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Keskusteluaiheita - Discussion papers

No. 395

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ESTIMATING STOCKS OF FIXED CAPITAL: METHODS USED IN DIFFERENT COUNTRIES

ISSN 0781-6847 14.02.1992

LEHTORANTA, Olavi, ESTIMATING STOCKS OF FIXED CAPITAL: METHODS USED IN DIFFERENT COUNTRIES, Helsinki: ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of Finnish Economy, 1992, 73 p. (Keskusteluaiheita, Discussion Papers, ISSN 0781-6847; no. 395)

ABSTRACT: This paper reviews perpetual inventory methods used in different countries for estimating stocks of fixed assets. The main sources used in this survey are various OECD documents and working papers. A conclusion is that the capital stock figures in different countries defy comparison in many respects. There is a great need to harmonize capital stock estimating methods. There is especially a need to collect more information about the way in which average lifetimes of assets have changed or are changing over time.

KEY WORDS: measurement of capital, perpetual inventory methods

ESTIMATING STOCKS OF FIXED CAPITAL: METHODS USED IN DIFFERENT COUNTRIES

CONTENTS

1. Introduction

Capital stock estimates have great importance for economic analysis both as direct measures of capital as a factor of production and as a means of estimating consumption of fixed capital. In addition, an overview of the national economy as presented in the national accounts is not really complete if the national balance sheet presenting tangible wealth can not be presented (OECD 1990b).

Stocks of capital goods are primarily important in the compilation of capital-output ratio's and production functions. A given statistical capital stock measure may not be appropriate, however, in explaining particular phenomena and relationships in economic theory.

Furthermore, it is important to realize the inability of static equilibrium concepts, i.e. stock measures, to analyse and explain continuous economic processes. Behind the complex relationship between the level and composition of output and the different contributions made by the various factors of production lies a wide variety of dynamic forces of economic change, such as technical progress, which defy statistical definition (Ward 1976).

The concept of capital in economics has not always been clearly defined and the problem of its measurement arises because the same term is used to serve different purposes. For each separate context an appropriate measure should be applied.

One of the main reasons for deriving measures of real capital is to try and explain the relative importance of capital and labour inputs in the process of production. The recent slowdown in productivity which has occurred in most countries in the post 1973 period has prompted speculation among economists that the phenomenon may be due in part to mismeasurement of the capital stock (OECD 1989).

Estimates of the capital stock may indeed be subject to various measurement errors. Productivity measurements, and the explanation for changes in growth rates depend critically on the accuracy of the measurement of the quantity of capital, its composition, average age, and other characteristics.

Accurate capital stock data are a critical input in the evaluation of productivity growth. An accurate knowledge of capital stock data would enable a more precise evaluation of the ability of industries to compete and adjust when faced with reduction or elimination of tariff barriers. The capital stock estimates derived by many statistical offices are nevertheless regarded primarily as a means of estimating capital consumption for the national accounts.

There are essentially two methods for estimating stocks of fixed capital: direct measurement of the stock and so-called perpetual inventory calculations. Estimates of the capital stock may be based either on benchmark surveys of capital goods or, more commonly, on the perpetual inventory method (PIM).

Direct measurement includes three basic methods: surveys of physical assets, surveys of book values and surveys of insured values. Only limited use has been made of direct measurement because the existing data are incomplete and because there are problems in valuation of the assets in the stock. Compiling statistics on stocks of capital goods, however, requires use of direct observation (enquiries or interviews) every now and then. The most common way of conducting enquiries is by sending out questionnaires. The alternative is to make use of secondary material and supplementary assumptions.

Commonly, capital stock data are constructed by a simulating procedure known as the perpetual inventory method. This method makes use of existing investment series. It simulates capital stock from cumulated past capital formation expenditures appropriately adjusted for discards.

The perpetual inventory method involves adding up capital formation over a relevant period and subtracting them at the rate they are scrapped from the capital stock. As statistical data on scrapping are usually lacking, they have to be estimated. Nowadays, frequency functions for the retirement of capital goods are used. These reflect the dispersion of scrapping around the average lifetime of different types of assets. In all OECD countries capital stock estimates are derived by the PIM.

The 'data' on capital stocks produced in this indirect manner depend on assumptions concerning the lifetimes of capital goods. Therefore the accuracy of the overall results is questionable. Also the structure of the stocks by vintage is the result of the assumptions concerning the lifetimes and of the frequency (mortality) function chosen.

Several distribution functions have been used by different countries. More important than the mortality function chosen, however, is the way the average lifetimes are determined. Mostly this is done by crude assumptions or expert-guesses. Empirical data on lifetimes of capital goods are, in general, very scarce.

As stated in the programme paper of the Stockholm Conference on Technology and Investment in January 1990, today we need better methods for measuring and evaluating stocks and flows of physical capital and intangible capital and better understanding of the complementaries between them. For this purpose, it seems desirable to search for alternative techniques for measuring the capital stock in order to determine whether the basic PIM may be yielding misleading results in these circumstances, and if so how serious the discrepancy is and whether, for certain sectors and assets at least, superior methodology might be developed.

As is often pointed out, a major advantage of the PIM is its generality. It can be applied to all sectors and all assets. In addition, it can be modified to match almost any other statistical measure of capital. That is why, I will, in the following, primarily review the perpetual inventory methods used in different countries. The main sources used in this survey have been various OECD documents and working papers.

2. Definition of capital stocks

The stock of fixed capital in an economy is defined as consisting of durable and reproducible tangible assets. Capital assets consist of the goods that are included in gross fixed capital formation. In general, the goods are durable (lasting more than one year), tangible (intangible assets like patents and copyrights are excluded), fixed (inventories and work in progress are excluded, mobile equipment is included) and reproducible (natural forests, land and mineral deposits are excluded).

The following types of goods are included in fixed capital formation: machinery and equipment, vehicles, residential and other buildings, construction works, land improvements, orchards and plantations. Equipment purchased for use by the military are excluded from capital formation. The assets are usually grouped into the following broad categories of capital: buildings and structures, plant and machinery (including office equipment) and transport equipment.

As physical quantities of different types of assets cannot be aggregated, asset values in constant prices are used to construct a volume measure. The term capital stock denotes the value, at a given point in time, of the capital assets that are installed in the facilities of a producer. This value can be calculated as a gross or net basis. Gross valuation is generally thought to be more appropriate for measuring the contribution of capital assets to production. Net valuation is thought to be more appropriate for measuring the wealth of asset holders (Blades 1989).

A measure of the capital stock can look backward or forward. In the former case it estimates the productive capacity of existing assets, while in the latter case it estimates the sum of undiscounted future outputs derived from the assets. If the lifetime of all assets were infinite, the two measures would necessarily agree.

The relation between output-producing capacity of an asset and its future productive potential depends on the asset's remaining service life. The current output-producing capacity depends on how many assets there are in existence at present. The future output stream depends in addition on the age distribution of the assets in question.

In principle, the backward-looking measure gives us the gross stock of capital whereas the forward-looking measure gives us the net stock of capital. The net stock differs from the gross stock in that it is a measure of the value of the future stream of capital services the asset can provide. Thus, these two measures of the capital stock perform quite distinct functions in economic analysis.

Theoretically, the gross stock concept relates to the instantaneous productive capacity of capital or the flow of capital services. In this context we speak also of productive stocks of capital (Hansson 1989). The total productive stock of capital is defined as the volume of capital used in the production process of a country at a given time. In other words, it represents the total volume of the existing physical productive assets available.

According to this definition of capital, one lot of capital goods constitutes 'more capital' than another lot of capital if more output can be produced this year with the first lot (when the production function and the labour force are the same) (Usher 1976).

Gross capital stock expresses the value of assets on the assumption that there has been no decline in their productive capacity or efficiency due to age. Each asset in the gross stock is therefore valued at the price at which it would be purchased if it were still new.

For the net capital stock, the same assets are valued at the prices at which they would be purchased if they were required on the open market in their present state. The reduction in price over an asset's lifetime reflects the fact that each year there is an decline in the future income stream that the asset can be expected to generate. Since present-state prices are not generally observable, they are estimated by assuming that asset values decline in some regular fashion over their lifetimes. In practise, the most common assumption is either that prices decline by an equal amount each year (straight-line depreciation) or by an equal percentage each year (declining balance depreciation).

The net stock represents the cumulated depreciated value of the existing gross stock of capital. It is loosely related to a balance sheet definition of capital since this is also designed to reflect the notional, remaining, income-generating capacity of the existing vintage composition of capital stock. However, book values reflect accounting concepts and usually relate to the accumulated historical costs of different years, rather than to future benefits and real potential output and earning capacity. In many cases, these allowances also ignore price changes and imply average lifetimes for fixed assets which are unrealistically short (Ward 1976)

The earning capacity of capital is affected by its average age and expected survival pattern as well as by its composition and distribution between different industrial sectors.

In summary, the net stock concept concerns the real wealth of capital. This measure is equal to the present value of the future income stream from the existing capital stock. The changing market value of an asset as it ages reflects the discounted stream of expected quasi-rents over its shortening remaining lifespan. Even if the asset's productive qualities remain unchanged throughout its life, it will usually decline in value at an accelerating rate as it ages.

The market value of existing capital is influenced by the evaluation on the market of the expected value of future income generated by the capital, as well as the rate of interest which is relevant for discounting the value of future income to the present period. For this reason the net worth value of assets declines with growing age, regardless of the fact that their capacity to participate in production may not decrease, or may decrease only insignificantly.

Economic depreciation is determined by changes in the real wealth of capital while physical deterioration is determined by changes in the gross capital stock. The two dimensions of capital are formally related to each other by the age-efficiency function for capital and the market interest rate. In other words, a dual relationship exists between gross and wealth stocks of capital (Hansson 1989).

Real wealth differs from the other measures of capital in real terms in a number respects: for example, any technical change that enhances the productivity of capital goods increases the quantity of real wealth as well.

Early studies of capital were primarily concerned with producing estimates of total national wealth. The primary focus of attention in this review, however, is not the wealth stock but the specific problem of measuring capital as a factor of production.

The concept of capital on which the SNA's (System of National Accounts) stock estimates rest is that of capital measured by its cost. Measured by its cost, capital provides a basis for determining if the use of factors of production is becoming more or less efficient over time.

It has been argued that cost-based measures of capital are not appropriate for determining industrial capacity, or for analyzing the determinants of investment or production, because identical amounts of real capital will represent different capacities to produce goods and services. For such analyses, capital should be measured in terms of its ability to contribute to production. In lieu of such measures, rough allowances for embodied technological change - the costless quality change - are sometimes added to the cost-based measures (Young, Musgrave 1976).

Robert J. Gordon (1971) would measure real capital on the demand side, comparing new and old machines according to their usefulness as assessed by performance characteristics. The primary question is in what units is capital to be measured, and whether any price index can be constructed to reflect the quantity of capital in its own units. The demand concept of price indices advocated by Gordon leads inevitably to a measure of real wealth.

Dan Usher argues that long-run productive capacity[1] is the most appropriate concept of capital for inclusion in an investment function, because firms assess the need for new capital goods in accordance with their plans for the future and not just in accordance with their capacity to produce today. Instantaneous productive capacity would be the appropriate concept for the computation of capital-output ratios and for estimating production functions (Usher 1976).

The central question is why do we want to measure capital, i.e. what it is we are supposed to be measuring. The answer dictates which of the many possible definitions is appropriate for our purpose.

3. Valuation of capital in stock measures

Capital stocks can be valued at three kinds of prices - constant replacement cost, current replacement cost and acquisition cost. Valuation at constant replacement cost ("constant prices") means that each asset is valued at the prices prevailing in some selected base year. The gross capital stock at constant replacement cost indicates the value of the stock of capital assets assuming that all assets were purchased new in the base year. The net capital stock at constant replacement cost shows the value of the capital stock if all assets were purchased in their present state in the selected base year.

Valuation at current replacement cost ("current prices") means that each asset is valued at the prices prevailing in the current year. Thus, the gross stock at current replacement cost shows the value of the capital stock if all assets were purchased new in the current year.

[1] In the long-run productive capacity concept the discounting over the lifetime of an asset is also taken into account.

To obtain the current replacement cost, assets purchased in earlier years have to be revalued in the prices of the current year using suitable price indices. To obtain the constant replacement cost, asset purchased in years other than the selected base year have to be revalued in the prices of the base year.

Valuation at acquisition cost ("historic cost") means that each asset is valued at the prices prevailing at the time the assets were purchased. The use of acquisition costs means that assets are aggregated using a variety of different prices, i.e. the assets are not being measured in the same way. The stock estimates thusly obtained may approximate the asset values shown in company balance sheets.

The United States is the only OECD country to publish capital stock estimates at acquisition costs. In the United States, estimates are also published at constant and current replacement costs. All OECD countries value the capital stock at some approximation to replacement cost. In principle, insurance values relate to replacement cost of assets equivalent to the gross capital stock concept adopted in the national accounts and derived from the PIM.

4. Capital services and capital aggregation

If we are concerned with factors contributing to the gross product, including the using up of capital assets, then the appropriate measure of capital input is not a gross capital stock but a measure of the flow of capital services. The choice of a gross capital stocks series or especially a net capital stock series to represent capital input flows would appear to be theoretically incorrect.

It is often assumed that the potential flow of capital services is proportional to some measure of the capital stock. The basic measurement difficulty stems from the fact that the size of the capital stock and the rate of flow of capital services from that stock must be measured by imputation rather than observation.

There is no observable market in capital services.

In addition, the fact that an item of capital is not used up in the production period implies that the capital services needed in different years cannot be purchased separately. Hence, there is a need to distribute the productive services of a capital asset over its lifetime by some method of imputation.

If the sum of annual imputations of the flow of capital services is equal to some measure of the stock, it follows that the annual difference in that stock gives the required imputation. On the other hand, if a stock measure is used as a proxy for the flow of real capital services, it is not obvious that it should be the net stock (Wyatt 1983).

The basic question as regards this method of imputation is whether the capital services provided by new vintages of capital be given greater weight than those given to older vintages. The use of net capital stock rather than gross capital stock seems to be motivated by just this idea that the newer vintages should be given greater weight. The newer capital represents a proportionally greater share of the total stock because it has a longer expected remaining life - not because of it is technically more efficient or requires less maintenance.

When annual physical depreciation is assumed to be proportional to the stock of capital, no distinction can be drawn between the net and gross stocks. Moreover, the stock itself or, equivalently, the depreciation (capital consumption) of the stock may be used as a measure to impute the potential capital services available. Such an imputation would be derived from the principle that, after adjusting for depreciation, all assets in existence are equivalent in productive capacity.

It can be seen therefore that an assumption of geometrically distributed depreciation makes the imputation of service flows rather straightforward since the depreciation is itself proportional to the stock. An imputation may therefore be based on any of these measures. This is an important reason why such an assumption about depreciation is popular in productivity studies.

Another reason is the proposition that all reasonable forms of depreciation tend towards a stable proportion of the capital stock if that stock is growing steadily or has a constant asset age distribution. However, empirical results give cause to doubt that geometric decay characterises much of the fixed capital stock (Wyatt 1983).

Usually, national accounts estimates of capital stocks are not suitable indicators of the potential flow of capital services. The aggregate gross stock is constructed using asset prices, rather than service prices, making it unsuitable for this purpose. In addition, it is not correct to measure the rate of flow of capital services by the decline in value of the capital asset, i.e. by economic depreciation, because this reflects in large part the discounted value of the shortening remaining lifespan of the asset. Even if an asset's productive qualities remain unchanged throughout its life, it will decline in value as it ages for two reasons: first because it is older, and hence can produce less in the remainder of its life, and secondly because at any moment of time future output is worth less than current output, i.e. after discounting to the present. Neither of these factors is valid if we are examining ex post the relation between output and inputs (Wyatt 1983).

By contrast, the imputation for depreciation of fixed assets in the national accounts sense of capital consumption is free of the undesired distortion of the time-profile of capital's productivity that discounting introduces.[2] Capital consumption is measured by the decline in an asset's undiscounted future productive potential over its expected remaining lifespan, in other words by the change of the net stock.[3]

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[2] Consumption of fixed capital is defined in the SNA as the estimated value, at current replacement cost, of the producible fixed assets used up in the period of account as a result of normal wear and tear, which does not take into account maintenance, foreseen obsolescence and the normal rate of accidental damage.

[3] Note that the "normal" measure of capital consumption derived from a perpetual inventory model of the gross capital stock with fixed lifetimes for assets follows a straight-line reducing balance formula connecting the gross concepts with the net measure of the capital stock.

Although capital consumption reflects the gross stock for a given asset type, and thus reflects the instantaneous productive capacity for the class of assets, it is superior to the gross stock for a mixed collection of asset types because it also reflects the durabilities of those assets. As a measure of instantaneous productive potential, capital consumption gives a greater weight to the less durable asset because it must be rendering its services more intensively than a more durable asset of the same initial value. Capital consumption in fact implicitly changes the aggregating weights for assets in the capital stock, from asset prices nearer to the appropriate service prices. As Dan Usher (1976) points out, assets should be aggregated using their service prices when the capital stock is treated as a factor of production.

If the survival assumptions underlying the gross capital stock are valid, they reflect the time profile of productive capacity for particular assets, and hence provide a suitable basis for imputing the potential flow of capital services. Furthermore, if the relationship between asset prices and service prices embodies a zero discount rate, then capital consumption turns out to be a correct measure to apply because capital is then aggregated in a manner consistent with its interpretation as productive capacity.

If we measure the depreciation of an asset by the decline in the undiscounted future potential over its remaining lifespan, as in the straight-line method of calculating depreciation, then we are implicitly distributing the flow of capital services evenly over the asset's life.

As Hibbert et al. (1977) observe: "When we are concerned with estimating the volume of capital services provided each year by the capital stock of a given industry, it may be reasonable to adopt the assumption that for the stock as a whole the services can be regarded as flowing at a constant rate over the lifetime of each part of the stock". The authors recognize, however, that this argument is strictly valid only for an industry which has its capital stock in a steady-state configuration. But for industries that are growing or declining rapidly the assumption may be questionable. This may be some importance for example if, as Barna (1957) and Stuvel (1955) have argued, the survival curve is linear declining as opposed to rectangular (Hibbert, Griffin, Walker 1977).

Accepting the validity of the straight-line depreciation method as a measure of the flow of capital services, there is nevertheless a problem in using a common PIM assumption. The problem arises because of the way in which assets of different durabilities are aggregated together. The constant price replacement cost value of an asset reflects not only its current (and future, steady) output potential, but also the length of its lifetime. In other words, the price weights that are used in forming the gross stock estimates include an element of undesired discounting (Wyatt 1983).

Assuming, however, that there is no discounting in the value of assets of varying durabilities, so that an asset that lasts 20 years has double the price of one that lasts 10 years, then the annual flow of capital services is proportional to annual capital consumption. However, in general, market prices do reflect the discounted value of future capital services, and hence the above principle will tend to undervalue the annual productive services of more durable components of the capital stock.

Unfortunately, establishing empirically correct patterns of depreciation is quite difficult. On the other hand, as stated before all reasonable forms of depreciation give almost the same aggregate depreciation figure when the age distribution of the capital stock is constant.

The proportionality approach exemplified by declining balance depreciation implies the need to construct estimates of the capital stock which are different from officially produced estimates. The national accounts estimates normally assume the lifespan of assets to be distributed round some average lifespan, and also usually include relatively conservative assumptions about any decline in productive efficiency with age.

As Wyatt points out, there are now two possibilities for empirical researchers: either to recalculate capital stock aggregates in a manner more consistent with the intended application or to adopt the depreciation assumptions embodied in official PIM estimates of capital aggregates and then make a simple combination of these aggregates to approximate a consistent imputation for the flow of capital services (Wyatt 1983).

The first to suggest a combination of capital measures were Raymond Goldsmith (1962) and Edward Denison (1974). They also suggested a weighted average of real gross and net stocks.

When researchers have opted for re-estimation of capital aggregates, they have done so by changing the assumed profile of physical depreciation so that it is a constant proportion of the stock. This is merely a convenience for re-estimation. It may mean that what was an inconsistently aggregated series is transformed into a consistently aggregated series but with less plausible depreciation assumptions (Wyatt 1983).

Regardless of whether capital is regarded as a stock or a flow (capital services), it is in principle always a volume measure. It should reflect the actual physical capacity available for repeated use in the production of other goods and services.

One of the first questions discussed in the literature of the measurement of capital is capital aggregation. Without going deeper into this fundamental issue, there are some features that deserve special attention. First of all, the aggregation problem concerns our possibilities to construct a unique measure of aggregate capital input for each state of technology, output and combination of non-capital inputs.

In practice, capital stock aggregation requires a weighting scheme for investments of different vintages. Usually the total capital stock is treated as the sum of the increments in every preceding year. The increments are not, however, quantities that may be compared directly from year to another. It is only legitimate to aggregate across capital vintages.

Secondly, in using price indices, there is no simple way of deciding which price index is appropriate. The continual change in the technology of production brings forth new processes and new machines every year, depriving us of a reference point from which the real capital stock can be compared forward and backward.

The same real value of gross capital stocks may represent quite different capital assets which, in practice, will vary in their usefulness to contribute to production. The impact of marginal additions to labour and capital utilized in production depends mainly on the prevailing age distribution of the capital available in the economy. Moreover, because of variations in the pattern of retirements, annual investment expenditure cannot be taken as a proxy for the increase in the capital stock.

The problem can, in principle, be effectively resolved by converting each "block" of capital into "equivalent annual capital inputs" whereby capital values are adjusted for individual lifetimes before the process of aggregation. Each separate component of the stock is simply reduced by the same factor which is the inverse of the average lifetime of the capital concerned. The movement in the adjusted annual equivalent gross capital stock estimates is very different, however, from the movement in the conventional gross capital stock (Ward 1976).

Finally, as Miller (1990) points out, it is worthwhile to note that although estimates of a capital stock measure are on average correct, it does not imply that flows of services calculated using this measure will be even approximately correct. At best, the average lifetime used is correct, and therefore small shifts in the lifetimes of capital goods (plus or minus five years according to Miller) are consistent with the available evidence. However, such small shifts correspond to wide swings in the fraction of investment used for replacement and hence in the increase in the capital stock. Thus in estimation of net stocks, small shifts in the allocation of obsolescence or deterioration between adjacent years may have large effects on covariances with other variables.

In perpetual inventory methods capital disappearance has been taken to depend solely upon the age of the capital goods, with a given fraction of each vintage disappearing in a particular year. In addition, the percentage disappearing has usually been taken to be the same for all vintages. As Miller emphasizes, there are nevertheless strong theoretical reasons to believe that when technical progress or price changes are unusually rapid the rate of obsolescence is also unusually rapid, causing the errors in the stock and associated flow of services adjusted for obsolescence to be correlated with the rate of technical progress.

5. Lifetimes and scrapping of capital goods

An asset's life has two ends, "birth" (vintage) and "death" (discard). It is the decision to discard a capital good which primarily determines its life. The actual service life of an asset is a random variable reflecting quality differences, maintenance schedules, changes in relative factor prices, changes in demand conditions etc.

In the case of capital measurement it is necessary to separately identify repair and maintenance expenditures, damage, obsolescence and real using-up of capital reflected in shorter remaining working lives. Usually, wear and tear are assumed to be offset through repair and maintenance until the assets reach the end of their service life, i.e. the point at which they are discarded either because of obsolescence or because repair and maintenance costs become too high.

The physical productive capacity of an asset, if it has not been subject to any modifications or upgrading during its lifetime, will tend to deteriorate over time and perhaps progressively more so as it gets older. Sometimes an inadequate allowance is made for the effect of repairs and maintenance on the life and physical capacity of an asset. The more effective the maintenance and the greater the amount of repairs undertaken, the greater the volume of capital services that will remain in assets over a longer period.

Most capital goods have very long physical lives if they receive adequate maintenance and any components that wear out are replaced. For example the physical life of structures are usually much greater than the lifetimes used in perpetual inventory studies. This is because of the fact that most capital appears to be replaced before it becomes inoperable. An asset is often replaced with something better, possibly because of changed circumstances (Miller 1990).

In net capital series most capital disappearance is not due to physical disappearance of the capital goods, but is due to a reduction in the amount of capital they are considered to represent due to obsolescence or deterioration. As stated above, an asset's economic life may be influenced by economic conditions and the rate of technical progress. An increase in the rate of technical progress, perhaps stimulated by changes in the relative prices of factor inputs, may cause the economic life of assets to end before they are physically obsolete.

When a firm installs capital, it chooses a production process that reflects prevailing and expected future relative factor prices. An increase in the price of one factor (e.g. energy) alters the optimal production process, thereby rendering some capital prematurely obsolete. There is, however, conflicting evidence concerning the extent to which assets are either retained or discarded when economic recession or boom condition prevail. The issue is complicated by the impact of official fiscal and monetary policy, for example in the shape of investment incentives, scrapping grants, etc.. (Ward 1976)

When there are important unexpected changes in the structure of an economy, it is clearly appropriate to remove assets from the estimated stock of capital before they reach the end of their normal service lives. This so-called premature scrapping of assets has been taken into account by capital stock estimates using the PIM, for instance, in Germany. As a result of sructural adjustment during the early 1980s, the assets used in certain declining industries such as shipbuilding, railways and basic metals were believed to have been scrapped much earlier than had been expected when they were originally installed (OECD 1989).

A related question arises concerning the impact of the two oil shocks. Some analysts (e.g. Baily 1981) have suggested that the observed productivity slowdown of the 1970s reflected primarily the mismeasurement of the capital stock as a result of premature retirement in the face of the oil price shocks. Since no OECD countries made any adjustment to their PIM service lives to reflect premature obsolescence as a result of the oil shocks, this may provide a purely statistical explanation for the apparent slowdown in capital, and total factor, productivity (OECD 1989).

In this case, the growth rates of gross capital stocks would have been overstated resulting in underestimation of the growth of both capital productivity and total factor productivity. However, empirical studies provide conflicting evidence for this assertion. In general, the oil shocks of the 1970s had no discernible effect on the service lives of assets (OECD 1989). For example, a study by Hulten et al. produced no evidence that the rise in energy prices in the United States resulted in premature scrapping of nine common types of industrial equipment (Hulten, Robertson, Wykoff 1988).

Some evidence on the United Kingdom is provided by Wadhwani and Wall (1987). They used current cost accounting (CCA) data to estimate the net capital stock in manufacturing industries. In the period immediately following the 1979 oil shock, the net capital stock based on CCA data, which reflect actual service lives, declined more slowly than the net capital stock estimated by the Central Statistical Office (CSO) using hypothetical fixed service lives. These results suggest a lengthening rather than a shortening of asset lives following the second oil shock. Wadhwani and Wall concluded that there is no evidence of massive, premature scrapping in the large firms (OECD 1989).

Accelerated scrapping or, more generally, sudden changes in the average length of service life of physical capital goods, cannot be detected simply by inspecting the capital stock series compiled by national statistical offices. The reason is that these series are calculated on the basis of traditional, constant rates of depreciation and retirement.

Hence, the question has arisen whether the official capital stock series can still be regarded as a plausible approximation to the economically useful capital stock. It is now generally accepted that the sharp rise in relative energy prices after 1973 and 1979 reduced or even eliminated the profitability of part of the installed stock of equipment, which in turn led to an accelerated rate of scrapping. Moreover, there are other factors which may have increased scrapping rates - and hence shortened the service life of capital goods - such as changes in industrial competitiveness and the consequential need for structural adjustment (OECD 1985). As is the case with so many aspects in the measurement of capital, hard empirical evidence is nevertheless difficult to find.

6. Average service lives of fixed assets

The average useful life of capital assets is the average length of time during which assets are engaged in economic production before retirement occurs. In other words, it is the expected average period of usage of the assets, assuming that throughout the whole period of their usage the age retirement schedule remains unchanged. This definition is fully in accordance with the traditional way of calculating people's life expectancy figures, used in demography.

In principle, the service lives that are used in PIM stock estimates refer to the total length of time from the initial installation of assets to the moment when they are finally scrapped. However, since buildings and machines will often undergo many additions, renovations, alterations and modifications during their lifetimes, it is difficult to attach any great precision to average asset lives. The life of a capital good is a composite of the lives of the component parts which have either been added to or replaced in the capital since its initial construction.

The assumptions made about the economically useful life of capital assets is a key element in the compilation of capital stock series. The longer these service lives are, the larger, ceteris paribus, is the capital stock. From a purely technical viewpoint the useful life of equipment may be extended indefinitely given appropriate repair and maintenance. However, from an economic viewpoint the cost of operating a given machine may become too high relative to the flow of revenues and therefore it will be discarded (OECD 1985).

Clearly, any investment undertaken by firms is based on an assumed future stream of income which, in turn, is dependent upon changes in relative prices - for goods and factor inputs - and the overall level of demand. This assumed rate of return is, of course, the major risk or uncertainty surrounding each investment. It therefore follows that the average service life of equipment is itself an uncertain variable, as it depends on the deviations of expected relative price changes from those that are eventually realized. The exact service life of machinery can only be known ex post, that is, after it has been scrapped.

This implies that any capital stock series will provide a reliable approximation to the actual economically useful capital stock only if the assumed average service life of capital goods closely reflects the actual situation in industry.

There are, at the present time, two categories of countries - a short-life group consisting of the United States, Australia, Austria, Belgium, Finland, France, Germany, Italy and Canada, where service lives of equipment are estimated to range between 15 and 20 years, and a long-life group consisting of Iceland, Norway, Sweden and the United Kingdom with service lives ranging between 22 and 35 years (OECD 1989, 1990, see Appendix).

Are the average service lives used for capital stock statistics realistic? A study by the OECD (Blades 1983) showed that several OECD countries use very different service lives for seemingly similar types of assets. Differences raise questions of credibility. The empirical basis for estimating service lives appears to be rather weak in many countries. It follows that the average service lives used in OECD countries' gross capital stock estimates may very well be inaccurate. Some recent evidence on the plausibility of average service lives is available for instance in the United Kingdom and Canada (OECD 1989).

Is it reasonable to assume that average service lives remain constant from year to year? In compiling their capital stock estimates, only four countries presently assume declining service lives, namely Australia, the United Kingdom, Canada and Germany. In the capital stock estimates of Australia and the United Kingdom, the lives of most assets are assumed to have been gradually declining since the 1950s. Australia assumes declines of about 5 per cent each decade, while the United Kingdom assumes declines of just over 1 per cent per annum for most types of long-life assets (OECD 1988b). In the case of Germany this reduction amounts to 0.5 % per year (EUROSTAT 1991).[4]

In Sweden the normal life of road beds is assumed to have fallen from 40 years in the 1940s to 30 years in the late 1970s, while the service lives of cars and trucks are assumed to have fallen over the same period from 5 to 2 and 6 to 3 years respectively (Tengblad, Westerlund 1976). For the sake of comparison, it can be mentioned, that, in Finland, cars and trucks are assumed to stay in the stock 10 years.

In Canada new estimates of service lives were introduced during 1990. For example, in manufacturing the average service life of assets fell from 25 to 17 years (OECD 1990). The old lives were gradually changed until they reached the new ones in 1987.

As presented above, in Germany onetime reductions in service lives were made in the early 1980's to reflect premature retirements of assets. All others countries (excluding Australia, the United Kingdom and Canada) assume that service lives remain constant over time, i.e. different vintages of a given type of asset all remain in use for the same period of time on average.

The United States and the United Kingdom have both revised their estimates of service lives since 1980. In the United States in a few cases service lives were reduced but the overall effect was to increase the average service life assumptions (OECD 1988b). By contrast, the new information that has become available for the United Kingdom has led to reductions in service lives for most types of assets. For example, the unweighted average for manufac-

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[4] In the Australian estimates the average service lives of equipment in public transport enterprises is assumed to have fallen by 1 each decade since the 1940s.

turing equipment is now 26 years compared with 33 years in 1980 and buildings in manufacturing are now assumed to last 60 years compared with 80 years previously. For other industries, however, service lives of some assets were increased.

Apart from the surveys carried out in the countries considered above, little empirical work has been done in measuring asset service lives. It has been the practice of virtually all other countries that publish capital stock estimates to assume a service life that remains constant over time.

Is there a tendency for asset lives to shorten? The identical assets are very likely to have different service lives depending on factors such as relative price movements, changes in demand for output produced by the asset, management efficiency and decisions concerning asset maintenance. These various factors are just as likely to increase asset lives as to decrease them.

The service life of a given type of asset almost certainly varies both between different users and from one period to another. However, while service lives can be expected to vary over time and between firms, there is no reason to expect any long-term tendency for the service life of a given type of asset to become shorter or longer (OECD 1989). When business conditions are favourable, assets will be used more intensively and discarded sooner. The industries which are most likely to have experienced reduced asset lives are those in which the greatest rate of technological change has occurred in the last few years or decades.

Service lives most likely decrease in periods with rapid technological and economic development. The U.S. Bureau of Economic Analysis (BEA) suggests that "during wars or other periods of high capacity utilization, equipment and structures may be used beyond their normal working lives. Unusual technological advances may also change service lives drastically, and there may be trends in service lives." (OECD 1982)

Some empirical evidence on this point is provided by a recent study in the United States by Hulten et al., which compares the prices of second-hand assets before and after the first oil shock.

The study exploits the relationship between asset prices and service prices. Since the price of second-hand asset is the present value of the net income expected over its remaining life, the price of a given type of asset of a given age would have been lower after 1974 if the increase in oil prices had led to premature scrapping, i.e. if it had shortened its service life (Hulten, Robertson, Wykoff 1988).

The result of the study was that the increase in oil prices had no effect on second-hand prices nor, by implication, on their expected service lives. Although this study was aimed at the specific question of whether the oil shock led to premature scrapping, it has a more general implication. The study shows that the service lives of several important types of capital assets did not change between the two periods 1954-1973 and 1974-1983. This study thus lends credence to procedures which assume nonvarying lifetimes in order to achieve a major degree of simplification, namely the use of a single number to characterise the process of economic depreciation.

The importance of this study is that it relates to specified types of assets. The only other similar evidence comes from a 1976 study by Nash on the service lives of road transport vehicles in the United Kingdom. Nash identifies a fall in the average age of motor vehicles for the United Kingdom over the period 1962-1963 to 1972-1973 on the basis of vehicle registration data by year of first registration (OECD 1989).

Other studies that bear on the question of changing asset lives refer to undifferentiated asset groups. A study by Cette and Szpiro (1987) provides estimates of the lifetime of industrial equipment in France on the basis of balance sheets of some 3200 companies. The method used was similar to that developed by Atkinson and Mairesse 1978, also in France. Atkinson and Mairesse used company accounts to construct time series of gross capital stocks for manufacturing assets and experimented with four different mortality functions in order to find combinations of mortality functions and service lives that best fitted the time series on gross stocks. By contrast with the Atkinson-Mairesse approach, the method used by Cette and Szpiro provides no information about mortality functions.

In the study of Cette and Szpiro, in only one of five industries producing capital goods, did the average service lives decline. In the other four, service lives were longer at the end than at the beginning of the period. By contrast, Atkinson and Mairesse found evidence of a slow decline in average service lives over the period 1966 to 1975. They also showed that estimates of service lives and mortality functions are not much influenced by aggregation of the data.

The difficulty in interpreting the Cette and Szpiro study is that their service-life estimates refer to all assets - structures as well as equipment. The result may be due to changes in the composition of the asset stock rather than to increases in service lives of assets of a given type. Nevertheless, their study clearly lends no support to the view that asset lives are declining.

Nash's investigation of road vehicles lends support to the view that capital assets are in general being retained in productive use for shorter periods. The somewhat ambiguous evidence from the Cette and Szpiro and Jaffey (Statistics Canada) studies is that the service lives may fluctuate but there are no long-term trends in either direction.

Even if the service lives of assets of a given type are not changing, it would nevertheless still be right to assume declining service lives in the PIM estimates if the asset mix of their capital stocks is changing to include relatively more short-life assets and if the service lives used in the model are "overall averages" each covering several different types of assets (OECD 1989).

The 1983 OECD study (Blades 1983) showed that some countries use just one service life to cover all equipment in manufacturing industries. Clearly, if the asset composition in these countries is changing to include more short-lived assets, they would be well advised to assume declining average service lives even if assets of a given type are still being retained in the stock for the same periods as before. The problem is that there does not always appear any evidence as to whether the asset composition of stocks really has been changing to include more short-lived assets or to include more long-lived ones.

7. Estimation of service lives

The average economic service life or expected useful economic life of a capital asset can basically be estimated by three different methods:

1) actual observation of the interval between the date of installation and the date of final retirement of specific assets,
2) from enterprise balance sheet data in different periods,
3) using standard income tax or corporate depreciation rates.

The main sources used by the OECD countries are asset lives prescribed by tax authorities, company accounts, surveys, expert advice and other countries' estimates. In general, it appears that tax-lives are based on a variety of sources of varying reliability including expert opinion, ad hoc surveys on particular assets in particular industries, and advice from trade organisations.[5] At its best, the use of "expert advice" may involve seeking advice from a panel of production engineers, or asking firms that produce capital assets for the expected or normal service lives of different sorts of equipment.

In most OECD countries the tax authorities specify the number of years over which the depreciation of various types of assets may be deducted from earnings before charging taxes. They will provide a general credibility check on service life estimates obtained by other methods, although various systems of accelerated depreciation are used to encourage investment.

Company accounts almost always record stocks and flows of assets at historic or acquisition values, and while this is a disadvan-

[5] Usually, tax lives are thought to be too short, because firms keep assets in service for some years after they have been fully depreciated for tax purposes. Tax lives are therefore adjusted to obtain estimates of actual service lives.

tage for many purposes, it does not necessarily prevent them from being used to estimate asset lives. There are at least two ways of using company accounts for this purpose. The first one is the Atkinson-Mairesse or Cette-Szpiro approach described above and the other is the method used by Tarasofsky et al. in Canada 1982. Tarasofsky et al. estimated average service lives by dividing the gross capital stock at the end of a given year by estimated depreciation (capital consumption) during that year. As long as depreciation is calculated by the straight-line method, this ratio is the harmonic mean of asset service lives (OECD 1989).

The advantage of the method is that one year's data on depreciation and capital stocks are enough to provide a service life estimate for that year. The method cannot be used, however, to generate a detailed breakdown of service lives by asset type and industry.

In Canada, information on asset lives were collected directly from companies in the 1985 Capital Expenditures Survey (CES). The results of this survey suggested that the service lives used hitherto were substantially overestimated. That is why Statistics Canada has now recalculated the capital stocks using the new service life estimates obtained from 1985 survey.[6]

At present, Canada is the only country to gather annual data on expected lives. The new information as reported is investment-weighted. In industries for which information on lives is incomplete, estimates based on similar reporting industries are used.

In the United Kingdom, a small-scale enquiry was carried out in 1960 by Barna. In this enquiry, questionnaires were sent to 90 firms in the manufacturing sector, of which 57 supplied information on dates of installation of assets and expected or normal lifetimes. In the mid-1970's the CSO in the United Kingdom again carried out a small survey of enterprises in the manufacturing and energy industries. The information from this survey has led to

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[6] The old information regarding service lives relied primarily on estimates made from a variety of sources such as company experiences, corporate tax returns, assessed relationship between capital cost allowances and investment expenditures, etc.

reductions in the estimated service lives for most types of assets.

In 1987, A.D. Smith used the current replacement cost accounts (CCA) that were available at the beginning of the 1980's to construct an estimate of the United Kingdom capital stock for the year 1983. He calculated also the average service lives needed to reconcile this stock estimate with the capital formation series. He obtained considerably shorter service lives than those currently being used by the CSO (OECD 1989).

Japan is the only OECD country to have used a large-scale asset survey to estimate service lives. The main purpose of the survey was to establish a benchmark figure for the capital stock, which has subsequently been updated by PIM. Respondents were also required to give the dates of acquisition and expected lifetimes for a very detailed list of fixed assets.

A number of other OECD countries are currently investigating service lives - usually by adding questions to their annual censuses of production or other regular surveys. These countries include, for example, Italy, the Netherlands, Spain, Sweden and Finland (Blades 1989, OECD 1991). So far, results and information on the methods used in these countries have not yet been released.[7]

8. Pattern of depreciation and its estimation

In order to know the value of existing capital stocks as they age, not only are good data on average service lives and realistic mortality functions required, but, as well, it is necessary to derive estimates of depreciation.

Depreciation or capital consumption is the reduction in the capitalized value of assets over a certain period of time. As presen-

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[7] The results in Finland are published in the series of Official Statistics of Finland by the name "Teollisuuden pääomakanta ja teknologia 1990", Industry 1991:23, Statistics Finland, (only in Finnish).

ted above, the capitalized value of an asset can be derived by discounting its future net outputs, or accumulating past net inputs, at some interest rate. The basic reason for the decline in the capitalized value is that, as the asset ages, the stream of future services it can supply is shortened. The rate of decline may be speeded up due to increased running costs and maintenance requirements.

There are two types of depreciation, namely physical and economic depreciation. Physical depreciation, which is also called mortality, refers to the loss in productive capacity of a fixed asset due either to loss of in-use efficiency or to retirement. Corresponding to this quantity concept of mortality is the price concept of economic depreciation. Economic depreciation refers to the asset's loss in monetary value with age at a point in time. Mortality is relevant to the analysis of physical investment, replacement requirements, and capital stock estimation, while economic depreciation is relevant to analysis of taxes, asset prices, and the measurement of income (Koumanakos, Hwang 1988).

While these two concepts of depreciation are closely related to one another, they are not identical. In one special case mortality and economic depreciation are congruent, i.e. in the case of geometric depreciation. An important distinction lies in the difference between the purchase price of a capital asset and the rental cost of using the asset for a certain period of time. In equilibrium, the former is equal to the expected present value of the latter. Economic depreciation refers to the decline in purchase price mainly because of age, while mortality is related to the rental price. Mortality can be seen as the capacity change in efficiency, implying a link between mortality and economic depreciation through the present value relationship.

Economic depreciation is determined by the interplay of several economic forces in the market place. Factors like the rate of technical change, capital taxation, expectations and attitudes towards risk, changes in factor prices, environmental regulations etc. all affects asset prices (Hansson 1989).

In summary, as a capital good ages, its value declines for two reasons, namely, physical depreciation and economic depreciation. First, the asset approaches the end of its expected life, and second, the asset's productive capacity per unit of time may decrease over its service life. This decline in an asset's productive capacity per unit of time as it ages is referred to as physical depreciation. At the same time economic depreciation has taken place due to both a decrease in the remaining potential output of the asset and a decrease in the efficiency of the asset.

In fact there are four elements to consider: 1) part of the capital stock has been retired, 2) some of the remaining capital stock may have deteriorated - that is, its marginal product in a physical sense is less than when it was new - or it requires more maintenance and repair, 3) the capital stock is older meaning it has fewer years of service life and 4) some of the capital stock has become obsolete, i.e. its marginal value product is less than when it was new because of availability of more efficient capital goods (Usher 1976).

The pattern of depreciation of fixed assets has continued to be a topic of interest for economists since Jorgenson (Jorgenson 1963). Usually, the discard function assumes that over the service life interval, the efficiency of the capital asset remains the same. The depreciation function has been formulated so that efficiency can be depicted as falling over the asset's service life. When calculating net fixed capital formation and net fixed capital stocks, an important decision to be made is the form of depreciation to be used.

There are three methods of depreciation in use: degressive, progressive and straight-line. Degressive depreciation entails applying a decreasing depreciation rate (arithmetic, geometric or other) to fixed assets, in relation to the number of years they have been in use. It accordingly presupposes more intensive utilization of the fixed assets during the first few years of their useful life, i.e. a relatively higher rate of depreciation in the early years.

The use of progressive depreciation entails applying a rate of depreciation which increases with the age of the fixed assets. It reflects the impact of any delays which may be caused by the incorporation of new plant and equipment into the production process.

Straight-line depreciation is the application of equal amounts of depreciation throughout the entire lifespan of the asset in question, and it is this form of depreciation which is recommended by the SNA.[8] In the national accounts of Finland, the straight-line depreciation method is used.

In the case of straight-line depreciation the asset's value declines in a linear manner throughout its life. The value of an asset is assumed to decline in each year by an amount usually equal to its initial cost divided by its expected life. In the case of delayed depreciation this declining starts not until after a certain delay reflecting a delay in economic depreciation.

In practice, actual depreciation rates are often unavailable. Therefore, the straight-line assumption is used as an approximation to the actual depreciation pattern on particular types of fixed asset. By using the straight-line method of depreciation, capital consumption for a given year is obtained by multiplying the gross stock of capital in that year by the depreciation rate 1/L, where L is the average service life of assets included in the gross stock.[9]

For most assets, especially those with long lives and those like buildings where the services they provide do not materially change over time, the conventional straight-line estimate of annual factor services used up seems appropriate. For some machinery and

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[8] The OECD has recently asked a question whether the present SNA recommendation of straight-line depreciation should be changed (OECD 1988b).

[9] It is worthwhile to notice that if consumption of fixed capital is estimated by the straight-line method, service lives do not change from year to year and all assets of a given type are retired on reaching their average service life (i.e. simultaneous exit method), then the ratio of the gross capital stock to the consumption of capital in the same year gives an average of the service lives of the assets. When bell-shaped mortality functions are used, the ratio generally overstates the average service life of assets. The longer the service life, the greater the overstatement.

equipment this method may be inappropriate because many types of equipment are comparatively more productive when still new. In such cases, a reducing balance or double declining balance method, which attaches a greater value to the capital services provided in earlier years, may be appropriate. The existence of rapid technical progress, which tends to reduce the normal average service life of assets through obsolescence, however, complicates such calculations (Ward 1976).

If we are attempting to construct estimates for a particular industry, it seems possible that divergences from straight-line depreciation may assume some importance. Especially, for rapidly growing or declining industries the assumption seems questionable.

In Canada, it was found that the pattern of depreciation in manufacturing is close to the geometric form. This means that the asset is depreciated at an equal percentage each year over its lifetime. In the case of geometric depreciation, productive efficiency declines at an accelerated rate and the gross and net measures of capital are identical. A simple version of perpetual inventory formula, with a constant rate of depreciation, can be used in the capital stock derivations. In this case, the duality relation implies that mortality is geometric as well (Koumanakos, Hwang 1989, Hulten, Wykoff 1981).

Although Canadian research in the area of depreciation supports use of the geometric form, it is important to recognize that measures of capital stock are needed for a variety of applications in economic and business analysis and that no single measure is appropriate for all purposes (OECD 1990).

In calculating net capital stocks, straight-line and geometric depreciation have nearly an equal number of supporters among OECD countries. Canada, the United States, Australia, Austria, France, Germany, Norway, the United Kingdom and Finland use straight-line depreciation, while Japan, New Zealand, Belgium, Iceland, Italy and Sweden use geometric depreciation (OECD 1988).

Most of the latter group assume that assets are discarded when they have been reduced to 10 per cent of their original value.

However, in the Japanese estimates, assets are retired at 1 per cent of their original value. Thus, the Japanese assumption implies very high depreciation in the early years of the assets' life (OECD 1988).

A widely employed assumption is that also the productive capacity of capital goods declines geometrically (or exponentially) with age at a rate typically equal to twice the straight-line depreciation rate. This hypothesis implies that replacement is a constant fraction of the capital stock at the beginning of each period.

As presented above, for geometric decline in efficiency the measures of gross and net capital stocks will be identical. A consequence of the geometric survival function is also that the expected remaining lifetime is independent of age. Therefore, one might as well own a new machine as two older ones as long as they produce the same instantaneous flow of capital services.

A non-geometric efficiency function implies a more complex relationship, since both the interest rate and the historical investment pattern then have to be accounted for in the capital stock calculations.

Physical depreciation (i.e. mortality) has been usually estimated through indirect methods by examining the behaviour of actual capital expenditures in different industries. Robert M. Coen tested five alternative forms of decay in investment equations for structures and equipment in twenty one US industries. In only one case did the standard exponential assumption prove the best. In addition, other evidence suggests that replacement investment is dependent on economic factors rather than on being determined mechanistically by a process as exponential decay (Feldstein, Foot 1971, Coen 1975).[10]

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[10] Coen uses the term capacity depreciation to represent physical depreciation. Care must be taken with the terminology, particularly the distinction between economic depreciation and efficiency or productive capacity depreciation.

Economic depreciation has been estimated by some researchers by examining the relationships between the ages and prices of certain types of new and used assets. For example, Ackerman studied used cars as a depreciating asset and found that the prices of used cars decline with age at a constant exponential rate.

Hulten and Wykoff applied the Box-Cox power transformation to a sample of used building prices to estimate the rate and form of economic depreciation and found that the appropriate depreciation pattern is approximately geometric. The use of the Box-Cox model to statistically discriminate between geometric, linear and rectangular ("one-hoss-shay") depreciation patterns is analogous to the use of the CES production function to discriminate between Cobb-Douglas and fixed proportion technologies (Hulten, Wykoff 1981).

Hulten and Wykoff found that on average the geometric pattern provides a reasonably close approximation. In addition, they found that the average rates of depreciation are considerably slower than those used in the official capital stock studies of the BEA.

The findings of Hulten and Wykoff indicate that economic depreciation is relatively stable over time and proceeds at a constant rate as capital ages. This implies that the simple version of the perpetual inventory method can be applied in the derivations of gross and net capital stocks. No distinction between the productive and wealth dimensions of capital is therefore necessary. Besides, a non-constant rate of depreciation would require us to account for the whole historical investment pattern in order to construct consistent capital stocks.

In the basic perpetual inventory method of calculating the capital stock depreciation is deducted from gross investment and the remainder is added to the previous period's capital stock. When depreciation is geometric, the amount of depreciation deducted is independent of the age composition of the capital stock. This simplifying feature accounts for the enormous popularity of geometric depreciation in empirical work on productivity, growth, and investment.

With non-geometric depreciation, the aggregate rate of depreciation for a stock of assets and the quantity of replacement investment depend upon the age structure of the capital stock. In addition, a nonconstant rate of depreciation suggests the need to consider the endogenous determination of the rate of depreciation.

The use of the Box-Cox model on a sample of used assets makes possible the estimation of the form and rates of economic depreciation. According to the study by Hulten and Wykoff depreciation patterns resemble the geometric form for the manufacturing sector and an accelerated straight-line form for the non-manufacturing sector. Except for a few industries, the depreciation functions of manufacturing industries resemble the geometric type of convex distribution for both building construction and machinery and equipment. When the composition of capital assets is not homogenous, however, it seems that the depreciation functions at the industry level are best characterized by multiple parameters.

Kendrick (1973) considers a net stock based on the declining balance method of estimating depreciation to be inappropriate, stating that it is not plausible that the output-producing capasity (as distinct from the present value of the future net income stream) declines more in early years than in later years. Kendrick's net stock figures are based on straight-line depreciation, but even so he admits that it probably tends to overestimate the overall decline in the output-producing capacity of depreciable assets as they age.[11] Kendrick also notes the preference of both Goldsmith and Denison for a weighted average of real gross and net stocks and explains that "an increase in the average age of assets will tend to be associated with decreases in productivity" (Kendrick 1973, Wyatt 1983).

Gollop and Jorgenson use a measure of the net capital stock which they derive directly from a perpetual inventory model according the formula:

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[11] The common procedure to calculate net capital stocks by linear depreciation is strictly correct if productive capital follows the "one-hoss-shay" (i.e. simultaneous exit) pattern and the discount factor is zero.

(1) $K^N_t = (1-\delta)K^N_{t-1} + I_t$

in which K^N_t is the net stock of capital at the end of year t, I_t is investment in year t, and δ is the rate at which the relative efficiency of capital good is assumed to decline geometrically with age.

Gollop and Jorgenson derive the depreciation parameter δ from an assumption about the average lifetime of the asset as twice the reciprocal of the lifetime. They note that this results in double declining replacement patterns for all assets. As before, the problem relating to this capital stock measure is that the double declining balance method makes the ability of an individual capital good to contribute to current production drop implausibly fast.

7. Mortality and survival functions

Which assets from previous investments are still in the capital stock in any given year depends on the average service life of the assets, and on the way that retirements are distributed around this average, i.e. the mortality functions.

The mortality functions show rates of discards or retirements around the average service life of assets. They are essentially probability density functions. The declining distribution functions are called survival (or survivor) functions. The survival functions show what proportion of the original members of the group of assets is still in service at each point during the lifetime of the longest-lived member of the group.

There are various functions available for simulating retirement patterns around the average service life of assets. In other words, various assumptions can be made about the weights to be attached to each year's investment expenditures. Assigning a weight of unity during the average service life of the asset corresponds to the retirement pattern of "simultaneous exit". In this pattern, assets of a particular type all remain in the stock until they reach the average service life assumed for that asset, at which point they are all withdrawn. This is a convenient assumption for purposes of computation but it is not very realistic. It is much more probable that some assets will be withdrawn before they reach the average lifetime and that some will remain active for several years longer.[12]

Several types of survival functions are feasible. The first category comprises the so-called linear functions. They are simultaneous exit, purely linear and delayed linear functions. The second category comprises distribution functions which produce a bell-shaped curve, namely quasi-logistic, gamma, Winfrey and Weibull functions. According to these four functions, retirements take place at an increasing frequency around the average length of life. The last category comprises only one function: the lognormal. The various functions have presumable been selected because they appear to fit whatever information is available concerned on actual retirements of various kinds of assets.

A linear declining survival curve implies a rectangular retirement distribution. The height of the rectangle - the amount of retirement - equals 1/2L where L is the average service life. No OECD countries presently use this retirement pattern for their regular capital stock statistics.

The linear retirement pattern assumes that capital assets wear out right from the outset and that the same amount will retire each year over the whole period of their expected lifetime. Usually, assets are assumed to be discarded by the same constant amount each year from the time of installation until twice the average service life.

The purely linear method presupposes that fixed assets are written off at a constant and equal rate in inverse proportion to the maximum lifetime. In a delayed linear retirement pattern, discards

[12] The decline in an asset's value is generally explained by pure aging or loss of in-place efficiency due to wear and tear. In the simultaneous exit case it is only the pure aging effect that causes the asset to decline in value.

are assumed to occur at a constant rate over some period shorter than 2L. Retirements start later and finish sooner than in the simple linear case. The United Kingdom and New Zealand use this retirement pattern for their capital stock estimates. In the case of the United Kingdom, it is assumed that all assets are retired over the period from 80 % to 120 % of their average service life. The rate of retirement in the mortality function is therefore equal to 1/L(1.2-0.8) per cent per year during the period when the retirements are assumed to occur.

In the absence of any firm information about the actual retirement patterns, the delayed linear function was adopted because of its computational simplicity. Barna concluded in his 1960 study that a delayed linear function, with discards starting 3 to 5 years after installation, best fitted the mortality pattern of manufacturing equipment (OECD 1989).

Another variation would be to assume that capital goods wear out at the same rate each year. This method would lead, however, to a larger number of assets being retired in the earlier years, which is unlikely in practice. No country assumes a geometric mortality function (Wyatt 1983).

The exponential decay method has the advantage that investment dates of a given capital stock are unnecessary. If one believes, however, that retirement frequency is dependent upon age of the machinery, fluctuations in gross investment will result in later fluctuations in the need for reinvestment. This effect is called the echo effect. As lifetime and homogeneity of fixed capital also differ, the choice whether to disregard the age structure depends much upon the industry in question.

The simultaneous exit mortality function has been used for capital stock estimates in Japan and Norway. It was used also in the United Kingdom until 1975 and in Canada until 1987 (Statistics Canada 1990). The simultaneous exit function assumes that all assets are retired from the capital stock at the moment when they reach the average service life for the type of asset concerned.

When an asset is not subject to any repair and maintenance during its lifetime and does not suffer from any deterioration in efficiency, it will have a rectangular survival distribution. The rectangular survival curve assumes that all assets of a certain vintage are discarded at the same moment. In some countries the retirements are all assumed to take place at the end of the asset's physical life, i.e. at the point of maximum durability. To allow for any diminished productivity the rectangular survival curve should be slightly modified to be concave to the origin.

In the model used by the United Kingdom two modifications have been made in order to introduce a greater degree of realism. The first one is the above-mentioned usage of a rectangular distribution with retirements being equally distributed over the period from -20 % to +20 % of the mean expected life. The second one is the assumption that investment expenditures take place at the beginning of the year. A more tenable assumption would be that they take place evenly throughout the year.

The assumption that all assets of a given vintage disappear simultaneously from the capital stock is clearly unrealistic. It is clear that some assets are used with different intensities by different producers and thus discarded at different ages. It may therefore be assumed that simultaneous exit is used for much the same kind of reasons as the delayed linear function - computational simplicity and lack of data on actual retirement patterns.

The United Kingdom's capital stock estimates were based on the simultaneous exit function until implausible irregularities appeared in the stock data due to the retirement of large quantities of war-time assets. Indeed, the assumption of a fixed lifetime may lead to implausible retirements because it reflects too precisely the capital formation series. This is one reason why an assumption that retirements are distributed around the average expected life is usually adopted.

The risk of these irregularities depends to a large extent on the degree of detail in the breakdown of capital assets. For example, if it is assumed that all machinery in a particular industry has the same average service life, it is much more likely that the assumption of simultaneous exit will cause irregularities in the stock series than if ten different types of machinery are distinguished for the industry, each type having its own average service life.

On the other hand, one would expect that application of a simultaneous exit function to a detailed asset breakdown produce results similar to those obtained using a delayed linear or bell-shaped function with a less-detailed breakdown of assets. If the bell-shaped mortality function is adopted, the criterion of homogenous categories of capital goods becomes less rigid, because this type of function allows for the fact that, firstly, two identical assets of the same age which have been used in the same industry do not necessarily have the same lifetime and, secondly, within the main categories of assets there are wide variations in the types of assets and hence their rate of retirements.

Of the four countries that have used simultaneous exit, Japan, Canada and Norway have in fact used rather detailed asset breakdowns.

Most countries use some kind of bell-shaped mortality function. The actual functions in use include normal, log-normal, gamma, quasi-logistic, Weibull and Winfrey functions. A truncated normal function is used in Canada and Italy, log-normal in France, gamma and logistic in Germany, logistic in Austria and Belgium, and Winfrey functions in the United States, Sweden and Australia.[13] In Finland a Weibull function is used. Recently, the Netherlands has chosen a gamma distribution function (OECD 1991a).

In Canada, alternative estimates have been made using simultaneous exit, linear, exponential and bell-shaped functions. The bell-shaped discard function used is a quadratic approximation to the normal distribution with retirements distributed over the period from installation to twice the average service life. The truncated bell-shaped function, introduced in 1990, is again based on a quadratic normal distribution but with tails cut off at 50 % and

[13] France uses a log-normal mortality function for the private sector, simultaneous exit function for the public sector and exponential function for dwellings.

150 % of the average life (Statistics Canada 1990).

The advantage of the log-normal distribution is that the function by definition is always starting with a zero probability in the investment year. The log-normal function has often been used as a model for the distribution of wealth.

In most cases symmetrical functions are used. Germany, however, uses also a left-skewed gamma function and Finland a left-skewed Weibull-function. Sweden and Australia use right-skewed as well as symmetrical Winfrey functions.

The left-skewed retirement distribution might be expected to apply in an area of rapid technological change in a particular industry. Given that types of capital cover broad classes of capital goods which comprise a range of average service lives, the true retirement function is likely to be skewed to the left.

The right-skewed retirement distribution may apply in industries where there is either a fairly low rate of technological change or initially expensive but very durable as well as flexible (in the meaning of alternative use) capital goods. A high standard of regular maintenance, repair activities and servicing which extend the life of a certain limited number of assets would normally be expected (Ward 1976). Possible examples include transport equipment - especially ships and aircraft.

The quasi-logistic (or semi-lognormal) survival curve takes account of the incidence of accidents, losses, damages, etc., on the life of assets. These have the dual effect of reducing average lifetimes and altering the shape of the survival function. This results in a normal curve for retirements because it is thought that there will be a tendency for a higher concentration of discards to be spread around an average lifetime which is assumed to occur in the middle of the total expected lifespan.

As with other functions, the actual survival curve may not take effect until several years after assets belonging to the same vintage has entered the stock of capital. Firms will not usually plan to retire capital assets before they have reached some expected minimum average, and usually technically specified, lifetime. Therefore any discards occurring before this average is reached will be entirely due to unexpected and unplanned causes. In addition, it is possible that when a new product is introduced the remaining items of capital will probably be disposed of very rapidly even though the majority may still have many further years of active service life physically remaining.

The triangular retirement distribution is a much simpler variation of the normal distribution which has been used in compiling some official estimates. It assumes a straight-line increasing trend of retirements that declines by the same number of discards each year thereafter. The average lifetime is taken as the middle of the lifespan unless there is again a lag before the retirement curve is assumed to take effect.

The gamma-probability density function has been derived to cope with two important and fundamental problems concerning the pattern of retirements. The first arises because it has been found that the distribution of capital retirements from a given vintage is not independent of the expected average service life of an asset.[14] Secondly, more recently acquired assets, although similar to assets purchased at an earlier date, are retired at a faster rate than their predecessors. They therefore have shorter expected working lives.

The Weibull distribution is perhaps the most widely used lifetime distribution model. It has been used as a model of lifetimes of manufactured items and in biomedical applications. The model is fairly flexible and has been found to provide a good description of many kind of lifetime data.

Many of the survival curves officially adopted tend to have a weak empirical foundation and in most cases the data simply do not exist. Thus, it seems likely that in most countries the selection of a particular function is based on the retirement patterns of

[14] If the observed lifetime of an asset is a period of time corresponding to the sum of r separate stages of life, each of which is exponentially distributed with the same mean θ, then the total lifetime of this asset has a gamma distribution with mean $r\theta$ (see e.g. Aitkin, Anderson, Francis, Hinde 1989).

only a few types of assets, for example, transport equipment. In addition, the models adopted tend to be rigid in the sense that the curves applied are not usually altered in shape or time scale for any particular type of asset or for different vintages of capital.

The main exceptions, for which there exists evidence, are the so-called Winfrey functions. These functions were developed at the Engineering School of Iowa State College during the 1930s (Winfrey 1935, OECD 1989). Data were assembled on the mortality patterns of 176 types of assets, from which 18 standard mortality functions were derived - six being left-skewed, seven symmetrical and five right-skewed. These are usually denoted by L, S and R respectively, with a number 0 through 6 moving from flatter to more peaked curves.[15]

The symmetrical distribution, for example S3, is a simplification of the normal distribution and it is used at least in the United States, Sweden and Australia. A Winfrey S3 function implies that approximately three quarters of assets are retired within 30 per cent of their mean average service lives.

In the United States the retirement patterns are based on the following curves: fixed nonresidential capital, the Winfrey S3 modified so that retirements start at 45 % and end at 155 % of the average life, and residential capital, the S3 modified so that retirements start at 5 % and end at 195 % of the average life. In Sweden for most types of buildings and for transport equipment right-skewed distributions are used of the type R2, R3 and R4. For engineering construction and most types of machinery and equipment symmetrical distributions of the type S1, S2 and S3 are used. Using a Winfrey distribution of service lives, the maximum age for a capital asset within a class of capital goods is twice the average service life for that class as a whole.

In 1978, Atkinson and Mairesse experimented with four different mortality functions - simultaneos exit, exponential, Weibull, and

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[15] While Winfrey curves are empirically well based in the 1930s, it is not obvious that these functions are still appropriate.

log-normal - and with a large number of average life assumptions, in order to find combinations of mortality functions and service lives that best fit time series on investment and gross stocks. They used company accounting data for manufacturing assets and investigated how many years' cumulated investment most nearly equalled each year's capital stock.

Atkinson and Mairesse found that, for plant and machinery, the simultaneous exit and sharply peaked log-normal mortality functions fitted the data about equally well, with average service lives ranging from 16 to 21 years (Blades 1989).

10. Estimation of capital stock by perpetual inventory method

10.1. Perpetual inventory procedure

The perpetual inventory method (PIM) is a simulation model for the capital accumulation process over a period of time. It accordingly produces a statistical estimate of an economic phenomenon.

The PIM is a method for weighting and summing up past gross investment flows. It derives the gross capital stock for a given year by cumulating past investment and deducting the cumulated value of the investment that has been discarded. It can also be applied to derive net capital stock in a similar manner by cumulating past investment and deducting the cumulated value of depreciation.

The stock of fixed assets at the end of a given year t, estimated by the PIM, is the sum of recorded accumulated residual asset values starting from the period t-L, L being the maximum lifetime of the fixed assets in question. The residual asset values mean constant asset values net of retirements in the case of gross stock, and net of depreciation in the case of net stock.

The perpetual inventory model basically relies on three data inputs: capital expenditures, capital goods price indices and service lives. In order to apply the PIM, the following types of information are necessary: gross fixed capital formation over an extended period of time or the value of the stock in an initial period[16], asset prices and price indices, the average service life of the assets and their survival function.

Due to the fact that benchmark data for capital stock estimates do not usually exist, time series for capital formation and price indices have to be compiled for very long periods. In the absence of long-run investment expenditure series, an estimate of the initial capital stock is necessary.

In principle, the model may also call for efficiency and capacity utilization coefficients. In addition, price indices can be adjusted for technical improvements and other quality changes (Tengblad, Westerlund 1976). These questions will be briefly considered in the section 10.4.

The perpetual inventory method produces what may be described as the capacity stock of capital. It covers the total number of objects that have been defined as capital assets and installed, at a given moment, in the factories and other establishments of producers. Some of these assets may be temporarily idle or withdrawn from production for lengthy periods. The PIM, at least as presently applied by OECD countries, will not produce estimates of the "utilized stock".

The service lives that are used in PIM stock estimates refer to the total length of time from the initial installation of assets to the moment when they are finally scrapped. Clearly, these lives may include periods when the assets are not being used to produce anything. The stock of capital will only be fully utilized in periods of peak economic activity. The level of optimum or maximum utilization of the services of capital, however, is a difficult concept to quantify.

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[16] Estimates for the value of the initial stock may often be of poor quality, but the accuracy of the initial estimate has a decreasing impact on the reliability of the stock estimates as years go by. After about 25 years most of assets in the initial stock have been withdrawn.

The intensity of capital use is also directly related to the form of labour operating the equipment. Improvements in the maintenance of critical equipment and the avoidance of breakdowns in complementary machinery will lead to an overall better utilization of the existing capital stock.

10.2. Theoretical background of the method

The basic perpetual inventory method can be represented as follows:

$$(2) \qquad K_t = K_{t-1} + I_t - d_t$$

where I_t is capital expenditure and d_t is discards, during the period t. By using the assumption of a constant rate of technical depreciation, the capital stock at time t, K_t, can be written:

$$(3) \qquad K_t = I_t + (1-\delta)\ K_{t-1}$$

where $\delta > 0$ is equal to the rate of depreciation and I_t is equal to the volume of gross investment at time t. Repeated substitution of equation (3) for previous periods i results in:

$$(4) \qquad K_t = \sum_{i=1}^{t} I_i\ (1-\delta)^{t-i} + K_o(1-\delta)^t \quad .$$

K_o is the initial capital stock. For large enough t, the influence of the size of the initial capital stock can be ignored. Thus (2) can be represented as:

$$(5) \qquad K_t = \sum_{i=t-L+1}^{t} I_i\ w_{t-i+1} \quad \text{when } 0 \le w_{i+1} \le w_i \le 1 \text{ for all i and } \sum_{i=1}^{L} w_i = 1$$

where K_t represents the constant-price gross capital stock at the end of the period t, I_i is the constant-price investment in period i, w_i the weight applied to investment in period i, and L is the maximum life of the capital good.

The weights in this formulation of the PIM represent the probability, as a function of age, of a capital good still being in operation at a given point of time. The function generating these weights is commonly referred to as the survival function. Thus, the basic equation (2) can be replaced with the equivalent age distribution equation:

$$(6) \qquad K_t = \sum_{k=0}^{t} w_{kt} I_k$$

where w_{kt} is the proportion of the vintage of capital goods, I_k, surviving at time t, and is given by the survival curve of I_k. The PIM uses an approximation of this curve, replacing the irregular and changing w_{kt} with some survival function ϕ, usually expressed in terms of a fixed mean value, L:

$$(7) \qquad K_t = \sum_{k=0}^{t} \phi_{kt}(L) I_k$$

The gross stock calculated by the PIM at the end of period t can also be represented as follows:

$$(8) \qquad K^G_t = \sum_{i=0}^{L} w_{ti} I_{t-i}$$

where L is the age at which the initial investment made in period t-L is completely withdrawn from the capital stock, I_{t-i} is the investment expenditure in the period t-i and w_{ti} is the weight these investments have in the capital stock of period t. More precisely, w_{ti} is equal to the proportion of the fixed assets purchased in period t-i, i=0,..,L, and still in use in period t. It is a value of the survival function estimated for assets acquired in t-i.

Proportion w_{ti} will vary in relation to the age of the fixed asset and decreases as the age of the asset increases. The t subscript in w_{ti} indicates that each period might have its own survival function or weighting scheme.

The following restrictions are imposed on the survival or weighting scheme indicated by w_i:

(9) $0 \leq w_i \leq 1$ and $w_{i+1} \leq w_i$.

These restrictions mean that the weight of a capital good can not be negative and not larger than its original value, and the weight in the next period can be less or equal to the weight in the previous period but never bigger since a withdrawal is final and goods cannot be brought back into the capital stock after they have been scrapped (OECD 1990b).

The implication of the constant deterioration assumption is that the relative prices of surviving vintages of capital are constant over time. Since relative prices are fixed, one can employ the Hicksian aggregation condition and form an aggregate capital stock over vintages as

(10) $$K_t = \sum_{i=0}^{L} w_i I_{t-i} = \sum_{i=0}^{L} K_{t,t-i}$$

where w_i is the physical survival rate, L is the physical lifetime of assets, I_{t-i} is the amount of real investment at time t-i and $K_{t,t-i}$ is the amount of t-i investment surviving to period t. The survival rates w_i are the proportionality factors that reflect relative marginal products (Berndt, Wood 1986, Diewert 1978).

The net stock at the end of the period t is analogously

(11) $$K^N{}_t = \sum_{i=0}^{L} w_{ti} I_{t-i} d_i$$

where L, w_{ti} and I_{t-i} are as before and discards d_i are, for instance, of the form:

(12) $$d_i = 1 - \sum_{i=0}^{L'} w_{ti} , \qquad L' \leq L$$

which indicates that the value of the asset declines linearly. As presented previously, this assumption is only one among many alternatives.

It is usually assumed that the fixed asset acquired in t appears in full in the stock of year t, since none is lost during the first year of use.

As is the case with most national estimates of the gross capital stock, it has been above implicitly assumed that there is no loss in productive efficiency over the lifetime of a capital good. However, for computational and practical purposes, the effective maximum service life used in the PIM is somewhat less than the total length of time from the installation to scrapping. For example, structures are usually not retained in the stock all the time of their total actual length of life.

Efficiency-adjusted measures of the capital stock are sometimes referred to as net capital stock estimates and, theoretically, they are the most appropriate measure for use in a production function. These net estimates should not be confused with wealth-based measures of the net capital stock, which represent the discounted future flow of capital inputs. These two measures will only coincide if the efficiency function is exponential so that there is a constant rate of decline in terms of efficiency units of a capital good with age (Björn 1989, Keese, Salou, Richardson 1991).

Let us now assume, as Hansson does in his study, that the relative efficiency of a machine is a function of its age, $\Phi=\Phi(s)$. If we normalize efficiency of a new machine to unity, $\Phi(0)=1$, and restrict $\Phi(s)$ to be nonincreasing, the function $\Phi(s)$ gives us the ratio between the marginal physical product of a machine aged s years old and the marginal product of a new machine (Hansson 1989, see also Hall 1968).

An individual capital good loses efficiency as it ages due to increasing maintenance and repair costs. Capital can also be taken out of service at a given point in time. To separate these two causes of efficiency decline Hansson writes the age-efficiency function $\Phi(s)$ as the product of in-place efficiency, $\Phi_E(s)$, and the probability of survival, $\Phi_S(s)$, i.e. $\Phi(s)=\Phi_E(s)\Phi_S(s)$, where both factors are restricted to be nonincreasing.

The gross capital stock at time t of vintage v, aged s=t-v years, is

$$(13) \quad K(t,v) = \Phi_E(t-v)\Phi_S(t-v)I(v) \ .$$

Integration over all vintages gives the total productive stock

$$(14) \quad K(t) = \int_{-\infty}^{t} \Phi_E(t-v)\Phi_S(t-v)I(v)dv \ .$$

In the equation above capital services of different vintages are perfect substitutes, while capital goods of different vintages are not.

Conceptually gross stocks measure the productive efficiency of capital and net stocks is a volume measure of capital related to the wealth dimension of capital. Hansson shows in his study that the age-price profile of used capital assets is an important link between net and gross capital. The point is that if information on the age-price profile is available, then it is also possible to infer from this profile the form of the age-efficiency function which, in turn, is the weighting function behind gross capital.

If we assume, as Hansson does, that there is no loss of in-place efficiency, then $\Phi_E(s)=1$ for all s.[17] The share of capital goods that survives s years is then $\Phi_S(s)$, which in this case is equal to $\Phi(s)$. If we further assume a constant rate of depreciation, the capital stock at time t can be written as:

$$(15) \quad K(t) = \sum_{s=0}^{\infty} K(t,s) = \sum_{s=0}^{\infty} (1-\delta)^{s} I_{t-s} \ .$$

Equation (15) can be simplified to the following formula:

$$(16) \quad K(t) = I(t-1)+(1-\delta)K(t-1) \ .$$

This equation was applied in the derivation of the Swedish capital stocks presented in Hansson's study. The depreciation rates δ and respective asset lifetimes were taken from the Hulten-Wykoff studies (Hulten, Wykoff 1981).

[17] The assumption of no in-place efficiency is a very restrictive one.

Now, when $\phi_E(s)=1$, integration over all vintages gives the following market value of the total stock at time t:

$$(17) \quad V(t) = \int_{-\infty}^{t} p(t,t-v)\Phi_S(t-v)I(v)dv$$

where the price p(t,t-v) is the discounted future service flow from an s=t-v years old capital good adjusted for the probability of survival. Dividing V(t) by p(t,0) gives the quantity wealth stock of capital or the net capital stock:

$$(18) \quad K^N(t) = \int_{-\infty}^{t} \frac{p(t,t-v)}{p(t,0)} \Phi_S(t-v)I(v)dv \; .$$

Thus, net capital is a volume measure of wealth. It is equivalent to the number of new capital goods which must be bought in order to keep the market value of the capital stock unchanged if the existing stock is to be fully replaced.

The net capital stock can be estimated once the probability of the survival function is chosen. Generally, net stocks are dependent on both the interest rate and the rate of retirement, but to make things simpler, let us make the assumption of a zero interest rate. If we look at the average age-price formula and set $\Phi_E(s)=1$, it is possible to derive the weighting function for net capital. This can be seen by integrating the numerator and denominator of the average age-price profile by parts.

The numerator, when r=0, is equal to

$$(19) \quad \int_{s}^{\infty} \Phi_S(u)du = \Phi_S(s)[\int_{s}^{\infty} -u \frac{\dot{\Phi}_S(u)}{\Phi_S(s)} du - s] \; .$$

The expression within brackets is equal to the expected remaining lifetime for a capital good of age s, $E(v|s)-s$. Likewise, if we set s=t-v=0, the expression for the denominator is

$$(20) \qquad \int_{0}^{\infty} \Phi_s(u)du = E(v|0) \ .$$

The formula (18) for net capital can now be rewritten as (see Hansson 1989):

$$(21) \qquad K^N(t) = \int_{-\infty}^{t} \frac{\Phi_s(s)[E(v|s)-s]}{E(v|0)} I(t-s)ds \ .$$

This equation indicates that the correct weight for a capital good aged s years is equal to the expected remaining lifetime, $E(v|s)-s$, times the probability of a new capital good surviving s years, $\Phi_s(s)$, divided by the expected total lifetime for a new capital good.

In summary, gross and net capital are related to each other by the age-price profile. If this function is known, then it is possible to calculate theoretically consistent gross and net stocks of capital. By observing the retirement process and by gathering data on used asset prices, we can, for a given interest rate, solve for the age-efficiency function.

10.3. Basic statistical formulation of the model

The basic PIM formulation for gross capital stock can be stated as follows:

$$(22) \qquad K^G_{it} = K^G_{i,t-1} + I_{it} - R_{it}$$

$$(23) \qquad R_{it} = r_i \, K^G_{i,t-1} \ .$$

From (22) and (23) it follows:

$$\begin{aligned}(24) \qquad K^G_{it} &= I_{it} + (1-r_i)K^G_{i,t-1} \\ &= I_{it} + (1-r_i)\, I_{i,t-1} + (1-r_i)^2 \, I_{i,t-2} + \ldots + (1-r_i)^t \, K^G_{io} \\ &= \sum_{T=t-\theta_i}^{t-1} w_{i,t-T} \, I_{iT}\end{aligned}$$

where $w_i = 1-r_i$, K^G_{it} is the gross capital stock of asset i at the end of period t, I_{it} is the gross investment in asset i during period t, R_{it} is the retirement of asset i during t, r_i is the retirement rate for asset i, w_{ij} is the proportion of original investment existing at the beginning of year j after which it is introduced, $j=1,2,\ldots,\theta_i$, and θ_i is the age of the oldest asset of type i in existence.

For net capital stock the formulation is as follows:

$$(25) \quad K^N_{it} = K^N_{i,t-1} + I_{it} - D_{it}$$

$$(26) \quad D_{it} = d_i \, K^N_{t-1} \, .$$

Analogously, it follows:

$$(27) \quad K^N_{it} = I_{it} + (1-d_i)\, K^N_{i,t-1}$$
$$= I_{it} + (1-d_i)\, I_{i,t-1} + (1-d_i)^2\, I_{i,t-2} + \ldots + (1-d_i)^t\, K^N_{io}$$
$$= \sum_{T=t-\theta_i}^{t-1} w_{i,t-T}\, I_{iT}\, c_{i,t-T}$$

where $w_i = 1-r_i$, K^N_{it} is the net capital stock of asset i at the end of period t, D_{it} is the depreciation of asset i during t, d_i is the depreciation rate for asset i, c_{ij} is the proportion of capital i invested in year j and not used up, while I_{it} and θ_i are as above.

In order to calculate the net stock, it is accordingly necessary to determine the degree d_i of depreciation of the fixed assets in relation to their age. The depreciated value of the capital stock of type i is usually calculated as follows:

$$(28) \quad K^N_{it} = \sum_{T=t-\theta_i}^{t-1} w_{i,t-T}\, I_{iT} \left\{ 1 - \frac{t-T}{L_{t-T}} \right\}$$

where the factor L_{t-T} denotes the expected total durability for capital goods, acquired in year T and remaining in year t, and the last term accounts for the assumption of a straight-line depreciation during the economic life of the existing goods (Tengblad, Westerlund 1976).

In view of the practical difficulties in obtaining net capital data directly, most net capital estimates have been calculated by adjusting the gross capital stock estimates for accumulated capital consumption. The application of an appropriate depreciation rate for each different category of capital is desirable but not always feasible.

In practice a variety of methods are used based on both gross stocks and investment. In formula (28), the net capital stock is derived by using the same PIM procedure as is used to obtain the gross stock estimates but with the formula adjusted to include a factor which relates the expected remaining lifetime of an object to its expected total economic life.

If estimates of gross stock are available, it is easy to calculate retirements between two stock years. As presented above, retirement is the physical removal of fixed assets from the production process. Retirements during year t are:

(29) $$R_{it} = I_{it} - (K^{G}_{it} - K^{G}_{i,t-1})$$

where I_{it} is the investment in year t and K^{G}_{it} and $K^{G}_{i,t-1}$ are the gross stock at the end of year t and t-1, respectively.

In principle, retirements may also be calculated directly from the survival functions s_j:

(30) $$R_{it} = \sum_{j=0}^{L_i} (s_{ij} - s_{i,j+1})\, I_{i,t-(j+1)} \; .$$

In exactly the same way as for retirements, it is possible to calculate the depreciation (the consumption of fixed capital) during year t:

(31) $$D_{it} = I_{it} - (K^{N}_{it} - K^{N}_{i,t-1})$$

where I_{it} is as above and K^{N}_{it} and $K^{N}_{i,t-1}$ are the net stock at the end of year t and t-1. Thus if $s_{ij}\, d_{ij} = c_{ij}$, the result is

$$(32) \quad D_{it} = \sum_{j=0}^{L_i} (c_{ij} - c_{i,j+1}) \, I_{i,t-(j+1)} \; .$$

According to (31) capital consumption in constant prices can be obtained as the difference between gross fixed capital formation and the annual change in depreciated capital stock values. The depreciation of fixed assets calculated in this way must be clearly distinguished from depreciation for tax purposes or depreciation allowances made in company accounts.

In the national accounts, the primary aim is to make as accurate an estimate as possible of the depreciation of the fixed assets over a given period 'in terms of normal wear and anticipated obsolescence'. Thus, the consumption of fixed capital depends to a large extent on the length of economic life of capital goods and the method of depreciation.

10.4. Modifications to basic model

The basic formula of the perpetual inventory method can be easily adjusted to extend its field of application for further refinements, such as provision for technical progress or the efficiency of the fixed assets.

The improvement in efficiency can, in principle, be taken into account by the following expression:

$$(33) \quad K_{it} = \sum_{T=t-\theta_i}^{t-1} w_{i,t-T} \, I_{iT} \, e_{i,t-T} \, p_{i,t-T}$$

where K_{it} expresses the available capital stock of type i and the coefficient $e_{i,t-T}$ expresses the ratio between the efficiency of the goods i in year t as compared with T, and $p_{i,t-T}$ expresses the price change for capital goods of type i purchased in years t and T. As before, I_{iT} symbolizes gross fixed formation of a specific type of objects i in a given sector, in year T, $w_{i,t-T}$ symbolizes the share of I_{iT} which still exists in year t, and θ_i expresses the limit of durability for capital objects i (Tengblad, Westerlund 1976).

Besides the efficiency coefficient e_i related to the age of asset i, we can introduce into the formula a correlation factor τ to reflect the fact that newer capital is equivalent to a larger number of 'units' of older capital of the same value. Also, the price ratio p_i can be adjusted for quality changes and embodied technical progress in an asset. Compared to the basic cost-based measure of capital stock, the stock measure with the efficiency factor would probably have increased somewhat faster.

If survival rates are deemed to change, the gross capital stock can be estimated by the following formula:

$$(34) \quad K^G_t = \sum_{i=1}^{n} [\sum_{T=t-\theta_i}^{t-1} w_{i,t-T} I_{iT}] .$$

If we could survey service lives accurately, for instance annually, we could further improve our PIM application by replacing average service lives L with J_t and L_t, to give, for example, the net measure:

$$(35) \quad K_t = \sum_{k=t-J_t+1}^{t} (t-k+1)\frac{I_k}{L_k}$$

where I_k is the capital expenditure during year k, L_k is the lifetime of vintage k and J_t the age of the oldest item to be discarded. A close measure of J_t might be the weighted average age of discards d_t, obtained from their age distribution (Jaffey 1990).

10.5. Method used in the national accounts of Finland

The proportion of capital goods surviving at time t can be estimated in a number of ways. In the capital stock model used in the national accounts of Finland, their estimation is based on the assumption that the distribution of the actual service lives of assets, and thereby of retirements, around the average service life conforms to a Weibull probability distribution.

That proportion of investment in year t which remains in the gross capital stock at the end of year t_n, n=1,2,.., follows the Weibull survival function and is calculated by the formula:

$$(36) \qquad w_t = \exp \{- [\frac{1}{L} \Gamma(1 + \frac{1}{\beta})(t_n - t + 0.5)]^{\beta} \}$$

where $\Gamma(1+1/\beta)$ is the mean of the standard Weibull distribution, $\Gamma(.)$ is the gamma function, L is the estimated average service life of assets and β the shape parameter of the Weibull distribution. The shape parameter value $\beta = 8$ is used.

The distance $t_n-t+0.5$ is the average age of vintage t assets at the end of year t_n. Because investment expenditures are assumed to occur evenly during the year, the age of these assets at the end of the year is half a year. This explains the adjustment of the age by 0.5.

The average service life L can be written as the mean of the Weibull distribution:

$$(37) \qquad L = \frac{\Gamma(1+1/\beta)}{\lambda^{1/\beta}}$$

where λ is the scale parameter of the distribution. From (37) we get

$$(38) \qquad \lambda = \left\{ \frac{\Gamma(1+1/\beta)}{L} \right\}^{\beta}$$

Thus, that proportion of investments in year t still in use at the end of year t_n is described by the survival function:

$$(39) \qquad w_t = \exp \{-(\lambda\tau)^{\beta}\} = \exp \{-[\frac{\Gamma(1+1/\beta)}{L} \tau]^{\beta} \}$$

where $\tau=t_n-t+0.5$.

The Weibull distribution with the shape parameter β=8 gives capital goods a quite steep retirement pattern.

The gross stock at the end of year t_n is calculated as the sum:

$$(40) \quad K^G_{t_n} = \sum_{t=t_1}^{t_n} w_t \, I_t$$

where I_t is the investment expenditure in year t and w_t is that fraction of investments in year t still in use in year t_n. Included in the calculations are only those years t for which

$$(41) \quad t \geq t_n-1.5L > t_n-100 \; .$$

It follows that $t_1 = \max(t_n-1.5L,\ t_n-100)$ rounded to the nearest integer.

The maximum service life of assets is assumed to be one and a half times the average service life, but less than a hundred years. This means that the dispersion of retirements around the average service life L is assumed to lie in the interval (0, 1.5L]. Thus, the mortality distribution adopted is a truncated left-skewed distribution with discards distributed between 0 % and 150 % of the average service life.

The net stock at the end of year t_n is calculated as the sum:

$$(42) \quad K^N_t = \sum_{t=t_1}^{t_n} w_t \, I_t \, d_t$$

where $t_1 = \max(t_n-1.5L,\ t_n-100)$ and

$$d_t = 0 \text{ for all } t \leq t_n-L+0.5,$$

$$= 1 - \frac{1}{L}(t_n-t+0.5) \text{ else.}$$

The depreciation rate d_t calculated by the straight-line method is the remaining service life divided by the total service life.

11. Sensitivity of capital stock estimates to different assumptions

The precision of the perpetual inventory estimates depends primarily on the accuracy of basic investment and price index data and on the assumptions about the average lifetimes and associated patterns of retirement of different types of capital assets. There are problems with all of these, although it is mostly the difficulty of accurately surveying lives that has raised doubts on the reliability of the present estimates (Jaffey 1990).

Estimating service lives is one of the difficult problems in using the perpetual method to calculate capital stocks. There is usually no hard information about the mean lifetime of particular types of assets or about its stability over time. Information about how long assets remain in the capital stock, however, is both crucial to the overall accuracy of the stock estimates and is usually of poor quality. Estimated service lives differ widely between countries.

Any change in an assumed service life will inversely affect the annual estimates of capital consumption of that asset. The effect on the capital stock estimates may be considerable and this will be most pronounced when a fixed-life assumption and a rectangular survival distribution are assumed. The possibility that average lives are changing over time could lead to significant errors. If service lives really are falling, the failure to reduce assumed service lives will introduce substantial errors into the estimates of consumption of fixed capital and net capital stock, and smaller, though not insignificant, errors into the gross stock calculations (Hibbert, Griffin, Walker 1977).

Hibbert et al. note that "the relationship between the change in assumed lifetimes and the changes in estimated stock and capital consumption is partly dependent upon the rate at which new capital consumption is taking place, i.e. the rate at which the capital stock itself is changing". Hibbert et al. go on to explain that "with increasing capital stock over time, a given percentage reduction in assumed life lengths leads to a relatively smaller percentage change in estimated stock and some increase in capital consumption because capital consumption now represents a greater using up of more recently acquired assets."

The use of incorrect service life assumptions will have an unpredictable impact on the growth of the stock of capital. The use of erroneous service lives does not produce any systematic bias into the estimated growth of the capital stock (OECD 1989). Changing service life assumptions obviously affects the estimated size of the capital stock. Less obviously, it also affects the rate of growth since the service lives act like weights. The overall effect of adopting the shorter service lives is to give greater weight to the types of assets that have been growing relatively slowly (Statistics Canada 1990).

Variations in the actual lives of assets comprising the group will produce different gross stock estimates than those generated by a fixed-life model. Unfortunately, what little evidence is available tends to suggest that not only do the mean lives of capital goods change over time, but also that their retirement patterns vary. If the mean lives of capital goods are changing in different phases of the economic cycle, it becomes very difficult to derive generally valid conclusions regarding the extent to which more realistic survival functions are likely to affect the gross capital stock series.

As is obvious, also the survival curves have a weak empirical foundation. The importance of various assumptions concerning average durability and dispersion for the survival curves has been analysed, for example, in Norway, Canada and Australia. It was found that the shape of the survival curve has a fairly marginal effect on the level of stock estimates compared to the effect of changing service lives. The gross stock estimates appear to be more sensitive to changes in the assumed average lives of assets than to variations in the survival functions.

Studies made by OECD have shown that perpetual inventory models based in turn on Winfrey S3, gamma-probability density and rectangular survival distributions generate capital stock estimates which rarely differ by more than ten per cent in any one year. The choice of mortality functions can nevertheless have an important impact on the level and growth of estimated capital stock. This impact depends on how fast the components of the capital stock are growing as well as on the type of mortality function selected for each component.

Statistics Canada and the Norwegian Bureau of Statistics have published studies showing how their present capital stock estimates would be affected by the use of different mortality functions. The Norwegian study shows gross capital stock estimates using four different types of mortality functions: a bell-shaped, a simultaneous exit, a linear and a declining balance function. Data published by Canada and Norway give the same general picture. Bell-shaped and simultaneous exit functions give similar levels and growth rates. This is because simultaneous exit is merely the mean approximation of the bell-shaped function. The main difference between the two is that the bell-shaped function produces a smoother growth pattern as it reduces the "echo effect" characteristics of the simultaneous exit whereby all assets of a given vintage are discarded exactly L years after they are installed, L being the average service life.

The smoothing effect of using a bell-shaped mortality function means that when capital formation is growing a bell-shaped mortality function will produce a lower estimate of the capital stock than simultaneous exit. Conversely, when capital formation is falling, it will produce a higher estimate than simultaneous exit.

Linear and declining balance functions (equal percentages discarded each year) give much smaller estimates of the capital stock. This holds for the obvious reason that with these functions more of each vintage is assumed to be discarded at an earlier date.

The conclusions may be summarized as follows: for gross capital stock, simultaneous exit gives the highest estimate, but that is only about 5 % higher than that obtained using bell-shaped mortality functions. The linear function produces an estimate that is lower again by about a further 5 %. For the net capital stock, bell-shaped mortality functions produce the highest estimates, while estimates based on simultaneous exit are substantially (20-25%) lower. For consumption of fixed capital simultaneous exit again produces a higher figure while the bell-shaped functions give estimates around 20 - 25 % lower (OECD 1982).

Thus, it appears that gross capital stock estimates are relatively insensitive to the mortality function used, but that for both the net stock and capital consumption rather different results can be expected depending on whether simultaneous exit or bell-shaped functions are selected. It should be noted that these results are due to the fact that the capital stocks (of Canada and Australia) are growing.

According to a OECD study, the bell-shaped function might be really the only plausible candidate. "It is contrary to common sense to assume that equal amounts of a given vintage are discarded each year starting immediately after installation (linear function) or, that the heaviest discards occur in the first years after installation (declining balance function)" (OECD 1989). The linear and declining balance mortality functions can therefore be dismissed as being unrealistic. Simultaneous exit is also inherently implausible, but its use can be justified as an operationally convenient approximation to the bell-shaped function.

Provided that the true mortality function is reasonably symmetrical and has a fairly pronounced peak, simultaneous exit will simulate the true level and growth of the capital stock. Similar remarks apply to the delayed linear mortality function used in the United Kingdom and New Zealand. These are rectangular approximations to the bell-shaped function.

According to Groes (1976) the most likely survival curve is usually believed to be some kind of logistic or Winfrey-function. In estimating this function, it is common to try a logistic function, where the discard frequency is a linear function of the stock.

12. Usefulness of the perpetual inventory stock measures

Criticism levelled at the perpetual inventory method has tended to concentrate on three main aspects: first the method is artificial and its links with reality have by no means been established, secondly the assumptions and above all the rigidity of the lifetime makes it inflexible and inert, and thirdly the use of very old and unreliable figures for fixed assets tends to make this type of estimate of capital stock even more approximate.

The precision of the capital estimates derived by the PIM depends on a wide variety of assumptions such as the stability of the retirement rate of investment goods, the shape of their survival functions, and the pace of technical change. Furthermore, Rymes (1976) points out how limited our knowledge is of intersectoral transactions in existing fixed capital, survival and depreciation functions, average economic lives, and biases in capital good price indices.

On the other hand, as Young and Musgrave (1976) explain, some of these questions are of minor importance, since trends and cyclical swings in gross capital formation data may swamp the effects of even substantial variations in life estimates and in survival and depreciation functions.

There are, however, several points deserving special attention. These are, for instance, the treatment of second-hand goods, capital repair and alteration, take-over of companies and valuation. It is not always clear that sales and purchases of second-hand equipment are correctly and consistently recorded. Intersectoral transactions of second-hand capital probably occur most frequently in the case of office buildings and vehicles and other multi-purpose or common-user equipment.

Inter-industry transfers may indeed be a potential source of error. A more serious source of error probably arises, however, when second-hand assets are sold predominantly for scrap, export or to consumers (e.g. cars).

Leased capital assets are currently attributed to the owner of the assets rather than the user. This creates a problem for the estimation of productive capacity and production functions on an industry basis when the lessor and the lessee are in different industries, which is often the case. A special problem has arisen in recent years in Finland from the practice of selling factories and office buildings to property leasing companies which then lease the property back to the original owners.

In addition, errors of estimation arise from inadequate data on prices. Errors in the measurement of price changes would lead to biases in the estimates of capital stock and capital consumption. Underestimating a rise in prices would give too much weight to the newer vintages of capital.[18]

Price indices adopted in the model generally reflect changes only in the prices of new assets. Price indices seldom measure precisely the true underlying changes in prices of a highly heterogenous group of goods and services because of the changing composition of the group even if there are no improvements in quality. Changes in physical quality and technical improvements introduce serious problems of ambiguity and imprecision (Ward 1976).

Recently, in Canada, the price indices to deflate capital stocks and flows have been revised. Where before the price indices were of a Laspeyres type, a Paashe index is now used. Also, the hedonic price method has important consequences for the measurement of the capital stock since these prices take into account the improved performance of new capital goods better than the older ones and thus give a better estimate of the capital services the capital stock deliveries in the production process.

Improvement in estimation can come only from more reliable information about service lives of assets, better data on the industries using particular types of assets and improved methods of

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[18] Usually, the price indices used by most OECD countries are believed not to underestimate but to overestimate price increases because they are believed to underestimate quality improvements.

revaluing fixed investment expenditure at constant prices. In addition, it is necessary to find out what is the role of premature retirement of fixed capital assets in response to changes in relative factor prices and technology.

The retirements of gross stock generated by a perpetual inventory model might be expected to provide useful information about replacement investment. However, the problem is that the timing of retirements is not known with sufficient confidence. In addition, it is not clear that the model generates a realistic level of retirements in a specific year. If that is the case, changes in the level of gross capital stock may only reflect the inherent structure of the model and the assumptions upon which the calculations are based.[19]

The assumption of a technically given retirement pattern has been criticised by Miller (1990). Clearly, in reality, scrapping is determined by changes in relative prices and technology and not just as a function of the age of capital assets. This is a weakness in all national estimates of the capital stock which use a perpetual inventory method.

It is desirable to have some reasonable firm benchmark estimates of the capital stock to provide an alternative figure against which the PIM estimates can be compared. These estimates can be made more accurate by establishing periodic benchmarks in order to obtain a secondary check on the accuracy of the estimates. Benchmarks estimates made at regular intervals should be used for calibrating the capital stock estimates and other data such as economic lifetimes of assets used in the capital stock simulations.

Where changes in the ownership or use of buildings and works are likely to be significant, it would seem that direct estimation will provide the only satisfactory basis for addressing this

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[19] The retirements generated by the PIM may nevertheless be of greater potential value for long-term studies.

problem.[20] There is, however, no guarantee that a direct survey could always yield better results, largely because of the extreme diversity of capital goods and the differences in the method of classification adopted in companies' accounts and national accounts.

In Canada, there has been in recent years a strong tendency in the practical application of the method to subdivide the gross fixed capital formation estimates into as many capital objects as possible. This improves precision because it is then to a larger extent feasible to apply more appropriate survival curves and price indices. The new Capital and Repair Expenditure Survey (CES) has considerably more disaggregation, particularly in terms of machinery and equipment. Disaggregation is particularly important when capital expenditure data are used to calculate capital stocks, because different categories of capital have different service lives. The finer the disaggregation, the more accurate the capital stock estimates.

Moreover, in Canada much effort has been directed to the collection of additional information about expected service lives of assets acquired during the year, and in particular about the way in which average lives may have changed and are changing over time. In most cases, the new estimates of service lives are shorter than the old ones. The assumption made in introducing the new lives is that service lives have been gradually declining to their present new values. Thus a major change, believed to be more realistic, has been the abandonment of the practice of assuming constant service lives. This pattern was adopted because it gave results which most closely approximated a reported benchmark value of fixed assets.[21]

Major questions in applying the PIM include whether to adjust the quantity of investment for improved quality and what capital disappearance rate to use. Does it, for instance, include obsoles-

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[20] For example, in the Netherlands the gathering of the data is done partly by direct interviews. The surveys cover more than 50 % of the capital stock. The rest of the total capital is estimated by the PIM.

[21] These innovations were incorporated during 1990 and they are believed to increase substantially the accuracy of Canada's estimates of fixed capital (OECD 1990).

cence? The latter question is really one of what characteristic of capital is to be considered to have disappeared as capital ages, and what units of capital are to be measured. In essence the answers depend on the purpose for which the capital stock estimates are desired.

Miller believes a reproduction cost-based gross stock is most appropriate for studies of factor substitution. A marginal product (or service price) weighted measure of services closely related to the net stock is appropriate for growth and productivity studies. The constant replacement rates and the associated PIM may be quite reasonable for estimating approximate capital stocks, or capital-output ratios.

The direct estimation methods, although used from time to time, have usually been rejected because they are believed to be less accurate than perpetual inventory methods. When the goal is merely to answer the simple question about how large the capital stock is, or what is the capital-output ratio, the correct criterion for selecting a measurement method is its accuracy. When the capital measurements are intended, however, to help measure something else, such as rates of technical progress or elasticities of substitution, the criterion is what measurement system will give the best estimates of the parameters of interest. In particular, as Miller points out, it may not be really logical to assume in this case that obsolescence occurs at a uniform rate.

13. Summary

All countries which estimate capital stock data have implemented the perpetual inventory method. A wide variety of survival functions and average service lives, however, is used in this estimation.

National estimates of capital stock data are based on quite different lifetime assumptions. For example, the minimum lifetime of equipment varies between 4 and 10 years and the maximum between 20 and 50 years. This variation is probably not only reflecting differences in real lifetimes but is also due to differences in assumptions. It follows that average service lives used in some capital stock estimates are not correct.

Many countries use accounting data or expert opinions as the main source of information for estimates on average lifetime. Occasionally, service lives of capital goods have also been determined so that the stock estimated using these lives and survival functions selected best fit the benchmark or other figures of gross stocks. These various methods result in great differences in the lifetime estimates.

There are, at the present time, two categories of countries: a short-life group consisting of the United States, Australia, Austria, Belgium, Finland, France, Germany, Italy and Canada, and a long-life group consisting of Iceland, Norway, Sweden and the United Kingdom.

Most countries use some kind of bell-shaped mortality function. The actual functions in use include normal, log-normal, gamma, quasi-logistic, Weibull and Winfrey functions. A truncated normal function is used in Canada and Italy, log-normal in France, gamma and logistic in Germany, logistic in Austria and Belgium, and Winfrey functions in the United States, Sweden and Australia. In Finland a Weibull function is used. Recently, the Netherlands has chosen a gamma distribution function.

The United Kingdom and New Zealand use a lagged linear mortality function.

In most cases symmetrical functions are used. Germany, however, uses also a left-skewed gamma function and Finland a left-skewed Weibull-function. Sweden and Australia use right-skewed as well as symmetrical Winfrey functions.

In compiling their capital stock estimates, four countries assume declining service lives, namely Australia, the United Kingdom, Canada and Germany. At present, only Canada gathers annual data on expected lives. A number of other OECD-countries are currently investigating service lives. These countries include, for example, Italy, the Netherlands, Spain, Sweden and Finland.

Three countries, Germany, Italy and Netherlands, calculate capital stock data according to the user and owner concept.

In calculating net capital stocks, straight-line and geometric depreciation have nearly an equal number of supporters among OECD-countries. Canada, the United States, Australia, Austria, France, Germany, Norway, the United Kingdom and Finland use straight-line depreciation, while Japan, New Zealand, Belgium, Iceland, Italy and Sweden use geometric depreciation.

As a conclusion, owing to the diversity in the depreciation patterns and lifetimes, the capital stock figures in different countries defy comparison in many respects. There is accordingly a great need to harmonize capital stock estimating methods.[22]

[22] During 1991, Eurostat (Statistical Office of the European Communities) carried out a substantial work in the field of capital stock data. It used the log-normal mortality function and calculated a set of harmonized capital stock for Germany, France, Italy, the United Kingdom, the Netherlands and Belgium for the period 1960–1989. Eurostat recommends the same method also to the member states.

Appendix.

Table . Average service lives of machinery and equipment

(excluding vehicles) in manufacturing activities (years)

ISIC Division		Canada	United States	Japan	Australia (1)	Austria	Belgium	Finland	France	Germany (2)	Iceland	Italy	Norway	Sweden	United Kingdom	Arithmetic Average
31	Food, beverages and tobacco															
	Food and beverages	29	20	(11)	19	22	15	20	16	15	22	18	25	20	26	20
	Tobacco	15	21	(11)	19	22	15	20	16	16	22	18	25	20	26	19
32	Textiles, clothing and leather															
	Textiles	26	16	(10)	19	18	15	19	20	16	22	18	25	20	28	19
	Clothing	21	15	(11)	19	15	15	19	20	12	22	18	25	20	24	18
	Leather	15	15	(10)	19	(17)	15	19	20	16	22	18	25	20	24	18
33	Wood and wood products															
	Lumber and wood products	26	12	(10)	19	15	15	18	20	12	22	18	25	15	23	18
	Furniture	26	14	(10)	19	15	15	18	20	12	22	18	25	15	23	18
34	Paper, paper products, printing etc.															
	Paper and paper products	22	16	(12)	19	20	15	17	20	16	22	16	25	(30)	32	18
	Printing and publishing	30	15	(12)	19	15	15	17	20	15(3)	22	16	25	30	32	20
35	Chemicals, petroleum products etc.															
	Chemicals	22	16	(8)	19	18	15	18	16	16	22	16	25	15	29	18
	Petroleum and coal products	26	22	(13)	19	18	15	18	16	19	22	18	25	30	23	20
	Rubber	15	14	(9)	19	18	15	18	16	15	22	15	25	15	24	17
	Plastic products	15	14	(9)	19	18	15	18	16	16	22	15	25	20	24	18
36	Non-metallic mineral products															
	Clay and stone products	26	19	(9)	19	18	15	15	16	13(4)	22	16	25	35	24	19
	Glass	26	19	(9)	19	15	15	15	16	14	22	16	25	35	24	19
	Other	26	19	(9)	19	18	15	15	16	14(5)	22	16	25	30	24	19
37	Basic metals	22	27	(13)	19	24	20	15	20	17	22	15	25	35	26	21
38	Fabricated metal products and machinery															
	Metal products	21	24	(11)	19	20	15	15	16	14(6)	22	20	25	25	26	20
	Non-electrical machinery	21	25	(12)	19	20	15	15	16	13	22	16	25	25	25	19
	Electrical machinery	22	14	(10)	19	20	15	15	16	15	22	16	25	25	25	19
	Motor vehicules	30	14	(11)	19	18	15	15	16	14	22	16	25	15	27	18
	Other transport equipment	30	17	(11)	19	18	15	15	16	14(7)	22	16	25	15	27	19
39	Other manufacturing															
	Instruments etc.	13	14	(11)	19	--	15	20	20	16	22	18	25	20	24	18
	Other	13	17	(11)	19	--	15	20	20	16	22	18	25	20	24	18
	Arithmetic Average	22	17	11	19	18	15	17	18	15	22	17	25	23	26	19

( ) Average calculated by the Secretariat.

(1) 19 years applies for the 1960s with asset lives reducing over time at the rate of 5% per decade.

(2) Vehicules are included (3) Excluding publishing (4) Manufacture of pottery, china and earthenware only (5) Including quarry (6) Including structural steel erection and railroad equipment (7) Excluding railroad equipment.

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