[Nicholas Oulton](#) and Gavin Wallis

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Capital stocks and capital services:
integrated and consistent estimates for the United Kingdom, 1950-2013

NICHOLAS OULTON*†

and

GAVIN WALLIS‡

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*Corresponding author

†*London School of Economics, Houghton Street, London. WC2A 2AE. UK*

(*e-mail:* *n.oulton@lse.ac.uk)*

‡*Bank of England, Threadneedle Street, London. EC2R 8AH. UK*

(*e-mail:* *gavin.wallis@bankofengland.co.uk)*

Abstract

The evolution of capital services is crucial for understanding labour productivity growth. Capital stocks and the wealth-income ratio are important for understanding welfare and inequality. Accordingly, we present annual estimates of fixed capital services and capital stocks for the United Kingdom, 1950-2013, for the whole economy and for the market sector. Our estimates cover nine asset types including R&D. We compare estimates of capital services based on an endogenous (ex post) rate of return with ones based on a hybrid method which allows for ex ante risk: firms' expectations may not be satisfied. Contrary to expectation, we find that capital intensity (capital services per hour worked) rose during the Great Recession even though labour productivity fell. And the wealth-income ratio is now substantially lower than it was in the early 1980s unless dwellings are included in the total.

1. Introduction[1]

Capital services and capital stocks are two related but distinct concepts, each useful in its own way. The evolution of capital services is crucial for understanding labour productivity growth. Capital stocks and the wealth-income ratio are important constituents in analysing welfare and inequality. Capital services are a flow which in nominal terms equals profit or, in national income accounting terms, gross operating surplus. On the other hand, the aggregate of all capital stocks constitutes the stock of wealth. Operationally, the difference between the two concepts of capital lies in the weights used to aggregate over the various assets. For the wealth measure, in real terms, we weight each real asset stock by the share of that asset in the total value of wealth. For the services measure, we weight each real asset stock by its share in total profit. An asset's share in total profit equals its so-called *rental price* (or user cost) multiplied by the stock of the asset and divided by the total of such returns (profit).

By consistent and integrated estimates of these two concepts of capital, we mean first that the assumptions lying behind the estimation of each stock are consistent across the two concepts. For example, the price index for investment in each asset type must be the same for both concepts, as must the asset-specific depreciation rates. This may seem obvious but

consistency is not always found in practice. Second, both concepts of capital yield an estimate of aggregate depreciation, also known as capital consumption, which is the difference between gross and net income in the national accounts.

This paper presents annual estimates of fixed capital stocks and capital services for the United Kingdom, 1950-2013, for the whole economy and the market sector.[2] Our estimates cover eight asset types (structures, machinery, vehicles, computers, purchased software, own-account software, mineral exploration and artistic originals) and also a ninth, R&D. We compare the effect on the estimates of capital services of using either an exogenous (ex post) rate of return or an endogenous one. The latter uses a model which allows for ex ante risk: firms' expectations may not be satisfied so the realised rate of return may not be equalised across assets (Oulton 2007). We see how much the inclusion of R&D matters. We also look at what has happened to capital intensity (capital services per hour worked) in the Great Recession, a period when labour productivity fell in the UK. And we consider the evolution of the aggregate depreciation rate and of capital consumption as a proportion of GDP.

Capital services are the relevant measure for growth accounting and productivity analysis (OECD 2001): the contribution of capital to the growth of output is the profit share times the growth rate of capital services. So the measurement of capital services is one building block in the measurement of total factor productivity. But capital stocks are the relevant measure for other purposes. The ratio of capital stock (wealth) to the value of output is an important magnitude in growth theory. Any trends in this ratio may indicate that the economy is not in long run equilibrium. And this ratio has also been highlighted by Piketty (2014) as a foundation for the study of inequality. Depreciation (capital consumption) is a by-product of the estimation of capital stocks. Subtracting depreciation from Gross National Income yields

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[2]   Our framework enables us to estimate capital stocks and services for 19 industry groups but we do not present these more detailed results here.

Net National Income which is a starting point for the analysis of economic welfare (Weitzman 1976; Oulton 2004).

Our estimates of capital services are based on a version of the standard methodology as laid down in the OECD's *Measuring Capital* manual (OECD 2009). This methodology goes back to Griliches and Jorgenson (1967), Christensen and Jorgenson (1969), Hall and Jorgenson (1967) and Jorgenson (1989); see also Diewert (1980) and (2001). We estimate capital stocks by the Perpetual Inventory Method (PIM). We assume geometric depreciation. The depreciation rates which are consistent with those used in the National Accounts differ across assets and industry but for each asset the rate is constant over time. The aggregate capital stock is estimated as a chained volume index of the individual asset stocks. The weights are the shares of each asset in the total value of all assets. Aggregate capital services are estimated as a different chained volume index of the asset stocks. Now the weights are the shares in nominal profit (gross operating surplus plus that part of mixed income deemed to be a return to capital rather than to labour)) attributable to each asset; these shares derive from the rental prices which are calculated using the Hall-Jorgenson cost-of-capital formula (Jorgenson 1989; Hall and Jorgenson 1967). Capital services are referred to as the Volume Index of Capital Services (VICS) in the OECD Capital Manual (OECD 2009).

Our stocks and services estimates are for the period 1950-2013. They are based on investment data by asset and industry for 1948-2013. For R&D we have investment only from 1981. We distinguish nine types of fixed asset. Since our focus is on productivity analysis we do not consider dwellings. In estimating the rate of return we would have liked to have included inventories since firms presumably expect inventories to "pay their way", i.e. to yield a profit which at least covers their costs. At the moment we have not been able to do this as the relevant series on inventory stocks is not long enough. However we hope to remedy this in future work. We also exclude land and other natural assets due to data

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limitations.[3] Our fixed capital asset types are the same as those now recognised in the national accounts (which included R&D as an investment type for the first time in the 2014 Blue Book).[4]

Previous work

In the UK official estimates of capital stocks go back to Redfern (1955) and Dean (1964). But until comparatively recently there were no official estimates of capital services. Unofficial estimates of capital services appeared in Oulton and O'Mahony (1994) for 128 industries within manufacturing (for three asset types: plant & machinery, buildings and vehicles). Oulton (2001) and Oulton and Srinivasan (2003) produced annual estimates of capital services and stocks for the whole economy incorporating explicit allowance for ICT assets. More recent estimates of capital services for the UK appear in the EU KLEMS database

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[3] The value of land bundled together with that of structures is included in the balance sheets which form part of the UK National Accounts. But the structures part of this is estimated by a different method from that used here (and also in official estimates of the stock of structures), namely the PIM applied to gross investment in structures. While it would be possible to develop consistent estimates of the aggregate value of land in the UK, it would be difficult to break this down by industry.

[4] It would be possible to expand the number of intangible capital assets beyond software and R&D as has been done for example by Corrado *et al*. (2009), Dal Borgo *et al*. (2013), and Goodridge *et al* (2013) but we decided to remain within the boundary of the assets recognised in the latest System of National Accounts and European System of Accounts.

which again makes special provision for Information and Communication Technology (ICT): see O'Mahony and Timmer (2009).

The UK's Office for National Statistics (ONS) produces estimates of capital stocks, e.g. Vaze et al. (2003). But they were withdrawn from publication in 2011 after ONS quality assurance checks raised issues with the quality of the data. Since then the ONS have conducted an extensive period of development work and quality assurance. The ONS published its latest capital stock estimates in July 2014 (ONS 2014); these cover just the period 1997 to 2012. The ONS has also regularly produced estimates of capital services since 2005, always characterised as "experimental". The most recent comprehensive set is in Appleton and Wallis (2011).[6] However the assumptions employed for services are not consistent with those the ONS uses for stocks, for example the depreciation assumptions differ as do some of the price indices, e.g. for ICT assets.

There is therefore scope for a paper which (a) uses a consistent framework for stocks and services (broadly in line with the recommendations of the OECD's Capital Manual); (b) makes proper allowance for ICT assets, including using defensible price indices to deflate nominal investment in ICT; (c) takes account of the recent Eurostat requirement (following the incorporation of the 2008 System of National Accounts (SNA 2008) into the 2010 European System of Accounts (ESA)) to reclassify R&D expenditure as a form of investment

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[6] In January 2014 the ONS released multifactor productivity estimates which included indicative estimates of capital services growth www.ons.gov.uk/ons/rel/icp/multi-factor-productivity--experimental-/indicative-estimates-to-2012/art-indicative-estimates-to-2012.html

in the National Accounts;[7] and (d) uses the most up-to-date data available (annual investment data up to and including 2013).

Plan of the paper

In section 2 we set out our methodology more formally. We also discuss here the difference between endogenous and exogenous rates of return. Section 3 presents the results. We consider here how much difference the choice of rate of return makes. We also look at the impact of including R&D as an additional asset. And we examine the behaviour of capital intensity (capital services per hour worked), particularly since the Great Recession began in 2008, a period in which labour productivity fell and has yet to fully recover. Section 4 concludes.

2. Methodology

Stocks and services

Let A_{ijt} represent the stock of the i-th asset ($i = 1, ..., N$) in the j-th industry ($j = 1, ..., M$) at the end of year t. Let d_i be the geometric rate of depreciation applicable to the i-th asset. This rate is assumed to be the same for all industries and constant over time[8]. And let I_{ijt} be gross

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[7] Estimates of capital services which include a wider range of intangible assets, not just software and R&D, are in Goodridge et al. (2013).

[8] In the empirical application depreciation rates are constant over time but vary by industry.

investment in the i-th asset by the j-th industry in year t. Then the stock A_{ijt} grows over time in accordance with:

$$A_{ijt} = I_{ijt} + (1-d_i)A_{ij,t-1} \qquad (1)$$

Starting stocks in year 0, A_{ij0} are assumed known. The growth rate of the aggregate capital stock in the j-th industry is calculated as a Törnqvist index of the growth rates of the individual assets:

$$\ln(A_{jt} / A_{j,t-1}) = \sum_{i=1}^{i=N} \overline{w}_t^A \ln(A_{ijt} / A_{ij,t-1}) \qquad (2)$$

where the weights are

$$\overline{w}_{ijt}^A = \frac{1}{2}(w_{ijt}^A + w_{ij,t-1}^A)$$

and

$$w_{ijt}^A = \frac{p_{ijt}^A A_{ijt}}{\sum_{i=1}^{i=N} p_{ijt}^A A_{ijt}}$$

Here p_{ijt}^A is the price of a unit of capital of the i-th type (the asset price). The level of the real capital stock in some reference year is the nominal value of the stock in that year. The level in all other years is derived by applying the growth rates from equation (2) to the reference year level.

The capital services delivered by any asset during year t are assumed to be proportional to the stock of that asset at the end of year $t-1$ with the constant of proportionality normalised to equal 1:

$$K_{ijt} = A_{ij,t-1}, \quad i=1,...,N; \; j=1,...,M \qquad (3)$$

Aggregate capital services in the j-th industry are calculated as a Törnqvist index of the capital services delivered by each asset; the weights are the shares in industry profit attributable to each asset, w_{ijt}^K:

$$\ln(K_{jt} / K_{j,t-1}) = \sum_{i=1}^{i=N} \bar{w}_{ijt}^{K} \ln(K_{ijt} / K_{ij,t-1}) \tag{4}$$

Here

$$\bar{w}_{ijt}^{K} = \frac{1}{2}(w_{ijt}^{K} + w_{ij,t-1}^{K})$$

and

$$w_{ijt}^{K} = \frac{p_{ijt}^{K} K_{ijt}}{\sum_{i=1}^{i=N} p_{ijt}^{K} K_{ijt}} \tag{5}$$

and by definition the value of capital services equals profit or gross operating surplus (*GOS*)

$$\sum_{i=1}^{i=N} p_{ijt}^{K} K_{ijt} = GOS_{jt} \tag{6}$$

The p_{ijt}^{K} are the rental prices (user costs), given by the Hall-Jorgenson formula (Hall and Jorgenson 1967):

$$p_{ijt}^{K} = T_{ijt} \left[r_{jt} + d_i(1 + \pi_{ijt}) - \pi_{ijt} \right] p_{ij,t-1}^{A} \tag{7}$$

where T_{ijt} is the tax factor; r_{jt} is the nominal rate of return in the *j*-th industry which is assumed to be the same for all assets (more on this below); and π_{ijt} is the rate of growth of the *i*-th asset price:

$$\pi_{ijt} = (p_{ijt}^{A} - p_{ij,t-1}^{A}) / p_{ij,t-1}^{A}$$

The level of real capital services in some reference year is the nominal value of profit in that year. The level in all other years is derived by applying the growth rates from equation (4) to the reference year level.

Törnqvist indices are commonly used in the growth accounting literature. But in official statistics in Europe chained Laspeyres indices are generally mandated. So we also present results on the latter basis. Using chained Laspeyres the growth rate of capital stocks is given by

$$A_{jt} / A_{j,t-1} = \sum_{i=1}^{i=N} w_{t-1}^{A}(A_{ijt} / A_{ij,t-1}) \tag{8}$$

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And that of capital services is given by

$$K_{jt} / K_{j,t-1} = \sum_{i=1}^{i=N} w_{ijt-1}^{K} (K_{ijt} / K_{ij,t-1}) \qquad (9)$$

Endogenous versus exogenous measures of the rate of return

Under the endogenous (ex post) approach we calculate the average rate of return from equation (6) and then plug this rate into equation (7) to estimate the rental price weights, i.e. we assume that each asset earns the same rate of return, namely the average rate. The capital gain or loss term π_{jt} is taken to be the actual rate of growth of the asset price. This in effect assumes a world of perfect certainty in which the firm succeeds in equalising the rate of return across all assets in every time period ($r_{jt} = r_t$, all j) and in which expectations of capital gain or loss are always realised. Under these assumptions the rental price equals the marginal product of that type of capital. But these assumptions are obviously implausible. The essence of the firm's investment problem after all is that decisions have to be made in advance of knowing the full facts, e.g. whether demand is going to be high or low or how the prices of assets will in fact change.[9] In addition the endogenous approach often leads to empirical difficulties. Rental prices estimated by this method are frequently negative which makes no sense economically.[10] These then have to be smoothed away, sometimes by

[9] The literature generally finds that uncertainty plays an important role in investment dynamics. For recent contributions see Feil and Musshoff (2013) and Di Corato et al. (2014).

[10] In a study covering 14 countries and 10 industries over 1971-2005 Oulton and Rincon-Aznar (2012) found that 746 out of a possible total of 27,930 rental prices, or 2.6%, were negative using the ex post method.

omitting the capital gains term altogether, which is obviously ad hoc. On the other hand this approach has the advantage of consistency with the National Accounts: the sum of the earnings of all assets equals gross operating surplus, in accordance with SNA 2008.

An alternative is the exogenous approach. Here we take a rate of return from financial data, e.g. an average of the realised rate of return on equities and the yield on corporate bonds. This still leaves the problem of actual versus expected capital gains. And consistency with the National Accounts is now lost since the earnings of all assets no longer add up to gross operating surplus.

Oulton (2007) suggested an alternative, hybrid approach which combines elements of the endogenous and the exogenous approaches.[11] Theory suggests that firms must take investment decisions in the absence of full information about the outcomes. They are therefore guided by the *required* rate of return and the *expected* growth rates of asset prices, i.e. they make their investment decisions in the light of ex-ante, not ex-post, user costs. As shown in Oulton (2007), the actual, ex-post rate of return will generally differ across assets even though ex ante firms try to equalise it. The ex-post rates of return will only equal the required rate in full equilibrium, when all expectations about prices and the level of demand are realised.

In a competitive market, in full equilibrium, the required rate of return should be equal to the actual rate of return on each asset, but not otherwise. Nonetheless under competitive conditions the required rate of return should be related to the actual rate. In fact if we observe no trend in the average real rate of return as estimated from equation (6), then we may assume that the real required rate of return is equal to that average.

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[11] The theory here draws on Berndt and Fuss (1986) and Berndt (1990).

The capital gain term in equation (7) should be interpreted as the expected capital gain which can obviously differ from the actual one. The expected growth rate of an asset price can be estimated from a time series model of the actual price.

This approach leads to the following modification to the rental price equation (7):

$$p_{ijt}^K = T_{ijt}\left[E_{t-1}r_{jt}^* + d_i(1 + E_{t-1}\pi_{ijt}) - E_{t-1}\pi_{ijt} \right] p_{ij,t-1}^A \tag{10}$$

Here E_{t-1} is the expectation as of the end of year t-1. $E_{t-1}r_{jt}^*$ is the expected required nominal rate of return in the j-th industry in year t which is given by:

$$E_{t-1}r_{jt}^* = \rho_{jt} + E_{t-1}\pi_{Yt} \tag{11}$$

where π_{Yt} is the aggregate inflation rate in year t (interpreted as the GDP deflator) and ρ_{jt} is the required *real* rate of return in the j-th industry in year t.[12] In practice at the industry level the real rate of return often takes on highly implausible values, being persistently very high or very low. So it is impossible to estimate required real rates from actual real rates. But for the whole economy or the market sector the actual real rate of return is much more plausible and is generally stationary (Oulton and Rincon-Aznar 2012). This suggests using the same required real rate in all industries, namely the time average of the observed aggregate real rate of return:

$$\rho_{jt} = \rho = \sum_{t=1}^{T}(\bar{r}_t - \pi_{Yt}) \tag{12}$$

where $\bar{r}_t$ is the aggregate nominal rate of return, calculated from an aggregate version of equation (6) and (7). Putting equations (10), (11) and (12) together, we get that

$$p_{ijt}^K = T_{ijt}\left[\rho + d_i(1 + E_{t-1}\pi_{ijt}) - (E_{t-1}\pi_{ijt} - E_{t-1}\pi_{Yt}) \right] p_{ij,t-1}^A \tag{13}$$

Consistency with the National Accounts is not assured under this approach since the estimated returns to each asset no longer necessarily add up to gross operating surplus.

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[12] This approach assumes that investment is reversible after one year. See Di Corato et al. (2014) for a model in which investment is irreversible.

However, Oulton (2007) showed that consistency can easily be restored. Under the assumption that the firm's production function is CES each rental price estimated by equation (13) is proportional to the true one (which equals the marginal product of the asset) and the factor of proportionality is the same for each asset.[13] So the weights of equation (5) when calculated using equation (13) are correct under the hybrid method. And consistency with the National Accounts is restored by grossing up the return to each asset by a common factor so that the total of the returns equals gross operating surplus.[14]

3. Results

Data

Our estimates require (a) a time series of current and constant price investment series by industry and asset; (b) starting stocks; (c) depreciation rates by industry and asset; (d) gross operating surplus; and (e) tax-adjustment factors.

Investment data from 1997 onwards is taken directly from the regular ONS business investment release[15] and supplemented with ad hoc ONS releases on software, artistic

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[13] Oulton (2007) also considers the possibility that the production function is translog and gives some reason for thinking that proportionality of rental prices to marginal products will continue to hold approximately.

[14] Erumban (2008) and Inklaar (2010) have applied the hybrid approach of Oulton (2007) to EU KLEMS data.

[15] www.ons.gov.uk/ons/rel/bus-invest/business-investment/index.html.

originals and mineral exploration.[16] All pre-1997 data is taken from the 2003 release of the investment data underlying previous ONS capital stock estimates.[17] The pre-1997 data available in this release has not been subject to revision because the new methodology for estimating Gross Fixed Capital Formation has only been implemented from 1997 onwards. And in practice, there is no reason to think it needs to be revised unless there are significant ESA related changes. The dataset includes both current and constant price investment at 42 industry and 4 asset level. In order to join this data to the latest estimates it was first transformed from SIC03 to SIC07 and then aggregated to the 19 industry level. The SIC conversion was done using turnover weights. This is the same approach the ONS tend to use. The asset split of the data is expanded using information from historic supple-use tables.[18] The data are then spliced together with the latest estimates from 1997 onwards to give a consistent time series for the period 1948 to 2013. Implied deflators are calculated from the final time series of current and constant price investment.

To get the PIM rolling we needed a starting stock for each asset. Starting stocks are based on the dataset underlying Wallis (2009) which is fully consistent with historic ONS capital stock data. These starting stocks include the official estimates of the one-off loss of capital associated with the Second World War (Dean 1964).

Geometric depreciation rates are the same as those used for official capital services estimates and vary by both asset and industry; they are similar to those in Fraumeni (1997). No additional allowance is made for the possible (though disputable) effect of premature

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[16] www.ons.gov.uk/ons/about-ons/business-transparency/freedom-of-information/what-can-i-request/published-ad-hoc-data/index.html.

[17] www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-31299.

[18] For example, in the historical investment dataset computer hardware and computer software are not separately identified from the rest of plant and machinery.

scrapping. Table 1 shows how depreciation rates vary by asset, with the range representing the industry variation.

Because dwellings are not modelled as part of the productive capital stock, they do not form part of the input into production, so the portion of the operating surplus attributable to dwellings has been deducted from total UK gross operating surplus. We then add 20% of mixed income, which is our estimate of the part of mixed income which represents a return to capital rather than labour; this is based on the share of profit in market sector gross value added. For the ex post method, profit and therefore rates of return are measured at the whole economy level. For the estimates that include R&D we have to adjust operating surplus for the treatment of R&D as an asset rather than as intermediate consumption. To do so we simply add nominal R&D investment to gross operating surplus.

Tax adjustment factors are from Wallis (2012) and vary by asset but not by industry.

Our estimates are for 19 industry groups and for two aggregates, the market sector and the whole economy. The industry groups are sections A-S of the Standard Industrial Classification 2007 (SIC07).[19] The whole economy comprises sections A-S. The market sector is defined by dropping sections O, P and Q.

Stocks compared to services: the ex post method

Table 2 shows average annual growth rates over 1950-2013 and for various sub-periods for the VICS and the capital stock. These results are for the whole economy and use the ex post method. We show growth rates for the VICS and the capital stock, with and without R&D,

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[19]   In this paper we do not show the detailed results for the 19 industry groups.

and for two index numbers, chained Laspeyres and chained Törnqvist.[20] The VICS has grown more rapidly than the capital stock over the whole period and within each sub-period. On the chained Törnqvist measure the difference is about 0.4 per cent per year, 1950-2013; relative to 1950 an index of the VICS is 29% higher in 2013 than an index of the capital stock. The growth of the VICS has slowed down between the first and second halves of the whole period, particularly since 2000; the latter period is of course affected by the Great Recession which commenced in early 2008. Using a chained Törnqvist rather than a chained Laspeyres index has little effect on either the growth rate of the VICS or that of the capital stock. Finally, the inclusion of R&D raises the growth rate of the VICS by about 0.15 per cent per year since 1981. Table 3 shows comparable results for the market sector (i.e. after excluding Public Administration and defence, Education, and Health), using again the ex post method. Both the VICS and the stock grow a bit faster than in the whole economy. The difference is about 0.1 per cent per year for the VICS and 0.2 per cent per year for the stock.

Charts 1 and 2 show the two measures of capital for the whole economy over the whole span 1950-2013, with R&D included, using the chained Törnqvist index. Chart 2 does the same for the market sector. The picture is similar in both. The more rapid growth of the VICS in the period from the 1970s up to around the mid-2000s is apparent. Since the Great Recession began this pattern has reversed, with the stock now growing more rapidly than the VICS.

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[20] Annual, chained Laspeyres estimates of the levels of capital stocks and of the VICS in 2011 prices for the whole economy and the market sector, including R&D, can be found on the Bank of England's website at http://www.bankofengland.co.uk/research/Documents/onebank/threecenturies.xlsx.

The hybrid method

To implement the hybrid method we need an estimate of the required real rate of return. Chart 3 shows the actual real rate of return (the nominal rate minus the growth rate of the GDP deflator at basic prices) in the UK market sector as a whole from 1950 to 2013. Initially the rate falls but from about 1975 onwards it appears to fluctuate around a stable mean. We therefore take the time average, 1975-2013, of the actual rate as our estimate of the required real rate. We use this value, 7.92% per year, for both the market sector and for the whole economy estimates. The growth of the relative price of each asset was well fitted by an AR(1) model. We therefore take the one-step ahead forecast from this model as our estimate of the expected growth rate of the relative price of each asset. The growth of the GDP deflator was also well fitted by an AR(1) model. So we use the one-step ahead forecast from this model as our estimate of the expected growth rate of the GDP deflator. When rental prices are estimated in this way it turns out than none of them are negative. By contrast, under the ex post method 7 rental prices were found to be negative in the market sector; these were removed by applying a three-year moving average to the ex post rate of return.

The overall pattern of the VICS since 1950 as measured by the hybrid method appears in Chart 4 (whole economy) and Chart 5 (market sector). There is very little difference between the Laspeyres and the Törnqvist indices. The average annual growth rates of the VICS as estimated by the hybrid method, with R&D included, are shown in Table 4 (see Appendix Table A1 for annual growth rates). We can note that the chained Laspeyres index and the chained Törnqvist indices are very similar, as are the corresponding ex post indices(compare Tables 2 and 3).

The ex post and the hybrid methods are compared directly in Charts 6 and 7. Clearly their paths are very similar, though the VICS grows a little more slowly on the hybrid measure: for

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the whole economy the difference is about 0.04 % per year over the whole period, which cumulates to about a 2.6% difference in the levels in 2013.

Capital intensity before and after the Great Recession

Between the peak in 2008Q1 and the trough of the recession in 2009Q3, UK labour productivity (GDP per hour worked) fell by about 4.5%. Though the UK economy is now recovering and GDP has passed its previous peak level, labour productivity has stagnated. And at the time of writing it is some 15% below what one would have expected based on its previous trend. There have been many explanations offered for this most unusual behaviour (Oulton 2013) but one possibility is that capital intensity (capital services per hour worked) fell during the recession and the subsequent slump. Certainly investment in the market sector fell but this does not necessarily mean that capital services fell, still less that capital intensity fell.

Chart 8 and Appendix Table A2 show capital intensity in the UK market sector from 1999 onwards; here the numerator is the hybrid measure of capital services with R&D included and the denominator is total hours worked in the market sector. We can see that capital intensity actually rose after the start of the Great Recession in early 2008 and is currently about 10% higher than it was at the pre-recession peak in 2007. The near constancy of capital intensity from 2009 onwards could help to explain why the growth of labour productivity has been so weak over this period. But the fact that capital intensity is currently higher than at the peak of the boom makes it harder to explain the fall in labour productivity which occurred during the Great Recession and from which the UK economy has yet to fully recover. So it seems that we must seek elsewhere for an explanation of the UK's labour productivity puzzle.

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Our PIM allows for asset sales but does not allow for premature scrapping, i.e. a scrapping rate greater than implied by our (fixed) geometric depreciation rates. Conceivably, assets might have been scrapped prematurely during the Great Recession so that actual asset lives were shorter than assumed in the PIM. If this has been an important factor in the Great Recession then our estimates of capital services and stocks are overstated for that period. However, there is no direct evidence in favour of scrapping in the UK. And in the only case where we have alternative estimates of a stock from tax records, namely vehicles, the evidence goes the other way: in the 1991-92 recession the average age of vehicles rose. Theoretically the effect of a recession on capital stocks is ambiguous. Firms in difficulties may scrap assets prematurely (for this to reduce national stocks the assets must be either physically destroyed or sold abroad). But other firms may respond to recession by replacing their assets less frequently so that asset lives get extended (Gordon 2000). Separate from the issue of the size of the capital stock is its degree of utilisation. Unfortunately we have no good measure of this either in the UK.

Is depreciation rising in importance?

The last twenty five years or so have seen a shift in the composition of investment towards assets such as computers and software with shorter lives and therefore higher depreciation rates. Does this mean that the aggregate (average) depreciation rate is rising? If so, this would have implications for welfare which is more closely related to net domestic product than to gross domestic product (Oulton 2004). Chart 9 shows the aggregate depreciation rate, computed as total depreciation divided by the aggregate value of the capital stock, all in current prices. We see that the average depreciation rate rose steadily from 1950 when it was 4.15% before peaking at 6.17% in 1995. Thereafter it has fallen steadily to 4.86% in 2013. So

the intuition that the depreciation rate should have risen steadily turns out to be wrong. This is partly because price effects offset quantity effects — the volume of ICT capital has risen rapidly but this has been counteracted by falling ICT prices. Also, investment in ICT is lower now than in the 1990s.

Depreciation as a proportion of GDP (both in current prices) shows a similar hump-shaped pattern, rising from just over 7% in 1950 to peak at just almost 13% in 1990; it currently stands at a shade under 10%. (Chart 9 and Appendix Table A2). In comparing depreciation as a proportion of GDP with the depreciation rate (depreciation as a proportion of the capital stock) the missing factor is the capital-output ratio (the capital stock as a ratio to GDP), where all ratios are in current prices: Depreciation/GDP = Depreciation/Capital stock *times* Capital stock/GDP . The capital-output ratio appears in Chart 10 and Appendix Table A2. It averages about 2 over the whole period but again shows a hump-shaped pattern, peaking at 2.90 in 1981 before declining to 1.91 (not much above its 1950 level) on the eve of the Great Recession in 2007. The steady decline from 1981 to 2007 is interesting in the light of the claim in Piketty (2014) that the wealth-income ratio has risen and will likely continue to do so in countries like the UK. In fact the opposite has occurred. Of course, Piketty's argument relates to total wealth which includes land, dwellings and net foreign assets as well as reproducible fixed capital, the assets measured here. If the value of dwellings (including the land on which they stand[22]) is added to our wealth measure, dwellings constitute 60% of the total in 2013, up from 49% in 1997. Now the wealth-income ratio does indeed rise from 1997 onwards. It is well known that the real stock of housing has not risen very fast in the United Kingdom; between 1997 and 2012 the real net stock of dwellings grew at only 1 per cent per year, much slower than the other main asset types (ONS 2013, Table 3). So the rise in the ratio of dwellings to GDP (in current prices) is mainly a relative price effect. At any

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[22]   We use the ONS measure of the current price value of dwellings (cdid: CGLK).

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rate, any claim that there is a tendency for the wealth-income ratio to rise over time must rely on the inclusion of housing wealth in the total.

4. Conclusions

This paper has presented integrated measures of capital stocks and capital services for the UK from 1950 to 2013, for both the market sector and the whole economy. By "integrated" we mean that a common dataset and a common set of assumptions (e.g. about depreciation rates and asset lives) is used for the estimates of both stocks and services. So though the concepts of capital stocks and capital services differ, as is now well understood, the estimates of the two concepts are consistent with one another.

The main findings are as follows:

1. Aggregate capital services (the VICS) have grown consistently faster than the aggregate capital stock over the 63 year period 1950-2013, by about 0.4 per cent per year.

2. Adding R&D to the assets covered raises the average growth rate of the VICS by about 0.15% since 1981.

3. The hybrid method produces slightly slower growth of the VICS than does the ex post one. However it must be recalled that to get the ex post method to work at all a certain amount of smoothing is necessary. The hybrid method can be seen as giving a theoretical justification for smoothing which otherwise would be quite ad hoc.

4. The aggregate depreciation rate increased from 1950 to 1995. But thereafter it has declined.

5. Depreciation (capital consumption) as a proportion of GDP shows a hump-shaped pattern. It has been declining since 1990. So the gap between NDP and GDP has been falling in recent years.

6. The capital-output ratio (measured in current prices) also shows a hump-shaped pattern, peaking in 1981. Thereafter it has declined steadily right up to the start of the Great Recession in 2008.

7. Finally, capital intensity (capital services per hour worked) continued to rise for some time after the Great Recession began. In 2013 it was about 10% higher than at the peak of the boom in 2007. This was despite a fall of around 4.5% in labour productivity, peak to trough, and a slow recovery thereafter.

TABLE 1

Depreciation rate ranges by asset type

Asset type	Depreciation rate range
Structures	0.01 to 0.05
Machinery	0.06 to 0.17
Vehicles	0.19
Computer	0.40
Own-account software	0.40
Purchased software	0.40
Mineral exploration	0.20
Artistic originals	0.13
R&D	0.20

TABLE 2

Average annual growth rates of VICS and capital stock (ex post method): whole economy, per cent per year

	Index	1950-2013	1950-1979	1979-2000	2000-2013
Without R&D					
VICS	Chained Laspeyres	3.96	4.26	3.79	3.55
Capital stock	Chained Laspeyres	3.53	4.03	3.05	3.18
VICS	Chained Törnqvist	3.91	4.24	3.70	3.47
Capital stock	Chained Törnqvist	3.52	4.02	3.02	3.16
With R&D					
VICS	Chained Laspeyres	4.00	4.26	3.94	3.48
Capital stock	Chained Laspeyres	3.56	4.03	3.14	3.14
VICS	Chained Törnqvist	3.95	4.24	3.85	3.40
Capital stock	Chained Törnqvist	3.54	4.02	3.11	3.13

Source: Office for National Statistics and own calculations.
Note: R&D investment available only from 1981.

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TABLE 3

Average annual growth rates of VICS and capital stock (ex post method):
market sector, per cent per year

	Index	1950-2013	1950-1979	1979-2000	2000-2013
Without R&D					
VICS	Chained Laspeyres	4.07	4.54	3.80	3.42
Capital stock	Chained Laspeyres	3.75	4.39	3.25	3.07
VICS	Chained Törnqvist	4.02	4.52	3.72	3.36
Capital stock	Chained Törnqvist	3.73	4.38	3.22	3.05
With R&D					
VICS	Chained Laspeyres	4.11	4.54	3.97	3.35
Capital stock	Chained Laspeyres	3.77	4.39	3.36	3.03
VICS	Chained Törnqvist	4.07	4.52	3.90	3.29
Capital stock	Chained Törnqvist	3.76	4.38	3.33	3.01

Source: Office for National Statistics and own calculations.
Note: R&D investment available only from 1981.

TABLE 4

Average annual growth rates of VICS (hybrid method)
R&D included, per cent per year

Index	1950-2013	1950-1979	1979-2000	2000-2013
Whole economy				
Chained Laspeyres	3.94	4.27	3.80	3.39
Chained Törnqvist	3.91	4.27	3.75	3.34
Market sector				
Chained Laspeyres	4.09	4.52	3.97	3.29
Chained Törnqvist	4.06	4.53	3.92	3.23

Source: Office for National Statistics and own calculations.
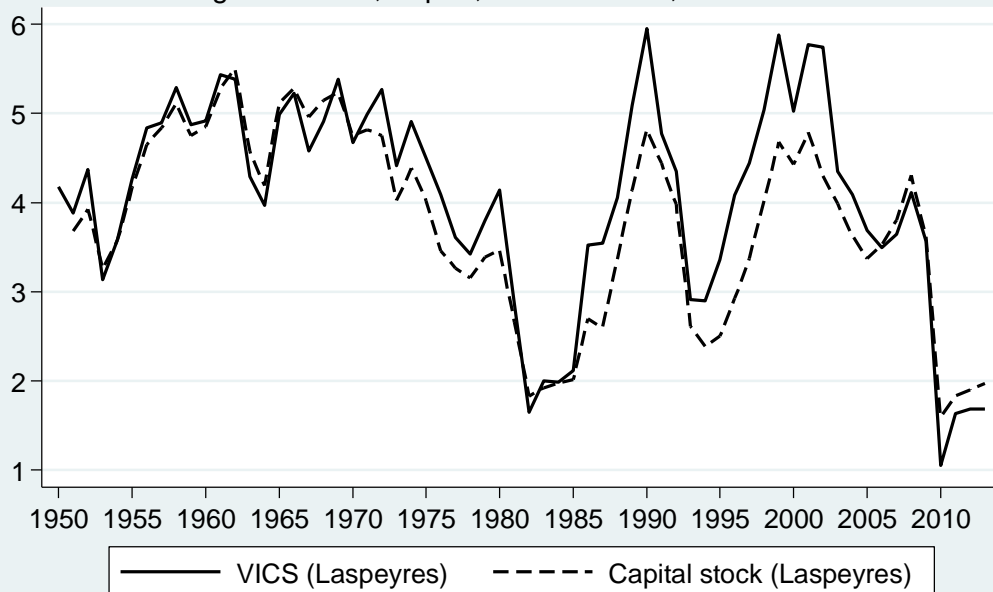Note: R&D investment available only from 1981.

CHART 1

Capital stocks and capital services in the UK (ex post method)
growth rates, % p.a., whole economy, 1950-2013
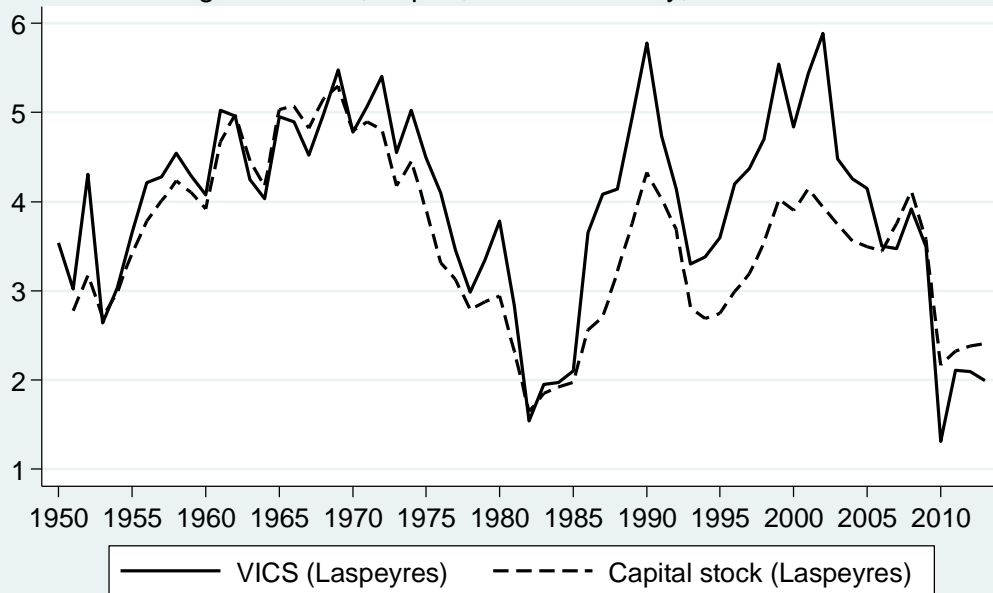
Note: R&D excluded. Capital stock lagged one year.

CHART 2

Capital stocks and capital services in the UK (ex post method)
growth rates, % p.a., market sector, 1950-2013

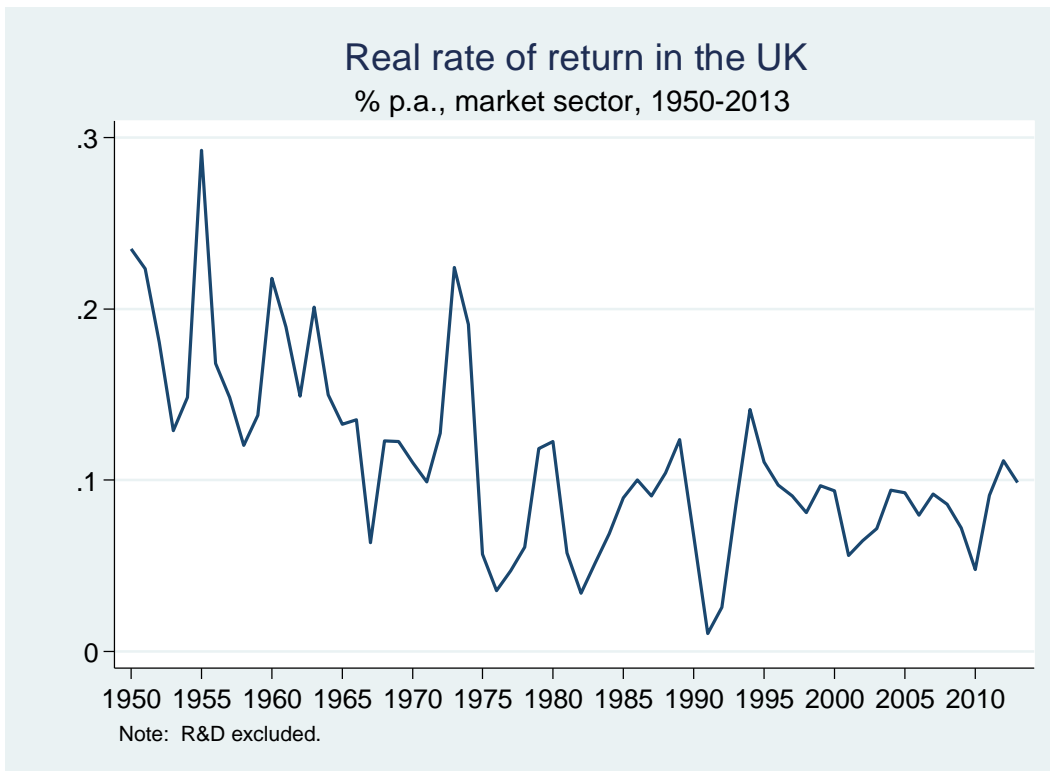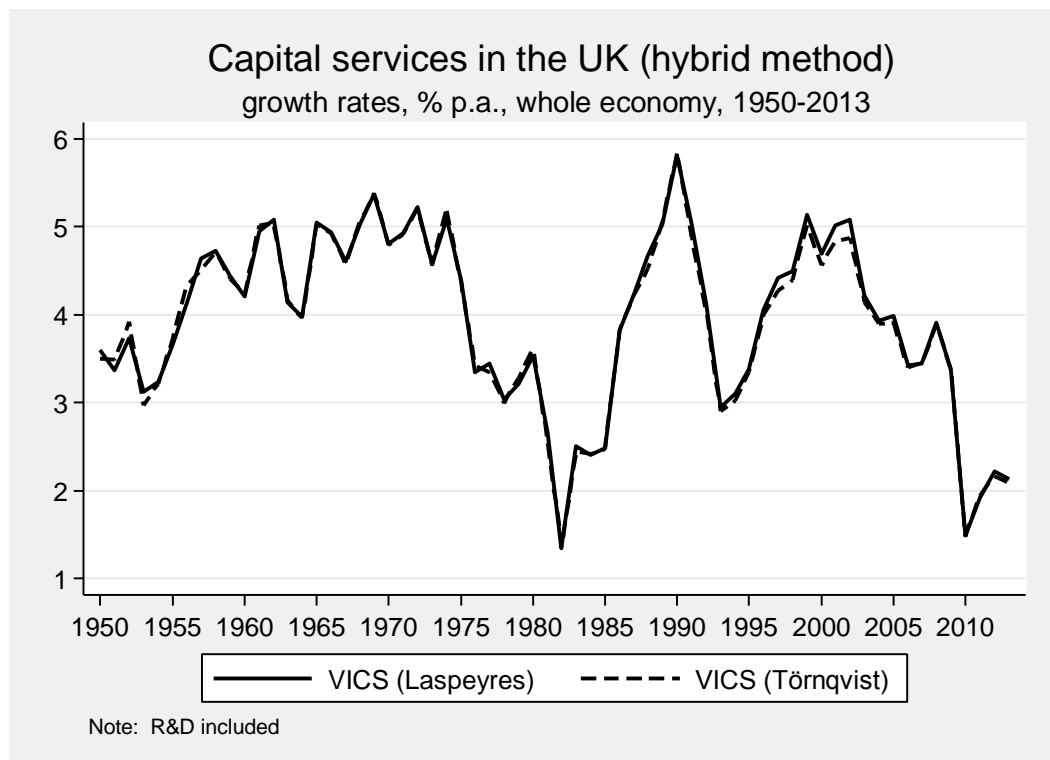Note: R&D excluded. Capital stock lagged one year.

CHART 3

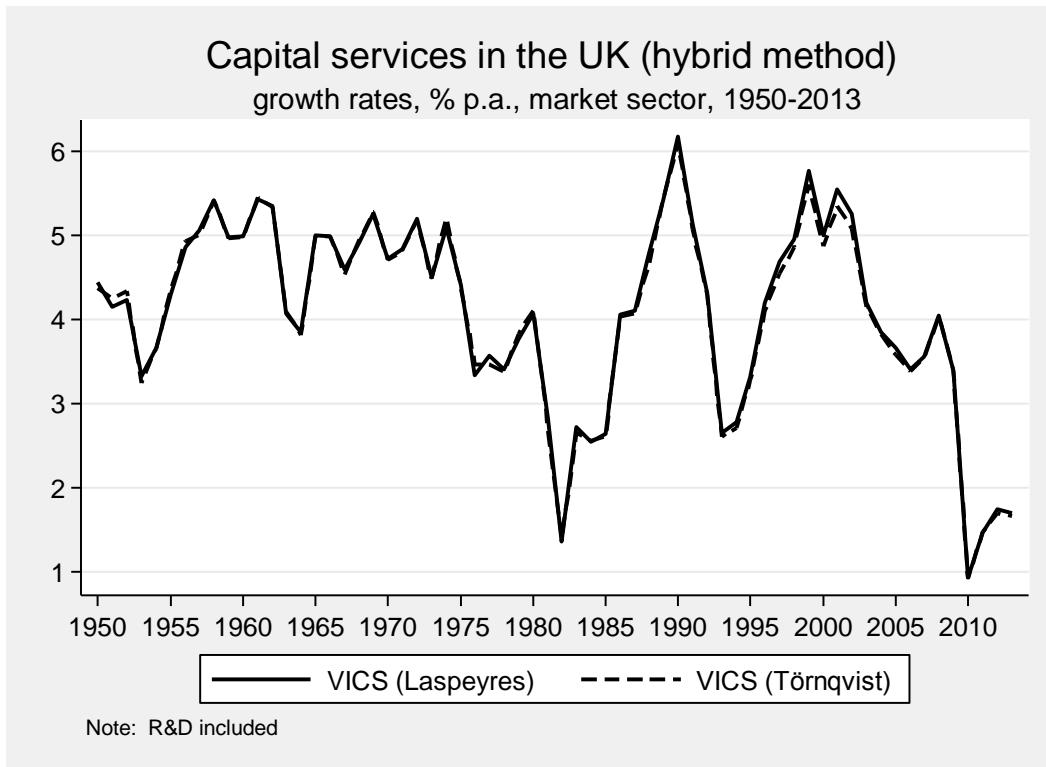## Real rate of return in the UK
% p.a., market sector, 1950-2013

Note: R&D excluded.

CHART 4

Capital services in the UK (hybrid method)
growth rates, % p.a., whole economy, 1950-2013

VICS (Laspeyres) — — — VICS (Törnqvist)

Note: R&D included

CHART 5

Capital services in the UK (hybrid method)
growth rates, % p.a., market sector, 1950-2013

Note: R&D included

CHART 6

Hybrid and ex post estimates of VICS compared
market sector, per cent per year

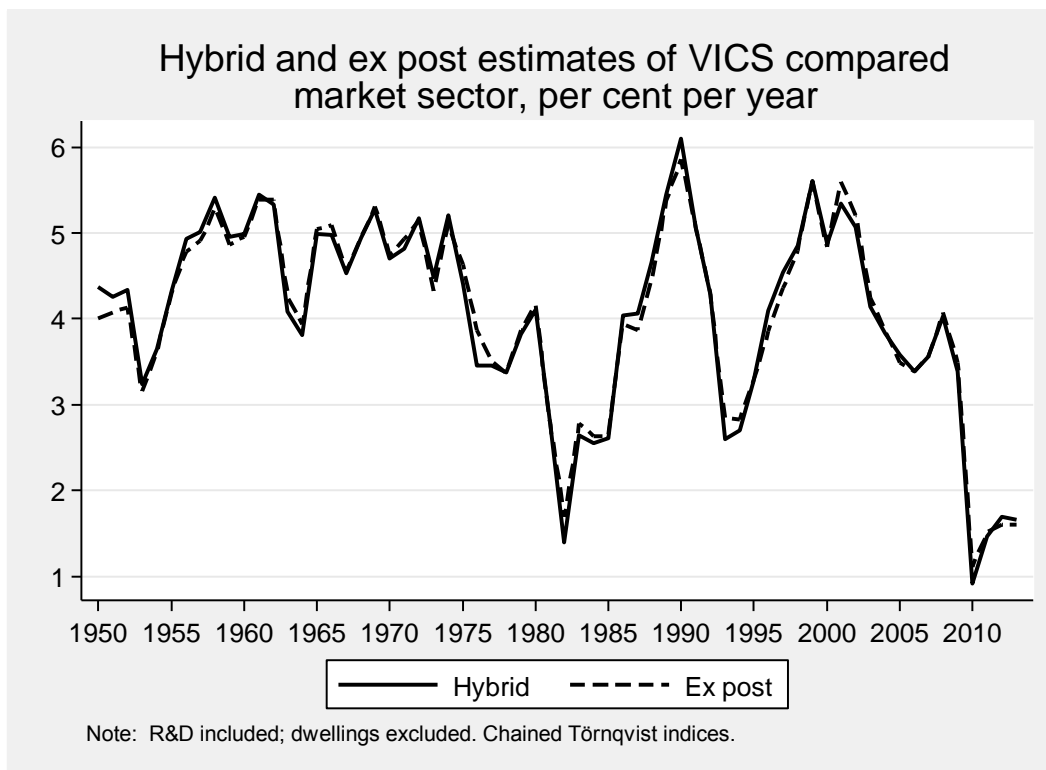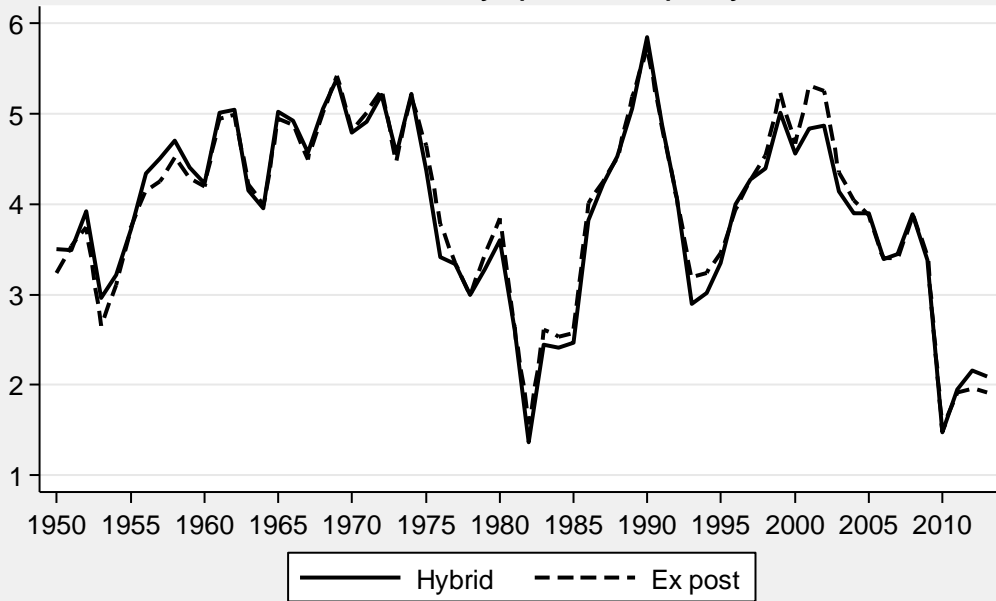Note: R&D included; dwellings excluded. Chained Törnqvist indices.
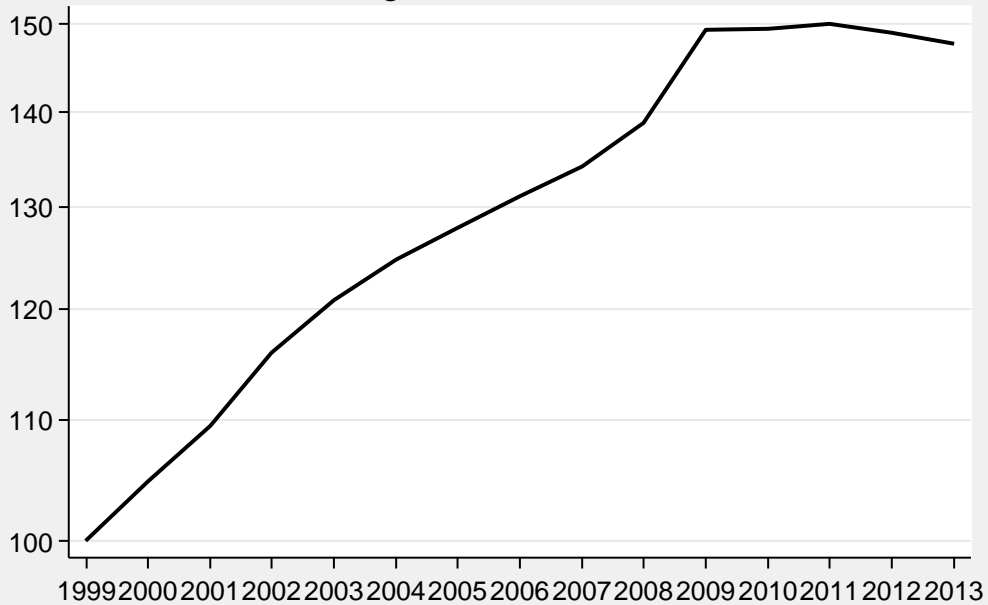
CHART 7

Hybrid and ex post estimates of VICS compared
whole economy, per cent per year

Note: R&D included; dwellings excluded. Chained Törnqvist indices.
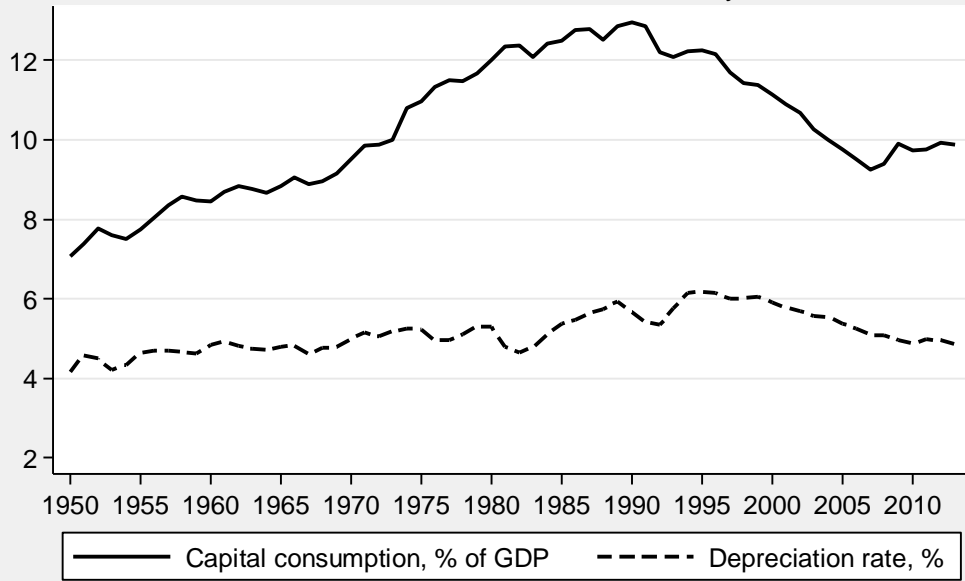
CHART 8

Capital intensity in the UK market sector
log scale, 1999=100

Note: Capital intensity is capital services (hybrid Törnqvist) per hour worked. R&D included.
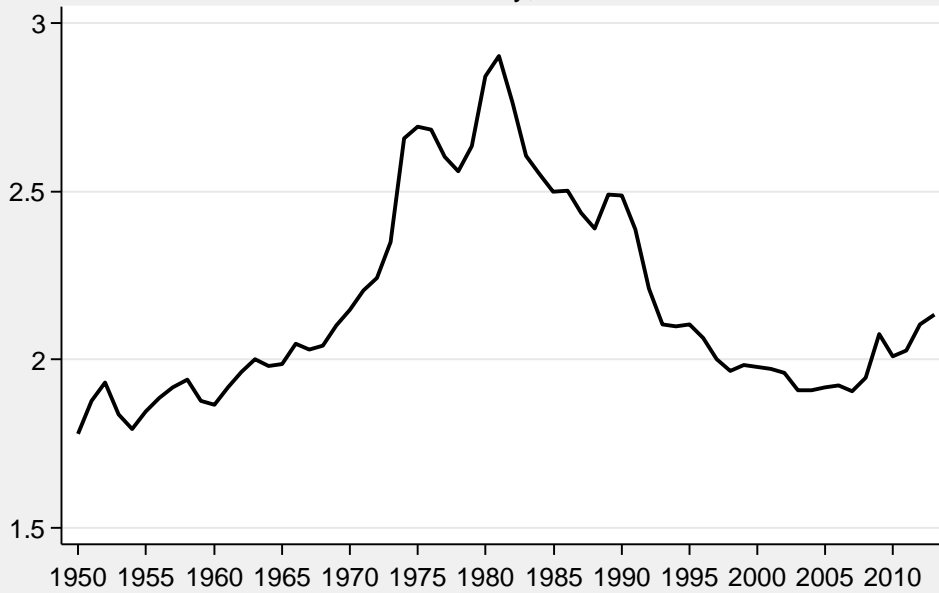
CHART 9

Capital consumption and depreciation rate in the UK
% of GDP and % of net assets, whole economy, 1950-2013

Capital consumption, % of GDP   Depreciation rate, %

Note: R&D included; dwellings excluded. Depreciation, net assets and GDP in current prices.

CHART 10

Capital-output ratio in the UK
whole economy, 1950-2013

Note: R&D included; dwellings excluded. Capital (net assets) and GDP in current prices.

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