rate of the productive services that the capital stock is capable of providing. The official estimates of the capital stock produced by the Office for National Statistics aim to be measures of wealth, not capital services. So while they are appropriate for their intended purposes, such as balance sheet analysis, they may not be appropriate for productivity analysis or in measures of capacity utilisation. This article discusses the theory behind a different concept of capital, called here the volume index of capital services (VICS), and presents estimates of the VICS for the United Kingdom—based on both a five-asset breakdown and an eight-asset breakdown—for the period 1979–99. The eight-asset breakdown includes three information and communications technology (ICT) assets: computers, software and telecommunications equipment. The VICS measure has grown faster than the wealth measures, and the divergence is more apparent when ICT assets are included explicitly.*

## Introduction

The aim of monetary policy is to keep inflation low and stable, in accordance with the target set by the Chancellor. Low and stable inflation is desirable because it is believed to be conducive to higher economic growth. In setting interest rates, the Monetary Policy Committee assesses the likely growth of aggregate supply over the medium term. Aggregate supply depends crucially on the volume of productive services provided by the capital stock. Measuring capital services presents a number of difficulties, both practical and conceptual. Progress in overcoming these difficulties will contribute both to a better understanding of the growth process and to a firmer basis for monetary policy.

Statistical agencies, including the Office for National Statistics (ONS), commonly estimate two different measures of aggregate capital, known generally as the gross stock and the net stock. Several different asset types are distinguished, eg buildings, plant and machinery, vehicles, etc. The gross stock of any asset is simply the sum of the past history of gross investment in that asset in constant prices, less the sum of losses due to accidents, scrapping and disposals. The aggregate gross stock is the sum of the gross stocks of the different assets. The net stock differs from the gross stock in that allowance is also made for depreciation, often at a straight-line rate over each asset's known or assumed service life (see the box on pages 298–99 for an explanation of concepts of depreciation).

Both the gross stock and the net stock are really measures of wealth; the net stock in particular is the right concept for a balance sheet. Economic theory, however, suggests that the wealth concept of capital is not appropriate for a production function or for a measure of capacity utilisation. For the latter purpose, we need a measure of aggregate capital *services*. A third concept of aggregate capital, which will be called here the volume index of capital services (VICS), answers this need.

### What is the VICS?

In principle, the VICS measures the flow of capital services derived from all the capital assets, of all types and all ages, that exist in a sector or in the whole economy. The main difference between the VICS and wealth measures of capital is the way in which different types and ages of assets are aggregated together. In the VICS, each item of capital is (in principle) weighted by its rental price. The rental price is the (usually notional) price that the user would have to pay to hire the asset for a period. By contrast, in wealth measures of the capital stock each item is weighted by the asset price (ie the price at which it could be sold to another user).

Two major problems arise in constructing a measure of aggregate capital services. First, how to aggregate over different vintages of the same type of capital. Second, how to aggregate over different types of asset. A key concept in solving both problems is the marginal product of capital. This is hard to measure directly. But a profit-maximising firm (assumed to be unable to influence input prices) will accumulate capital up to the point at which its marginal revenue product equals what it would have to pay per period to hire the asset, the rental price. The rental price thus provides an empirical counterpart to the marginal revenue product of capital. The rental price is frequently not observable, but, as will be shown below, it can be related to the asset price, which generally *can* be observed.

An important practical implication of using a VICS rather than a wealth measure is that the VICS will give more weight to assets for which the rental price is high in relation to the asset price. If the stocks of such assets are growing more rapidly than those of other types, then the VICS will be growing more rapidly than the gross or net stock.

The VICS concept is not a new one. It came to prominence in the seminal growth accounting study of Jorgenson and Griliches (1967) and was employed in subsequent studies by Jorgenson and his various collaborators, eg Jorgenson *et al* (1987) and Jorgenson and Stiroh (2000). The theory was set out in Jorgenson (1989); a related paper is Hall and Jorgenson (1967) on the cost of capital. The OECD has recently published a manual on capital measurement, which contains a very full discussion of the various concepts, including the VICS, together with advice on how to measure it in practice (OECD (2001a)); the OECD productivity manual (OECD (2001b)) provides a more concise treatment.

Versions of the VICS are already produced officially for the United States by the US Bureau of Labor Statistics and for Australia (see Australian Bureau of Statistics (2001)). So far as the United Kingdom is concerned, versions of the VICS have previously been estimated by Oulton and O'Mahony (1994) for manufacturing industries (for three asset types: plant and machinery, buildings, and vehicles) and by O'Mahony (1999) for 25 sectors covering the whole economy (for two asset types: plant and machinery, and buildings). Work is also now under way within the ONS to produce a VICS. The ONS hopes to start publishing an experimental VICS in 2002. It is hoped eventually to publish it on a regular basis as a statistic linked to (though not part of) official national income statistics. The estimates presented here, on which the Bank has worked closely with the ONS, should be viewed as preliminary and subject to improvement as a result of the ONS research programme.

This article presents two sets of estimates of wealth and the VICS for the period 1979 to 1999. The first set is based entirely on official figures for gross investment in five different types of asset: buildings (excluding dwellings), plant and machinery, vehicles, intangibles, and inventories. The second set expands the number of asset types to eight by distinguishing, in addition, computers, software, and telecommunications equipment. This second set of estimates makes a number of significant adjustments to the official investment series (see below). But before presenting the estimates, some discussion of the theory behind the VICS is required.

## The VICS in theory(1)

In real terms, the growth rate of wealth is a weighted average of the growth rates of the stocks of each asset. The weights are the shares of each asset in the value of total wealth. The value of the stock of any asset is the asset price times the stock.

The growth of the VICS is also a weighted average of the growth rates of the stocks, but in this case the weights are the shares in the value of total capital services. The value of the services yielded by the stock of a particular asset is the rental price times the stock. To calculate the VICS we need then to calculate the services that each asset yields and the growth rate of its stock.

### Asset stocks

The stock of any asset (asset $i$) in existence at a given moment (time $t$) is the result of all past investments, after allowing for losses due to accidental damage, scrapping or disposals, and the decline in efficiency of surviving assets due to age or use. Suppose that total losses due to all these causes are the proportion $d_{is}$ of the investment made in the $i$th asset $s$ years ago $I_{i,t-s}$. We may call $d_{is}$ the rate of decay. Then the contribution to the stock at time $t$ due to investment made $s$ years ago

(1) The theory briefly set out here draws heavily on Jorgenson (1989). Papers that focus on depreciation include Hulten and Wykoff (1996) and Jorgenson (1996).

is $(1-d_{is})\ I_{i,t-s}$. Another way to think of the factor $(1-d_{is})$ is as the ratio of the services of a typical unit installed $s$ periods ago to the services from a brand-new unit. This ratio equals the rental price of a unit that is $s$ years old divided by the rental price of a new unit.

A special case is when the proportional rate at which the asset decays is constant over time. Call this constant rate of decay $d_i$. Then the services yielded today by an investment done $s$ years ago, as a proportion of the original level of services, is $(1-d_i)^s$. The asset stock $(A_{it})$ now follows the simple relationship:

$$A_{it} = I_{it} + (1-d_i)\ A_{i,t-1}$$

So to calculate the stock, we need to know investment in constant prices and the rate of decay.

### Capital services

If firms maximise profits, the services produced by an asset are its marginal revenue product multiplied by the stock of the asset. Suppose that firms can hire each type of capital by paying a rental price per period. Then profit maximisation implies that the rental price will be equated to the marginal revenue product of the asset.

Financial leasing is a very common arrangement for machinery, and commercial buildings are frequently rented out by their occupiers. Nevertheless it is more common still for businesses to own their own capital. In this case, they can be thought of as renting the assets to themselves. But then there is no rental price to be observed. Even in the case of leased assets, it is generally easier to observe the asset price than the rental price. Fortunately, there is a relationship between the (usually unobserved) rental price and the corresponding (observed) asset price:

Rental price = [rate of return + rate of depreciation – rate of growth of price of new asset] x [price of new asset]

Here the rate of depreciation is the proportional difference between the price of a new asset and the price of an asset that is one period old.(1) The intuition behind this relationship is as follows. If a firm purchases an asset, with a view to renting it out, then it will want the rental price to be sufficient to yield a rate of return. Second, since the asset is going to depreciate, the rental price must cover this loss in value too. Third, the price of a new asset might change. If it goes up, this will reduce the cost of holding one that has already been purchased. In the case of computers, the price of new computers is falling; so holding them incurs a capital loss, which increases the rental price. The rate of depreciation is also high: in the business sector PCs have a service life of only 2 to 3 years. Hence the rental price as a proportion of the asset price is very high, 60% or more. By contrast, buildings have a long service life and so depreciate slowly; and the price of new buildings tends to rise over time. So their rental price is comparatively low in relation to their asset price.

In principle, we can estimate the rate of depreciation from studies of new and second-hand asset prices. The most extensive studies have been done in the United States. These generally find that a geometric pattern of depreciation (see the box on pages 298–99) fits the data well; see Hulten and Wykoff (1981a) and (1981b); and Oliner (1993) and (1996). Geometric depreciation has therefore been adopted as the ‘default assumption’ in the US National Accounts; see (Fraumeni (1997) and Herman (2000)).

The rate of depreciation and the rate of decay are different concepts and in general need not be equal (see the box again). But if depreciation is geometric, it can be shown that the two rates are in fact equal. This is very helpful since to calculate asset stocks we need to know the rates of decay, about which we have no direct evidence. But we do have some evidence for rates of depreciation, which we can use for estimates of rates of decay too.

The final piece of the jigsaw required to calculate rental prices is the rate of return. Profit maximisation implies that the rate of return will be equalised across all types of asset, at least *ex ante*. Assuming that rates of return are equalised *ex post* as well, we can estimate this common rate of return from the observed level of total profits.(2)

(1) The formula in the text also needs to be adjusted to allow for taxation and investment allowances; this has been done in the estimates reported below.
(2) Certainly firms would like to equalise rates of return *ex ante*. But *ex post* things might turn out differently if they are unable to adjust the size of their holdings with equal speed for all types of asset. For example, an airline may be able to adjust its stock of computers more easily than its stock of planes. The assumption of equal rates of return might be particularly hard to maintain in a recession and perhaps too in a strong boom. As we will see below, the assumption of equal rates of return does appear to break down occasionally, when rental prices are estimated to be negative.

## Depreciation and decay

Depreciation is geometric when an asset's value declines at a constant proportional rate as it ages. For example, suppose that the price of a new asset of a particular type is £10,000 in August 2001 and depreciation is geometric at 10% per year. Then in August 2001 a one-year-old asset of the same type will have a second-hand price of £9,000; a two-year-old asset will sell for (1.0 – 0.1) x 9000 = £8,100, and so on. A ten-year-old asset will sell for £3,487, and a twenty-year-old one for £1,216.

*Straight-line depreciation* is when an asset loses a fixed proportion of its *initial* value in each year of its service life. If the price when new is £10,000 and the service life is 20 years, then the asset loses one twentieth of £10,000, or £500, with each year of age. So a one-year-old asset is worth £9,500, a ten-year-old asset is worth £5,000, and a twenty-year-old asset is worth nothing. Straight-line depreciation is very common in business accounting but there it is usually applied to the historic cost of the asset. Straight-line depreciation is common too in national income accounting, but there the assets are revalued to current prices. The estimates of depreciation (capital consumption) in the UK National Accounts use straight-line depreciation.

Depreciation is a property of asset prices. Decay is a property of the services yielded by an asset as it ages. The two concepts are quite different but are connected, since theory suggests that the price of an asset should equal the present value of the services which it will yield over the remainder of its life. In other words, if one assumes a certain pattern of depreciation, this implies a corresponding pattern of decay, and *vice versa*. As mentioned in the text, if depreciation is geometric, then decay is also geometric; the converse is true as well. But no such simple relationship applies to other types of depreciation or decay.

For some assets, it has been suggested that the so-called 'one-hoss shay' or 'light bulb' pattern of decay is appropriate. In this case, the asset provides a constant level of service during its life, rather as a light bulb provides an approximately constant level of illumination up till the moment it burns out. It is sometimes suggested that this pattern is appropriate for computers and software. But here there is no counterpart to the physical failure of a light bulb. This makes it difficult to explain why these assets have such short lives if their efficiency is indeed unchanging while they are in service.

If decay is *hyperbolic*, the services from an asset decline at an increasing proportional rate with age. Both the US Bureau of Labor Statistics and the Australian Bureau of Statistics assume hyperbolic decay. Under this pattern the ratio of the services from an asset that is $s$ years old to the services from a new asset is given by the formula $(L - s)/(L - \beta s)$, where $L$ is the service life and $\beta$ is a positive parameter.

Charts A, B and C compare the age-efficiency profile (how services change with age) with the age-price profile (how the asset price changes with age) for the cases of light bulb, geometric and hyperbolic decay. For light bulb and hyperbolic decay, asset life is assumed to be 20 years and the discount rate is set to 7% per year. The geometric decay rate is assumed to be 10% per year. Both asset prices and services are shown as proportions of their values when new (age 0), which are set equal to one. With light bulb decay, the age-price profile is concave, whereas with geometric decay it is convex. A convex age-price profile is more consistent with the empirical evidence. But other patterns of decay, such as hyperbolic, can also generate a convex age-price profile: see Chart C where we have set $\beta$ = 0.3.

**Chart A**
**Light bulb decay**

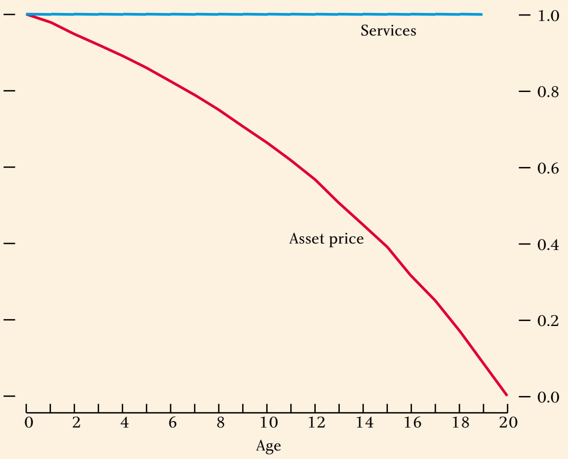
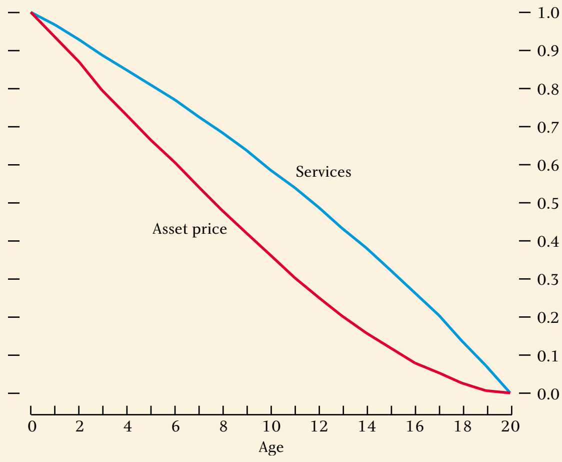


**Chart B**
**Geometric decay**


**Chart C**
**Hyperbolic decay**




In summary, to estimate the VICS we need rental prices and asset stocks. To estimate rental prices, we need asset prices and rates of depreciation. To estimate asset stocks, we need a back series of investment in constant prices. Asset prices and investment are readily available from the National Accounts. Depreciation rates present more of a problem. Here we use rates based on the ones used in the US National Accounts. The reasons for using US rates are twofold. First, they have some empirical backing since they are derived from studies of the prices of second-hand assets. No such studies have as yet been done for the United Kingdom. Second, we cannot use the rates employed by the ONS since these are straight-line, not geometric.

## Obsolescence versus physical decay

Some assets, like buildings, decay with age. Mechanical wear and tear causes many types of machinery to decay with use. Some assets, in particular computers and software, suffer little or no physical decay but are nevertheless discarded after relatively brief service lives. The cause is usually said to be 'obsolescence', due to the appearance of newer and better models. Does this make any difference to the analysis above?

The answer is no. Rental prices are measures of marginal products. Certainly these will decline if there is physical decay but this is not the only reason for them to fall. Anything that causes the *profitability* of capital equipment to decline will do just as well. Two possible causes of declining profitability are:

1. If capital once installed is used in fixed proportions with labour, rising wages will cause older equipment to be discarded even if it is physically unchanged. As equipment ages, its profitability declines and it is discarded when profitability reaches zero. (*Ex post* fixed proportions seem quite realistic for computers, where the rule is one worker, one PC.) But capital services from different vintages of the same asset are still correctly measured by rental prices: see Oulton (1995).

2. As capital ages, it may require higher and higher maintenance expenditure. This is particularly the case for computers and software, provided we understand maintenance in an extended sense to include maintenance of interoperability with newer machines and software. The profitability of a machine will then decline as it ages and it will be retired when profitability is zero: see Whelan (2000).

The basic principles behind the VICS are not affected in either of these two cases. To measure capital services, assets should still be weighted together by their rental prices. But depreciation will no longer be geometric, hence the decay rate will no longer equal the depreciation rate. This will affect the estimation of asset stocks. But we are normally interested in the growth rates of asset stocks and these will be relatively insensitive to the pattern of decay, as suggested by sensitivity tests reported below.

## Comparing the wealth measure with the VICS

As we have seen, both measures are weighted averages of asset stock growth rates and only differ in the weights. In the wealth measure the weights are shares in total wealth and hence depend on asset prices, while in the VICS the weights depend on rental prices. We have also seen that the ratio of the rental price to the asset price differs between asset types: the ratio is higher for assets with short services lives (high rates of depreciation) and falling asset prices. It is intuitively clear (and can be proved formally) that the VICS will give more weight than the wealth measure to assets with higher-than-average rental price/asset price ratios.

## The VICS in practice

The estimates of the VICS for the United Kingdom presented below use official series for investment in current and constant prices. These series include spending on assets like computers and software. But they are not distinguished separately. Later we also present estimates that do distinguish ICT assets separately and that make various adjustments to the official series, based on arguments in Oulton (2001).

### The data(1)

The UK National Accounts distinguish seven different asset types. Initially, the VICS will be calculated for five of these:

1. Buildings (excluding dwellings)
2. Plant and machinery
3. Vehicles
4. Intangible assets
5. Inventories

Computers and telecommunications equipment have always been included within plant and machinery, but not separately distinguished. Since 1998, software has been included under intangible assets.

Collectively, the returns on these assets are assumed to generate aggregate profits (gross operating surplus). Two other assets are also present in the national accounts, dwellings and valuables. The economic process generating housing returns is likely to be different from the one generating business profits, so dwellings are excluded here. This means that for consistency our measure of profit must also exclude returns to housing (see the appendix). Valuables, a small item, are excluded since we have no way of estimating an initial stock.

The National Accounts give us gross investment in constant and current prices for the first four of the asset types listed above, 1948–99. The price of each asset is calculated as an implicit deflator: investment in current prices divided by investment in constant prices. In the case of the fifth asset, inventories, we actually know the stock in 1998, in 1995 prices. The National Accounts give us the net change in inventories in constant prices. So we can calculate the stock in any other year. The price of inventories was assumed to be the implicit deflator for manufacturing output.

To calculate the stocks of buildings, plant, vehicles and intangibles for 1948–99, we need starting stocks for 1947 and assumptions about depreciation. The starting stocks were estimated using detailed industry-level investment data kindly supplied by the ONS; these series go back to the 19th century. The depreciation assumptions used here are as follows:

| Asset | Depreciation rate (per cent per year) |
|---|---|
| Buildings | 2.5 |
| Plant and machinery | 13.0 |
| Vehicles | 25.0 |
| Intangibles | 33.0 |
| Inventories | 0.0 |

For the four fixed assets, these rates approximate those used by the Bureau of Economic Analysis (BEA) (see Fraumeni (1997)). The zero rate for inventories is taken from Jorgenson and Stiroh (2000). These rates will be referred to as the baseline depreciation rates.

### Results for the five-asset model

Table A compares the rental price weights (calculated using the baseline depreciation rates) with the asset price weights. Clearly these are very different. For example, the rental price weight for plant is getting on for twice its asset price weight. So we would expect the VICS to give different results from a wealth measure of the capital stock. This is borne out by Table B, which compares the two types of measure. Over 1989–99, the baseline VICS grows more rapidly, by about

**Table A**
**Comparison of rental price and asset price weights**

| | Buildings | Vehicles | Plant and machinery | Intangibles | Inventories | Total |
|---|---|---|---|---|---|---|
| Average rental weights (shares in aggregate profits), per cent | | | | | | |
| 1979–89 | 36.0 | 11.1 | 42.2 | 2.9 | 7.8 | 100.0 |
| 1989–99 | 39.4 | 10.2 | 40.9 | 3.4 | 6.1 | 100.0 |
| 1979–99 | 37.7 | 10.7 | 41.5 | 3.1 | 7.0 | 100.0 |
| Average asset weights (shares in nominal value of aggregate capital stock), per cent | | | | | | |
| 1979–89 | 59.0 | 4.2 | 23.5 | 0.9 | 12.4 | 100.0 |
| 1989–99 | 58.7 | 4.2 | 24.7 | 1.1 | 11.3 | 100.0 |
| 1979–99 | 58.9 | 4.2 | 24.1 | 1.0 | 11.8 | 100.0 |

(1) More detail on the data is given in the appendix on pages 305–07.

0.4 percentage points per year. The divergence between the two measures becomes particularly marked in the past few years, as Chart 1 shows; in 1999 it is 1.6 percentage points.

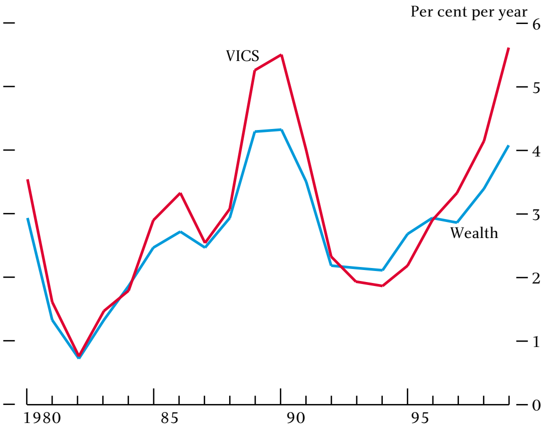
### Table B
### Comparison of VICS and wealth measure: growth rates

Per cent per year

| | Wealth (five assets) | VICS (five assets) |
|---|---|---|
| 1979–89 | 2.30 | 2.62 |
| 1989–99 | 3.01 | 3.38 |
| | | |
| 1989–94 | 2.84 | 3.12 |
| 1994–99 | 3.18 | 3.63 |

Source: Appendix, Table 2.

### Chart 1
### Growth rates of VICS and wealth compared (five asset types)



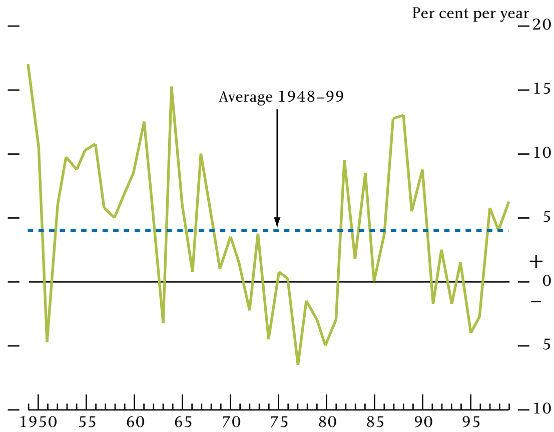

Source: Appendix.

## The sensitivity of the VICS to the depreciation rate assumptions

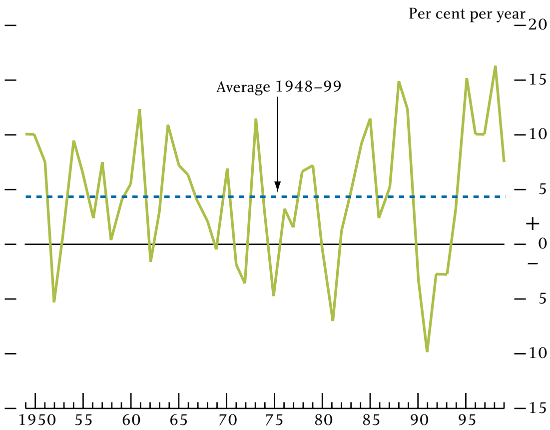
Even if the baseline depreciation rates are appropriate for the United States, it is not clear that they should be applied in the United Kingdom. It is therefore useful to consider how sensitive the VICS is likely to be to the depreciation assumptions. The *level* of each asset stock is sensitive to depreciation but the *growth rate* is less so. In fact, if the growth rate of investment had always been constant, then the stock would grow at the same rate, which would be completely independent of the depreciation rate. Year-to-year volatility of the growth rate of investment does not make the stock growth rate sensitive to depreciation, but changes in the trend growth rate of investment do.

Charts 2 to 5 show the growth rates of the four types of fixed investment. They are fairly volatile on a year-to-year basis. Apart from software, the major component of investment in intangibles is oil and gas exploration, which accounts for the erratic behaviour in the late 1960s and early 1970s. Buildings show signs of change in the trend growth rate. The average growth rates are in Table C. Over the entire 51-year period, the growth rates of the two largest items, plant and buildings, come out fairly similar but this is far from the case over shorter periods, including in particular the most recent one. Hence we can see already that the growth of the VICS is likely to differ from that of a wealth measure.

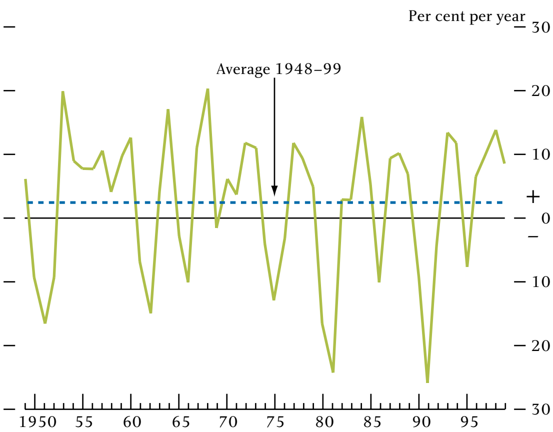
### Chart 2
### Investment in buildings



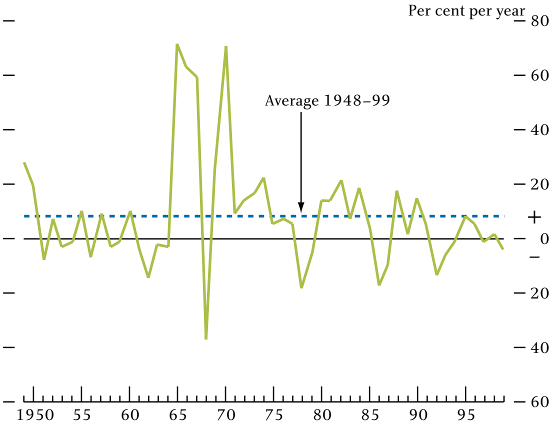

### Chart 3
### Investment in plant




### Chart 4
### Investment in vehicles



## Chart 5
## Investment in intangibles




## Table C
## Average growth rates of real investment

Per cent per year

| | Buildings | Plant and machinery | Vehicles | Intangibles |
|---|---|---|---|---|
| 1948–64 | 7.78 | 5.16 | 3.14 | 2.15 |
| 1964–89 | 2.46 | 4.12 | 2.29 | 15.16 |
| 1989–99 | 1.87 | 4.31 | 1.69 | 0.90 |
| 1948–99 | 4.02 | 4.48 | 2.44 | 8.28 |

Table D shows average growth rates of the VICS using three different depreciation rates of the fixed assets:

- Baseline (see above)
- 'Low'—50% of baseline rates
- 'High'—150% of baseline rates

The zero rate for inventories is the same in all variants.(1)

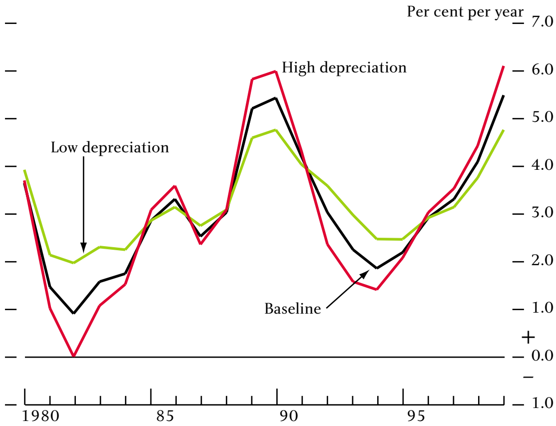
## Table D
## Average growth rates of VICS

Per cent per year

| | Baseline | Low | High |
|---|---|---|---|
| 1979–89 | 2.62 | 2.91 | 2.52 |
| 1990–99 | 3.47 | 3.49 | 3.49 |
| 1979–99 | 3.04 | 3.20 | 3.01 |

The average growth rates are remarkably similar over the past 20 years. Chart 6 shows the time path of the three versions of the VICS. These are again very similar. As the evidence for depreciation rates in the United Kingdom is fairly weak, it is comforting that the VICS seems relatively insensitive to uniform upward or downward movements in the rates (which might be interpreted as uniform shortening or lengthening of assumed services lives). One difference revealed by Chart 6 is that the higher the depreciation rate, the more variable the growth rate. The reason is that high depreciation rates mean that a higher weight is put on investment in the recent past in the VICS. Since investment is cyclical, the VICS tends to be more cyclical too.

## Chart 6
## VICS: effect of varying depreciation rates




These sensitivity tests use the rental weights without any adjustments. But the weights are not without problems. First, they are quite variable over time. However, using the mean of the weights over 1979–99 had very little effect on the results. Second, and perhaps more important, negative values sometimes occur. For example, since 1979 the rental weight for buildings has been negative once (1980) and that for inventories five times. Negative rentals indicate a breakdown of the assumption that firms are able to adjust all their assets optimally in every year. For the purpose of sensitivity testing, these negative values have been allowed to stand. But for satisfactory estimates of the VICS negative rental weights need to be removed. It turns out that this can be done by some simple smoothing, while constraining the weights to sum still to unity.(2)

### Adjusting for ICT

We now consider the effect of distinguishing separately the services produced by information and communications technology (ICT) assets. Measuring the contribution of such assets involves numerous conceptual and empirical problems. These are considered in Oulton (2001), which argues for a number of adjustments to official figures. The two changes that have the most impact on the results are: (1) the use of US price indices (adjusted for exchange rate changes) to deflate UK investment in ICT assets; and (2) a tripling

(1) For the purpose of the sensitivity analysis, the 1947 starting stocks were held fixed while the depreciation rates for the 1948–99 period were varied. To minimise the influence of the starting stocks, I present results only for 1979 onwards.
(2) Tables A and B and Chart 1 use smoothed rental price weights. This accounts for the slight difference between the baseline results in Tables B and D.

of the official nominal level of investment in software. Naturally, the resulting estimates need to be treated with caution and should be regarded as preliminary. Further research is clearly needed in this area. Ongoing work at the ONS may well lead to improved estimates in the future.

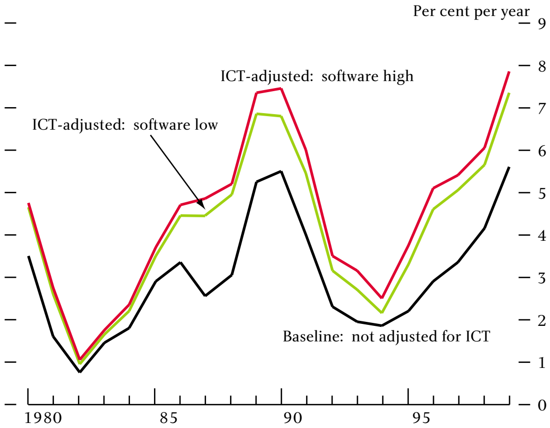
The three types of ICT asset and their depreciation rates (taken from Jorgenson and Stiroh (2000)) are:

| | Depreciation rate (per cent per year) |
|---|---|
| Computers | 31.5 |
| Software | 31.5 |
| Telecommunications equipment | 11.0 |

We now have eight types of asset in the VICS instead of five. Plant and machinery now excludes computers and telecommunications equipment, and intangibles now excludes software. The ICT-adjusted series are shown in two variants: 'low software' and 'high software'. The 'low software' deflator is based on the BEA's software price index as used in the US National Income and Product Accounts. The 'high software' variant uses one component of the BEA price index, that for pre-packaged software, which falls more rapidly.

Chart 7 shows the effect of incorporating these adjustments into the VICS. The ICT-adjusted estimates have a similar profile but lie uniformly above the baseline estimate. The adjustment clearly has a substantial effect on the aggregate growth rate. As Table E shows, compared with the baseline estimate of 3.38% per year, the high software variant of aggregate capital services grew at the substantially faster rate of 5.07% over 1989–99. Over the most recent period,

### Chart 7
### Growth of capital services, 1979–99: with and without ICT adjustment




1994–99, making the ICT adjustment raises the growth rate of the VICS by 2 percentage points.

### Table E
### Growth of capital services: with and without ICT adjustment

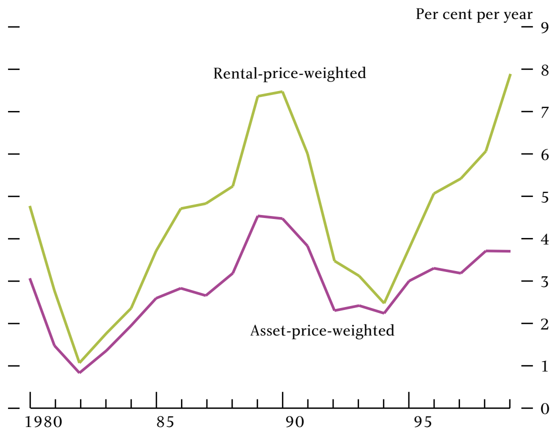
Per cent per year

| | VICS (eight assets, low software) | VICS (eight assets, high software) | VICS (five assets, baseline) |
|---|---|---|---|
| 1979–89 | 3.63 | 3.84 | 2.62 |
| 1989–99 | 4.62 | 5.07 | 3.38 |
| 1989–94 | 4.05 | 4.51 | 3.12 |
| 1994–99 | 5.20 | 5.63 | 3.63 |

Source: Appendix, Table 2.

It is also interesting to compare the effect of weighting by rental prices, which is theoretically preferred, to weighting by asset prices. The two series in Chart 8 and Table F use identical data but different weights. As expected, the series using rental price weights grows more rapidly and the effect is very substantial: for example, it adds more than 4 percentage points per year in 1999. One reason is that the rental weight for ICT capital is about three times its asset weight.

### Chart 8
### Growth rate of capital services, 1979–99: asset price versus rental price weights




### Table F
### Wealth and VICS measures compared

Growth rates, per cent per year

| | VICS (eight assets, high software) | Wealth (eight assets, high software) |
|---|---|---|
| 1979–89 | 3.84 | 2.43 |
| 1989–99 | 5.07 | 3.20 |
| 1989–94 | 4.51 | 3.04 |
| 1994–99 | 5.63 | 3.37 |

Source: Appendix, Table 2.

## Conclusions

The VICS uses rental price rather than asset price weights, so it gives more weight to assets with a high rental price/asset price ratio, ie to assets with short service lives and high rates of depreciation. It turns out that these are the assets whose stocks have been growing most rapidly in recent years. Consequently, the VICS has tended to grow more rapidly than a wealth measure. Over the period 1989–99, the VICS has grown at 5.07% per year when ICT assets are separately distinguished. This compares with a wealth measure based on exactly the same data and depreciation assumptions that grew at 3.20% per year. As ICT assets have grown in importance, the divergence between wealth and VICS measures has increased.

Since the VICS is the appropriate concept for productivity analysis, the present estimates have implications for the growth of total factor productivity (TFP). TFP growth is often estimated using a wealth measure of capital. If capital services have been growing faster than wealth measures, then TFP has been growing more slowly than a wealth-based estimate would suggest.(1)

The implications for capacity utilisation are a little harder to draw. Since capital services have been growing more rapidly than a wealth-based measure would imply, it might seem that capacity utilisation has been growing less rapidly. But the slower growth of TFP works in the other direction. Capital and capacity utilisation play numerous roles in the Bank of England's medium-term macroeconomic model. So teasing out the implications of these new estimates for monetary policy will require careful analysis, going beyond the scope of this article.

(1) This is true even though the adjustments made to investment in ICT lead to higher estimates of GDP growth (see Oulton (2001)).

## Appendix

This appendix describes the sources and methods used to construct the baseline estimates of the VICS, ie those which make no special allowance for ICT. The ICT adjustments are fully described in Oulton (2001).

The equations of the model are as follows:

$$A_{it} = I_{it} + (1 - \delta_i)\, A_{i,t-1}, \qquad i = 1,\dots, m \tag{1}$$

$$K_{it} = A_{i,t-1}, \qquad i = 1,\dots, m \tag{2}$$

$$p_{it}^K = T_{it}\left[r_t\left(p_{i,t-1}^A + \delta_i\right)p_{it}^A - (p_{it}^A - p_{i,t-1}^A)\right], \qquad i = 1,\dots,m \tag{3}$$

$$\Pi_t = \sum\nolimits_{i=1}^m p_{it}^K K_{it} = \sum\nolimits_{i=1}^m T_{it}\left[r_t\left(p_{i,t-1}^A + \delta_i\right)p_{it}^A - (p_{it}^A - p_{i,t-1}^A)\right]K_{it} \tag{4}$$

$$\log n\left[K_t / K_{t-1}\right] = \sum\nolimits_{i=1}^m \overline{w}_{it} \log n\left[K_{it} / K_{i,t-1}\right], \quad \overline{w}_{it} = (w_{it} + w_{i,t-1})/2,\ w_{it} = \frac{p_{it}^K K_{it}}{\sum_{i=1}^m p_{it}^K K_{it}},\ i = 1,\dots,m \tag{5}$$

$$\log n\left[A_t / A_{t-1}\right] = \sum\nolimits_{i=1}^m \overline{v}_{it} \log n\left[A_{it} / A_{i,t-1}\right], \quad \overline{v}_{it} = (v_{it} + v_{i,t-1})/2,\ v_{it} = \frac{p_{it}^A A_{it}}{\sum_{i=1}^m p_{it}^A A_{it}},\ i = 1,\dots,m \tag{6}$$

where
$m$ is the number of assets
$A_{it}$ is the stock of the $i$th type of asset at the end of period $t$
$K_{it}$ is capital services from assets of type $i$ during period $t$
$I_{it}$ is gross investment in assets of type $i$ during period $t$
$\delta_i$ is the geometric rate of depreciation on assets of type $i$
$r_t$ is the nominal post-tax rate of return on capital during period $t$
$T_{it}$ is the tax adjustment factor in the Hall-Jorgenson cost of capital formula
$p_{it}^K$ is the rental price of new assets of type $i$, payable at the end of period $t$
$p_{it}^A$ is the corresponding asset price at the end of period $t$
$\Pi_t$ is aggregate profit in period $t$
$K_t$ is aggregate capital services during period $t$
$A_t$ is aggregate real wealth at the end of period $t$

Equation **(5)** defines the growth rate of the VICS and equation **(6)** the growth rate of the wealth measure. These are chain indices of the Törnqvist type. Capital services in period $t$ are assumed to derive from assets in place at the end of period $t$–1 (equation **(2)**). So when comparing the wealth and VICS measures in the charts and the text, we compare the growth of capital services between periods $t$ and $t$–1 with the growth of wealth between the end of period $t$–1 and the end of period $t$–2.

### Investment

The following table shows the investment series we have used, together with the ONS codes for the current-price and constant-price series.

## Table 1

| | | ONS code, current prices | ONS code, 1995 prices |
|---|---|---|---|
| 1 | Other buildings and structures | DLWS | EQDP |
| 2 | Transport equipment | DLWZ | DLWJ |
| 3 | Other machinery and equipment and cultivated assets | DLXI | DLWM |
| 4 | Intangible fixed assets | DLXP | EQDT |
| 5 | Changes in inventories | Not used | ABMQ |

A complication is that while the nominal series for each type of investment goes back to 1948, the corresponding real series goes back only to 1965 for 'Transport equipment', 'Other machinery and equipment and cultivated assets' and 'Intangible fixed assets', and only to 1989 for 'Other buildings and structures'. For 'Other buildings and structures' over the period 1965–88, we have used the growth in the constant price series DLWT, which is the same as EQDP except that it includes transfer costs. For the years 1948–64, we have constructed our own implicit deflators for buildings and for plant and machinery from detailed, industry-level investment data provided by the ONS. These investment series are the ones employed in the ONS's capital stock model. These implicit deflators were spliced on to the later series in 1965. We have used our plant and machinery deflator to deflate investment in intangibles over 1948–64.

### Capital stocks

We have used US depreciation rates taken from Fraumeni (1997): see the main text. For the fixed assets, the stock of each asset was accumulated using the official investment series from 1948 onwards (see above), employing equation **(3)**. We therefore needed an initial stock for each asset in 1947. For 'Other buildings and structures', 'Other machinery and equipment and cultivated assets' and 'Transport equipment', a starting stock was generated using the same detailed, industry-level data supplied by the ONS; these data extend back to the 19th century. In generating these starting stocks, the same depreciation rates were employed as were used from 1948 onwards.

For inventories, the quarterly National Accounts gave the stock of inventories in 1995 prices at the end of 1998. The stock in each year in constant prices was then estimated by adding or subtracting the change in inventories in constant prices. The value of the stock of inventories in current prices was then generated by revaluing the constant-price stock using the price index for manufacturing [PLLU] from 1963 onwards and, prior to then, the implicit deflator for GDP.

### Asset prices

The asset price of each asset type is derived as an implicit deflator: the current-price investment series divided by the constant-price investment series.

### Tax/subsidy factor

The tax/subsidy factors were kindly supplied by HM Treasury.

### Rental prices

To calculate the rental prices and hence the weights for each asset type in the capital aggregate, we include inventories and all fixed assets except for dwellings and use these to solve for first the nominal rate of return and then for the rental prices. Hence the appropriate profit total is aggregate profits minus what should be attributed to ownership of dwellings.

Total profit is therefore measured as gross operating surplus [ABNF] less housing consumption [CDDF+CDDG]. Housing consumption needs to be removed since we are excluding housing from the VICS. Under ESA79, the two components of housing consumption were known as 'Other rents' [CDDG] and 'Imputed rents of owner-occupied dwellings' [CDDF] respectively. We use the old codes since the ESA95 ones do not go back before 1986. The old codes have been continued and have identical values with the new ones where they overlap. However, they do not go back before 1963. For 1948–62, we estimate housing consumption by applying the ratio of housing consumption to the official estimate of the net stock of dwellings in current prices [CIWZ], averaged over the years 1963–65, to the net stock in the earlier period.

The VICS and the wealth measures, with and without ICT adjustment, appear in Table 2 below.

## Table 2
## Wealth measures of capital stock compared with VICS, 1979–99

Growth rates, per cent per year

| | Wealth | | VICS | | |
|---|---|---|---|---|---|
| | five assets, no ICT adjustment | eight assets, ICT adjusted | five assets, no ICT adjustment | eight assets, low software, ICT adjusted | eight assets, high software, ICT adjusted |
| 1980 | 2.92 | 3.04 | 3.52 | 4.63 | 4.75 |
| 1981 | 1.31 | 1.49 | 1.60 | 2.61 | 2.74 |
| 1982 | 0.71 | 0.80 | 0.75 | 0.95 | 1.05 |
| 1983 | 1.31 | 1.37 | 1.46 | 1.65 | 1.75 |
| 1984 | 1.87 | 1.97 | 1.78 | 2.22 | 2.35 |
| 1985 | 2.48 | 2.56 | 2.90 | 3.52 | 3.71 |
| 1986 | 2.71 | 2.80 | 3.33 | 4.45 | 4.72 |
| 1987 | 2.46 | 2.63 | 2.55 | 4.47 | 4.83 |
| 1988 | 2.95 | 3.17 | 3.07 | 4.93 | 5.21 |
| 1989 | 4.29 | 4.52 | 5.26 | 6.83 | 7.34 |
| 1990 | 4.33 | 4.48 | 5.50 | 6.80 | 7.44 |
| 1991 | 3.49 | 3.80 | 4.00 | 5.47 | 5.99 |
| 1992 | 2.16 | 2.28 | 2.32 | 3.14 | 3.49 |
| 1993 | 2.13 | 2.38 | 1.94 | 2.68 | 3.14 |
| 1994 | 2.11 | 2.26 | 1.84 | 2.16 | 2.49 |
| 1995 | 2.69 | 3.00 | 2.18 | 3.28 | 3.77 |
| 1996 | 2.92 | 3.27 | 2.90 | 4.61 | 5.08 |
| 1997 | 2.85 | 3.15 | 3.33 | 5.05 | 5.41 |
| 1998 | 3.40 | 3.72 | 4.14 | 5.67 | 6.04 |
| 1999 | 4.06 | 3.70 | 5.62 | 7.37 | 7.85 |

Average growth rates, per cent per year

| | | | | | |
|---|---|---|---|---|---|
| 1979–89 | 2.30 | 2.43 | 2.62 | 3.63 | 3.84 |
| 1989–99 | 3.01 | 3.20 | 3.38 | 4.62 | 5.07 |
| 1989–94 | 2.84 | 3.04 | 3.12 | 4.05 | 4.51 |
| 1994–99 | 3.18 | 3.37 | 3.63 | 5.20 | 5.63 |

Source: Oulton (2001) for ICT-adjusted series.

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