Methods explained

Methods explained is a quarterly series of short articles explaining statistical issues and methodologies relevant to ONS and other data. As well as defining the topic areas, the notes explain why and how these methodologies are used. Where relevant, the reader is also pointed to further sources of information.

Perpetual inventory method

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SUMMARY

This article outlines where the perpetual inventory method (PIM) is used within the Office for National Statistics and discusses in detail the key parameters of a PIM; the asset service life, the retirement distribution and the depreciation function. It covers why these parameters are of importance in the application of a PIM and also highlights some of the key related conceptual issues. The article then concludes with an example illustrating how a PIM can be used to estimate gross capital stock, consumption of fixed capital and net capital stock, which are the principal uses of a PIM.

The perpetual inventory method (PIM) is an economic model that enables balance sheets (or stocks) to be calculated from the associated investment flows. It does this by accumulating past purchases of assets over their estimated service lives to estimate a gross capital stock measure. The main source of input data for the PIM is capital investment data (in constant price terms). Data are also required on the service life of the asset to ensure that the resultant gross capital stock measure does not include the stock of an asset that is no longer of any economic use.

In order to calculate estimates of consumption of fixed capital and net capital stock, it is also necessary to specify a depreciation function to account for the fact that assets lose value over time as a result of being subject to wear and tear as the asset ages.

Within the Office for National Statistics (ONS) a PIM is predominantly used to estimate gross capital stock, consumption of fixed capital and net capital stock for the UK National Accounts. Direct measurement of these series would be almost unwieldy, but efforts are now under way to pilot the future use of Whole of Government Accounts to measure the central government sector directly, with plans to extend this to local government.

These series (which are broken down by asset type, sector and industry) can be found in the *Capital Stocks, Capital Consumption and Non-Financial Balance Sheets* publication, which is produced on an annual basis. These data also form part of the non-financial balance sheet and can traditionally be found in Chapter 10 of the *Blue Book*. The tables include estimates of the market value of non-financial assets in the UK. Where market valuations are not available, net capital stocks are modelled using a PIM as a proxy.

This article primarily discusses the parameters that are central to the application of a PIM:

- the asset service life
- the retirement distribution, and
- the depreciation function

Asset service life

The *National Accounts Concepts, Sources and Methods* publication states that the most important assumption for a PIM is the estimated life length of an asset. This refers to the length of time, on average, that an asset is expected to be economically useful as it does not have an infinite lifespan. The life length of an asset captures how long the investment in a given asset remains in the capital stock measure.

Life-length means vary by asset type: for example, some buildings are estimated to have a life-length mean of 100 years whereas information and communications technology (ICT) assets, such as computers, are estimated to have a life-length mean of five years. There are also variations in mean life length within these broad asset types reflecting the heterogeneity of assets and the differing uses. For example, computer hardware is currently measured within the broad asset category 'plant and machinery'. Wallis (2005) showed that, when modelling capital services, it is important to treat computers as a separate asset because of the significantly shorter life length (five years) they have relative to the life lengths of other plant and machinery assets. This is because of the effect there is when modelling asset rental prices.

Estimates of assets life-length mean also depend on the year of purchase. Over a long time period it is observed that, in general, some life-length means have fallen. This may reflect technical progress.

These estimates of asset service lives relate to normal wear and tear and planned (or foreseeable) obsolescence. An asset is said to be made obsolete when it is no longer used in production, despite the fact that the asset could still be economically used. This is best illustrated with ICT assets where there is rapid technological change. A piece of computer hardware, which is a few years old, may not be able to support newly developed computer software, meaning that the computer hardware is obsolete. This leads to that asset being withdrawn from the production process, despite still being of economic use in its own right. A relatively large range of assets incorporate ICT-based assets when being used for production. In recent times, there has been a shift to investment in ICT assets, which are more susceptible to higher rates of obsolescence.

In practice, it is very difficult to accurately estimate asset life-length means because directly observed data on life-length means are not readily available. Instead, a combination of administrative data and expert opinion are used as the basis of these estimates. The Organisation of Economic Co-operation and Development Manual on Measuring Capital identifies the following as the main sources for estimating life-length means:

- asset lives prescribed by tax authorities
- company accounts
- statistical surveys
- administrative records
- expert advice, and
- other countries' estimates

The sources used to compile the estimates within UK National Accounts have changed over time. For some buildings, estimates of life-length means are available dating back to 1828. These first sets of estimates were produced by unofficial compilers based on external sources. More recently, other sources have been used, including information on depreciation allowances from HM Revenue & Customs, which was then known as the Inland Revenue. The Inland Revenue specified the time period over which depreciation could be deducted from profits before calculating tax liabilities, forming the basis of life-length mean estimates.

The most recent set of UK estimates makes use of more direct estimates, based on a study undertaken by the National Institute of Economic and Social Research (NIESR) in 1993 at the request of ONS. One of the main findings was that life-length means were previously overestimated. As a result of this overestimate, published net capital stock was artificially high, as the total amount of depreciation was spread out over a longer life length. ONS recognises this area as one of the most problematic in terms of measurement and it is currently under review.

Retirement distribution

Asset service lives are an estimate of how long an asset is expected to be of economic use on average. However, in practice, assets will not be available for use for this exact period of time: some assets will not last as long, others will last longer. To account for this, the PIM assumes that there is a retirement distribution around the estimated life-length mean, which can also be referred to as the discard pattern.

The retirement distribution shows the probability of the asset being retired/discarded around the life-length mean. There are several different distributions that can be modelled within the PIM. For example, some countries model a retirement distribution that is normally distributed. In the UK, the current approach is to model a uniform retirement distribution, also referred to as a linear distribution. This approach allocates equal probabilities to the asset being retired from the moment when it is first purchased, to twice its average life length. This is illustrated in **Figure 1**, where it is assumed that the asset has a life length of ten years.

The NIESR study showed that the estimates of capital stock and capital consumption were not very sensitive to the choice of retirement distribution used. Therefore, it is generally considered that this is the least important of the three parameters that are used in a PIM. However, a report by Meinen, Verbiest and de Wolf (1998) concluded that retirement patterns should not be treated as insignificant and they can have notable effects on the resultant capital stock and capital consumption estimates. They recommend that a delayed-linear distribution should be used. As shown in Figure 1, the problem with assuming a linear retirement distribution is that it states that an asset can be retired immediately after purchase, which is somewhat unrealistic. A delayed-linear retirement distribution addresses this by assuming that the period of potential retirement is shorter than this, which is symmetric around the life-length mean. There is no single defined delayed-linear distribution, but as shown in **Figure 2**, this period is symmetric around the life-length mean. In this example, it is assumed that the retirement period is between 75 per cent and 125 per cent of the life-length mean, which is again assumed to be ten years.

The PIM uses gross fixed capital formation data, producer price indices (to deflate the current price capital investment and other surviving past capital stocks data), life lengths and patterns of retirement distributions to model estimates of gross capital stock at a particular point in time.

Depreciation function

According to the *System of National Accounts 1993*, consumption of fixed capital

> represents the amount of fixed assets used up, during the period under consideration, as a result of normal wear and tear and

Figure 1
Linear retirement distribution

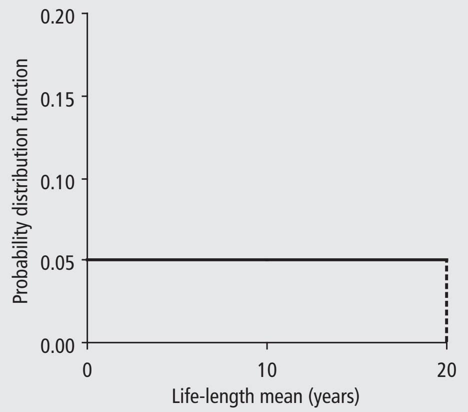
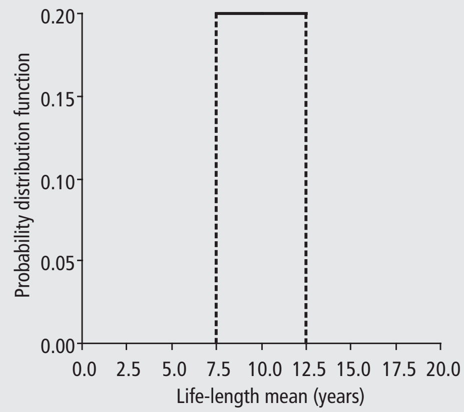


Figure 2
Delayed-linear retirement distribution



foreseeable obsolescence, including a provision for losses of fixed assets as a result of accidental damage which can be insured against

and must be calculated for all asset types (see **Box 1** for details). This is essentially the loss in value of an asset as it ages, although it is not exactly the same as depreciation – the latter is measured at historical cost (that is, based on the value of the asset when it was first purchased) whereas capital consumption is based on current replacement values. This means that it is based on the current value of an asset, not when it was first purchased.

Within ONS, there are three main uses of the estimates of consumption of fixed capital:

- to convert gross based estimates into the net estimates (such as gross operating surplus), for all sectors of the UK economy
- application to non-market sectors, where capital consumption forms the only component of gross operating surplus. By definition, this means that the estimate of net operating surplus is zero, which is consistent with the concept of zero profit in these sectors, and
- to estimate the input of capital into the production process for government sectors by the UK Centre for the Measurement of Government Activity

In order to calculate estimates of consumption of fixed capital, it is necessary to specify a depreciation function within the PIM. Depreciation measures the loss in economic value of an asset as it ages, due to that asset being subject to wear and tear. In terms of investment, depreciation can be thought of in two ways:

- the fall in the value of capital stock if there were no further gross investment at the whole economy level, or
- the amount of investment needed to maintain the value of the capital stock at its current level

The rate of depreciation varies by asset type and can also change over time (reflecting the fact that estimates of asset service lives can vary over time). The concept can be illustrated by producing the age-price profile of an asset, showing the relationship between the age of an asset and its value.

There are two commonly used depreciation functions that can be applied in a PIM: arithmetic (straight-line method) or geometric (reducing-balance method). An arithmetic depreciation function is based on a constant amount of depreciation over that asset's life length, with the market value of the asset falling to zero at the end of the asset's service life. A geometric depreciation function is based on a constant annual rate of depreciation over the asset life. This is shown in **Table 1**.

Assuming asset A has a life length of ten years, it can be seen that it is subject to an arithmetic depreciation rate. The market value of asset A when it was first purchased was £100. An arithmetic depreciation function means that there is a constant amount of depreciation over that asset's life. In this example, this results in the asset losing £10 of its market value on an annual basis until it reaches a market value of zero at the end of its life.

The market value of asset B when it was first purchased was also £100, but a geometric depreciation rate of 10 per cent is assumed.

Table 1
The effect of different depreciation methods

£

	Market value of asset A	Market value of asset B
Year	Arithmetic depreciation	Geometric depreciation
0	100	100
1	90	90
2	80	81
3	70	73
4	60	66
5	50	59
6	40	53
7	30	48
8	20	43
9	10	39
10	0	35

Box 1
Fixed assets

The *National Accounts Concepts, Sources and Methods* manual explains that there are two types of fixed assets in the UK National Accounts: tangible and intangible. Estimates of gross capital stock, consumption of fixed capital and net capital stock are available at this level of asset breakdown.

Tangible fixed assets:

- dwellings: refers to all types of housing as well as the expenditure on the construction of new dwellings and improvements to existing ones
- other buildings and structure: covers all buildings (other than dwellings) and most civil engineering and construction work. This also includes machinery and equipment that form a key part of buildings (for example, lifts)
- plant and machinery: tends to refer to traditional plant and machinery as identified in commercial accounts
- vehicles, ships and aircraft: covers vehicles that are intended for use on public roads and ships and aircraft that are owned by registered UK companies

Intangible fixed assets:

- mineral exploration: covers the costs of drilling and all related activities (for example, the costs of relevant surveys). The investment in this knowledge asset is independent of whether the outcome of drilling is successful or not
- own-account software: refers to software that is developed in-house and not intended for final sale, but for internal use. This is unlike purchased software, for which there is a market transaction. It also includes the creation of software originals intended for subsequent reproduction. Revised estimates of own-account software were included in the UK National Accounts in *Blue Book* 2007
- copyright and license costs for artistic and literary originals: refer to artistic output that is recorded, which encompasses, for example, expenditure on original films, sound recordings, and manuscripts. This expenditure relates to both the physical original and the copyright attached to it

This means that one year after the asset was first purchased, 90 per cent of the asset's market value will remain, 81 per cent after the second year, 72.9 per cent after the third year, and so on. Table 1 shows the market value of both assets at the end of each year. By definition, assuming a geometric depreciation rate means that the market value will never technically reach zero. However, the asset can be thought to be of no 'real' value (to zero decimal places) at the end of year 51.

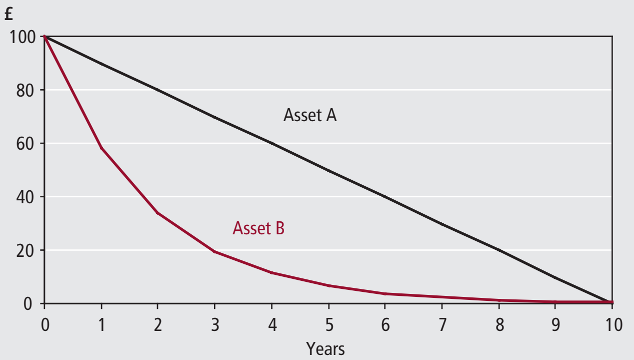
The UK National Accounts apply an arithmetic rate of depreciation to a PIM for the estimates of fixed consumption and net capital stock. This approach is simpler and tends to be the preferred method internationally.

One application of a geometric depreciation function within ONS is in the annual estimates of capital services. Capital services are the measure of capital input that is suitable for modelling productivity, as they measure the flow of services from capital assets that are more suitable for reflecting the input of capital into the production process. There are four main stages in the estimation of capital services, the first of which is to calculate a productive capital stock measure. Although in theory this differs from a net capital stock measure (because of the conceptual difference between depreciation and decay), it can be shown that by assuming a geometric depreciation rate in the PIM, this difference disappears (ONS 2007).

In the above example, asset A was assumed to have a life length of ten years. As a result of assuming a geometric depreciation rate of 10 per cent, asset B ended up having a life length of 51 years. There is a clear inconsistency in the service lives of these assets. However, in deriving which rate to apply to model the net (productive) capital stock for capital services, the geometric rate is a function of the life-length mean (see Wallis 2005). This means that the same life lengths are used for the capital stock measures and for modelling capital services. In terms of the above example, this would mean that asset B would have to be subject to an annual geometric depreciation rate of 42 per cent (as shown in the age-price profiles illustrated in **Figure 3**).

It should be noted that ONS also takes into account the premature scrapping of plant and machinery in their PIM models (with the exception of modelling the net (productive) capital stock in the estimation of capital services). It can be argued that, when an economy experiences a recession, firms are more likely to scrap their plant and machinery as they are unable to sell these assets for further use. Therefore, these assets are removed from the production process before the end of their asset service life. It is assumed that premature scrapping would not affect assets such as vehicles and buildings as second-hand markets for these assets are more prevalent. This results in the asset remaining in the stock measure for the whole economy.

Figure 3
Age-price profiles: market value over time



Gross capital stock, consumption of fixed capital and net capital stock

Using capital investment data and making assumptions on the life length, the retirement distribution and the method of deprecation, the PIM can be used to model estimates of capital stock and capital consumption. This article concludes with a simple example illustrating how estimates of gross capital stock, consumption of fixed capital and net capital stock are derived using a PIM. In practice, these estimates are produced on an industry, sector and asset-type basis, and aggregated up to form whole economy estimates. For simplicity, the example assumes that there is only one industry. Also, for simplicity, the retirement distribution is not modelled here, but is discussed at the end of this section in terms of how it would be accounted for in practice.

Assume that there are three assets, A, B and C, which have life-length means of 50 years, ten years and five years, respectively, and that the following one-off investments are made:

- £200 in asset A in year 1
- £50 in asset B in year 3
- £10 in asset C in year 5

Gross capital stock is calculated as the sum of past purchases of fixed assets excluding assets that are no longer of economic use (in other words, have reached the end of their service life). By the end of year 10, assets A and B are still of economic use. Asset A will have reached the end of its service life in year 50 while asset B is no longer of economic use in year 13, ten years after being first purchased. For asset C, as the service life is assumed to be only five years, it is no longer included in the gross capital stock estimate for year 10. This is shown in **Table 2.**

To estimate consumption of fixed capital, a depreciation function needs to be modelled within the PIM. Assuming an arithmetic depreciation function, it can be worked out that consumption of fixed capital is £4, £5 and £2 for assets A, B and C, respectively, on an annual basis. This measures the amount of capital that is used up in production that year. This is calculated by taking the initial market value of the investment in the asset and dividing it by its corresponding life-length mean.

Table 2
Gross capital stock

£

Year	Market value of asset A	Market value of asset B	Market value of asset C	Total market value
1	200	0	0	200
2	200	0	0	200
3	200	50	0	250
4	200	50	0	250
5	200	50	10	260
6	200	50	10	260
7	200	50	10	260
8	200	50	10	260
9	200	50	10	260
10	200	50	0	250

The net capital stock measure is derived by subtracting the estimates of consumption of fixed capital from the gross capital stock measure. The estimates of net capital stock are shown in **Table 3**.

Although ONS models an arithmetic depreciation rate in estimating consumption of fixed capital and net capital stock, it is also possible to calculate these using a geometric depreciation rate. To be consistent with the assumed life-length means stated above, assets A, B and C would have to be subject to annual depreciation rates of 12, 37 and 46 per cent, respectively. The estimates of net capital stock using a geometric depreciation rate are shown in **Table 4**.

Modelling a geometric depreciation rate in a PIM means that the net capital stock is calculated as:

$$K^i_{at} = \sum_{\tau=0}^{\infty}(1-\delta^i_{a,t-\tau})^{\tau} \cdot I^i_{a,t-\tau}$$

where K is the volume of net stock for a particular asset a in industry i at the end of period t (beginning of period $t+1$), I is investment in a particular asset a in industry i and δ is the rate of depreciation for an asset purchased in a particular year.

Comparing Table 3 and Table 4, it can be seen that consumption of fixed capital is much higher when assuming a geometric depreciation rate. As shown in Figure 3, the age-price profile of an asset when assuming a geometric depreciation rate is concave relative to the straight line profile that is seen when an arithmetic depreciation function is used. This illustrates the fact that the amount of depreciation is much higher (relative to modelling an arithmetic rate) in the first few years of the asset life when assuming a geometric rate, before slowing in latter years. Hence, the age-price profile will always be concave to the origin, explaining the estimates of net capital stock presented in Table 3 and Table 4.

In practice, the PIM also takes into account the retirement distribution of assets which has not been modelled in the above example. If an asset is assumed to have a life length of ten years, a delayed-linear distribution means that the asset may be retired symmetrically around the life length, for example between eight and 12 years. Since the area under the retirement profile is known to sum to one, it is possible to calculate the probability of when the asset will no longer be of economic use. In this example, the probability of the asset being retired between eight and nine years is 25 per cent, and the same between nine and ten years (this is a feature of modelling a uniform distribution). Since life lengths and retirement distributions are asset and industry specific, the modelling of retirement distributions are of importance.

Table 3

Net capital stock – arithmetic depreciation rate

£

Year	Market value of asset A	Market value of asset B	Market value of asset C	Total market value
1	200	0	0	200
2	196	0	0	196
3	192	50	0	242
4	188	45	0	233
5	184	40	10	234
6	180	35	8	223
7	176	30	6	212
8	172	25	4	201
9	168	20	2	190
10	164	15	0	179

Table 4

Net capital stock – geometric depreciation rate

£

Year	Market value of asset A	Market value of asset B	Market value of asset C	Total market value
1	200	0	0	200
2	176	0	0	176
3	155	50	0	205
4	136	32	0	168
5	120	20	10	150
6	106	13	5	124
7	93	8	3	104
8	82	5	2	89
9	72	3	1	76
10	63	2	0	65

Conclusion

This article has summarised the main areas within ONS where PIM models are utilised, principally in the estimation of gross capital stock, consumption of fixed capital and net capital stock. These estimates are published in the annual publication *Capital Stocks, Capital Consumption and Non-Financial Balance Sheets*. The key parameters of a PIM, asset service life, retirement distribution and the depreciation function, are discussed in detail in terms of their role within the PIM and with regard to some of the key related conceptual issues. The article then concludes with a theoretical example of how the PIM is used in practice within the UK National Accounts.

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