Measuring Capital
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Measuring Capital

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Preface

Welcome to the revised OECD Manual Measuring Capital. *This Manual should be of benefit to both producers and users of capital statistics.*

The publication of the original Measuring Capital *Manual in 2001 was a significant development in the statistical measurement of a vitally important component of economic activity. Capital plays a fundamental role in the process of production and it is a significant component of wealth and source of income. It is vital that both stock and flow aspects of capital are well measured in order to support the development and monitoring of economic policy, as well as economic analysis more generally. This revised edition of* Measuring Capital *builds on the original version, by taking account of new developments in capital measurement and ensuring consistency with the revised System of National Accounts – the 2008 SNA.*

As with the original edition, this revised edition takes the SNA as its starting point, in recognition that capital statistics are an important component of the national accounts. It also maintains an emphasis on an integrated approach to measuring capital in order to ensure consistency between the various stock and flow measures. Capital is an important component of productivity analysis, and because of this the Manual provides an important link between the SNA and productivity measurement. In continues to complement the OECD Manual Productivity Measurement.

The preparation of the revised Manual was guided by the Canberra II Group on the Measurement of Non-Financial Assets, with the OECD providing valuable secretariat support for the work of the Group. The Manual has been endorsed by the OECD National Accounts Working Party and the OECD Committee on Statistics.

The revised Manual is an excellent example of the cooperation between national statistical offices and international statistical organisations, and it was my great pleasure to Chair the work of the Canberra II Group. My thanks go to all those who participated in Canberra II discussions, and to the staff of the OECD who were involved in supporting the Group and in preparing the Manual. In particular, I would like to acknowledge the significant efforts of Charles Aspden and Paul Schreyer of the OECD. I would also like to thank the OECD for publishing this revised Manual.

Peter Harper

Chair

Canberra II Group on the Measurement of Non-Financial Assets

Acknowledgements

This *Manual* benefitted significantly from contributions of members of the Canberra II Group on the measurement of non-financial assets and from thoughtful comments provided by national statistical offices, in particular Statistics Canada, the U.S Bureau of Economic Analysis, Statistics Netherlands, Eurostat and the German Federal Office of Statistics. Special thanks go to Erwin Diewert (University of British Columbia) and Koji Nomura (Cabinet Office of Japan and Keio University) for many insightful comments, corrections and suggestions of draft versions of the document. Thanks are also due to Dale Jorgenson (Harvard University) and Chuck Hulten (University of Maryland) for their support during the gestation period of the *Manual*. All errors remain with Paul Schreyer (OECD), the principle author of the document.

Executive Summary

In 2001, the OECD published the Manual *Measuring Capital* to provide guidance to the concepts and practice of capital measurement. Since then, a number of developments have taken place, and most notably the revision of the 1993 System of National Accounts. The revision entailed many issues with regard to non-financial assets that also affect the original Capital Manual. The present document is a revision of the 2001 Manual, to take account of new developments and to ensure consistency with the revised System of National Accounts.

In the past, in many statistical offices, the main purpose of measuring capital was to provide a basis for the calculation of consumption of fixed capital so that net measures could be derived in the national accounts. The measurement of consumption of fixed capital remains a key reason for capital measurement but two additional objectives have increasingly gained in importance: establishing balance sheets for economic sectors and measuring capital services for the analysis of production and productivity.

The main objective of the present *Manual* is to deal with these additional objectives and to present an integrated and consistent approach towards capital measurement that encompasses different measures of capital stocks (gross, net and productive stock) alongside with the relevant measures of economic flows (investment, depreciation and capital services).

Many of the measurement concepts in the *Manual* reflect a fundamental ***dual nature of capital*** which is both ***storage of wealth*** and a ***source of capital services*** in production. In other words, there is a value or wealth side to capital and there is a volume or quantitative side to it. Depending on analytical purpose, it is either the value side for example in the form of the net capital stock or the volume side in the form of the productive capital stock that are the appropriate measure.

While the wealth and the production side of capital are different aspects that help analysing different questions, they are not independent of each other. Quite to the contrary, there is a clear link between the value of an asset and its current and future productive capacity and consistency in capital measures means taking account of this link.

The distinction between the wealth and the production aspect starts at the level of the individual asset and the first part of the *Manual* explores how, for a single asset, its age-price profile and its age-efficiency profile hang together. The age-price profile encompasses all the information about an asset's price history as it ages and reflects depreciation, a charge against income. The age-efficiency profile contains information about an asset's productive capacity over time and provides the key to measuring capital services, the asset's contribution to production. For single homogenous assets, the two profiles are related but in general different.

In practice, cohorts of assets are considered for measurement, not single assets. Also, asset groups are never truly homogenous but combine similar types of assets. When dealing with cohorts, retirement distributions must be invoked because it is implausible that all capital goods of the same cohort retire at the same moment in time. Thus, it is not enough to reason in terms of a single asset but age-efficiency and age-price profiles have to be combined with retirement patterns to measure productive and wealth stocks and depreciation for cohorts of asset classes. An important result from the literature, dealt with at some length in the *Manual* is that, for a cohort of assets, the combined age-efficiency and retirement profile or the combined age-price and retirement profile often resemble a geometric pattern, *i.e.* a decline at a constant rate. While this may appear to be a technical point, it has major practical advantages for capital measurement. The ***Manual therefore recommends the use of geometric patterns for depreciation*** because they tend to be empirically supported, conceptually correct and easy to implement.

Consumption of fixed capital or ***depreciation*** remains a central variable in capital measurement and there is a long history of debate about its exact meaning and its measurement. With the increasing importance of high-tech capital goods that undergo rapid technical change, there has been renewed discussion about the measurement of depreciation. In particular, the question has arisen whether a measure of depreciation should incorporate expected real holding losses or not. Some authors have suggested so, arguing that this is the appropriate way of capturing expected obsolescence. Others have come to a different conclusion, and draw a distinction between value changes of an asset due to ageing (which they identify with depreciation) and value changes due to overall price changes of the group of capital goods. The *Manual* finds that there is no single "correct" way of dealing with expected price changes in the context of depreciation measurement but rather that different analytical questions about net income give rise to different prescriptions about how to measure depreciation. For implementation, the *Manual* sticks with the approach towards measuring consumption of fixed capital that excludes real holding losses from depreciation. This corresponds to the practice of statistical offices.

Along with the volume of capital services, a price of capital services has to be specified and the *Manual* explains how such prices or unit user costs are derived and measured. They comprise two major elements that constitute the cost of using capital in production: depreciation, and the real costs of financing or a required real return to capital. There are several ways of formulating these elements when it comes to measurement and they are presented in the text. Attention is paid to how the return to capital is measured, and the literature has suggested *ex-post* calculations based on observed measures of property income in the national accounts as well as *ex-ante* calculations based on information from financial markets. For many reasons, results are not identical but ***the general evidence appears to be one of robustness of capital service measures with regard to the specifications for the return to capital***. Whether or not the capital service price takes account of real revaluation of the asset, on the other hand, seems to play a more important role for the resulting estimates.

The System of National Accounts estimates the value of output from non-market producers by costs. Capital costs are measured as consumption of fixed capital only, leaving out the other main element, financing costs. Reasons for this are of a practical nature (which interest rate should be chosen?) but there are also conceptual arguments such as the reluctance to see GDP rise when interest rates for government debt increase. At the same time, there are good conceptual and analytical reasons why the cost of capital should be measured as completely as possible for non-market producers. If not in the national accounts, then for analytical purposes it is therefore of interest to impute financing costs or a rate of return to government assets and the *Manual* describes several avenues towards doing so. In fact, for some non-market producers, households who own dwellings, such an imputation is already made in the national accounts and the *Manual* discusses how the information for owner-occupied housing can be used for other assets of non-market producers.

With regard to the ***scope of assets*** that are dealt with in the *Manual*, it covers predominantly fixed assets. However, three other types of assets are most relevant as sources of capital services: land (a largely non-produced asset), inventory (an asset that is not fixed) and natural resources other than land. These types of assets pose specific questions with regard to their measurement. In particular land is a quantitatively important asset that is notoriously difficult to measure. Consequently, the *Manual* devotes a special chapter to the measurement of land without making a claim of being exhaustive on the topic. Similarly, there is a special chapter on inventories. Natural resources other than land are also specifically dealt with but in less detail because reference is made to the International Handbook on Integrated Environmental and Economic Accounting (United Nations *et al.* 2003).

A significant number of pages in the *Manual* are allocated to the measurement of service lives, retirement functions and patterns of depreciation. Generally, ***good empirical information on asset lives is sparse*** and often dated. One of the annexes to the *Manual* brings together service lives as used in various countries.

The final part of the *Manual* is a mathematical description of the capital measurement process, taking into account the conventions specified in the national accounts. It is hoped that this systematic and consistent presentation facilitates implementation and programming routines.

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Chapter 1

Context, Purpose and Scope of the Manual

1.1. The role of capital measurement

It may be helpful to briefly recall the role that capital plays in a stylised system of national accounts. This can easily be done with a circular flow diagram, as shown in the figure below. Flows of quantities of goods and services are matched by monetary flows. In the simplest case with only consumers and producers, the basic exchange is between labour (hours worked) and consumer products. These are exchanged in the markets for labour and for consumer products and give rise to revenues and costs for producers, and expenditure and labour income for consumers. The flow of labour into the producer's sector and the flow of consumption goods out of it signal a production process whose analysis is central to many economic questions.

But labour is not the only input into production and this is the first instance where capital comes into play. Capital provides services to production, and is remunerated for these services with a rental when users of capital goods rent them from their owners for one or more periods. Often, users and owners are the same economic unit. The capital service is then internal to the economic unit but it exists nonetheless and should be measured for analysis. Parallel to the internal flow of capital services, an internal payment for these services can be envisioned, in the form of a price of capital services. The cost of capital in production and the associated service flow are not items that were recognized in the 1993 System of National Accounts – recently, however, the revised SNA has acknowledged these flows.

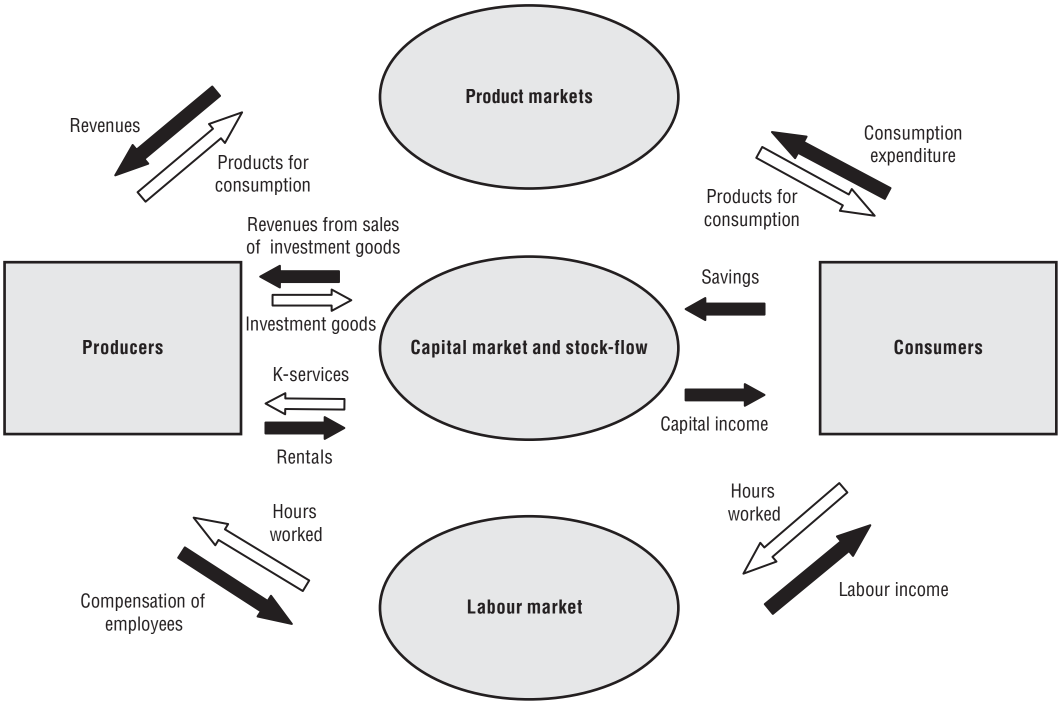
There is another instance where capital comes into play and it concerns capital as a storage of value. Producers buy capital goods and seek finance from consumers. The latter invest in capital goods by putting their savings at the disposal of producers, who in turn compensate consumers with interest or dividend payments, *i.e.* with capital income. The wealth aspect of capital is also where balance sheets come in – for a given date, all assets, financial and non-financial, should appear in the balance sheet of the unit that owns them to provide a comprehensive picture of economic wealth.

Because of the pivotal role of capital in an economy, it has to be measured. A large body of literature has dealt with the theoretical foundations of capital measurement and perhaps the most vocal debate in this context was the so called Cambridge debate. The present *Manual* is not the place to review or comment on this debate but it is quite clear that the measurement of capital cannot be done without some theory and capital measurement in the present text is largely done with reference to neoclassical capital theory.

Purely theoretical aspects aside, there is a central practical problem to capital measurement that raises many empirical issues – how to value stocks and flows of capital in the absence of (observable) economic transactions. This was phrased very clearly by John Hicks in *Capital and Time (1973)*:

"Let us put ourselves in the position of a statistician who is asked for a figure for National Capital; and let us grant that what is asked for is a value (here a money value) of National

Figure 1.1. **Circular flow diagram – the role of capital**



Source: adapted from Hulten (2006).

Capital. […] He has learned that for the measurement of National Income he needs a set of accounts, the running accounts (or flow accounts) of the national economy. So now, when he is asked for a measure of National Capital, he expects to serve it up in the form of a national balance sheet. But the task of constructing a national balance sheet is practically quite different.

It is characteristic of a running account, of whatever type, that most (though not all) of the items that enter into it are records of actual transactions. When an article is sold, money passes hands; so the value of the article is expressed in money terms, by buyer and seller, in the same way. When money is lent, currently, the same occurs. Thus, if it were the case that all entities within the economy […] kept proper running accounts, and if those accounts contained nothing but transaction items, it would be possible for a national running account to be compiled from them by a purely arithmetical process. Many of the accounts which he would need for this purpose are of course not available to the national income statistician; he has to estimate them. But in making such estimates, he is estimating an actual figure […] though information about it is not available to him […].

What in the case of running accounts is a complication, that can thus to some extent be avoided, in the case of the capital account is central and unavoidable. The assets, the possession of which is recorded in a balance sheet, are assets that are held, not goods that are sold. They may be sold, when time comes, but they are not being sold at the date to which the balance sheet refers."

The question of valuation is central to stocks but non-observable transactions are also a central issue when it comes to estimating volumes and prices of flows of capital services: there are some rental markets that deliver market observations on capital services but the bulk of capital is still used by its owners. The statistician then has the choice between ignoring these economic flows and estimating price and quantity of capital services that are internal to the economic unit. As long as this is done with the necessary caution, based on good theoretical reasoning and on as much empirical information as possible, the ultimate objective of measuring capital can be advanced, namely to better understand processes of value creation and economic well-being.

1.2. Purpose of this Manual

This *Manual* serves two complementary purposes:

- To present an integrated system of stocks and flows associated with the measurement of capital;
- To provide practical guidelines for estimation of these stocks and flows. Particular care is taken to ensure consistency with the System of National Accounts.

This *Manual* is organised in three major parts. Part I presents concepts of capital measurement in a non-technical way. With the help of numerical examples, the text provides the economic and statistical rationale for the measurement of the flows and stocks associated with capital. Probably the single most important message that this *Manual* advances is that of a coherent set of flows and stocks in relation to capital: capital formation, depreciation, capital services being the key flows and the net and the productive stock being the most important stock measures in this context. If national statistical offices manage to produce such a consistent set of capital measures, much will have been achieved by way of the usefulness of the national accounts.

Part II of the *Manual* is orientated towards precision and implementation. The text aims at being as precise as possible, by way of a technical presentation of some of the concepts and measurement procedures.

The main purpose of this Manual is to show how a coherent and analytically useful set of measures of flows and stocks of capital can be constructed.

Part II of this *Manual* also takes a look at some capital measures whose integration into the national accounts is still outstanding and/or may not be forthcoming although these measures would seem useful from an economic perspective and may also have become part of the more research-oriented literature. These include the imputation of full user costs to government assets, a scope of productive assets that includes land, other natural resources and inventories.

Part III is an algebraic exposition of the measurement model underlying capital stocks and flows. This part of the *Manual* starts from a basic economic relation about asset values, and shows how expressions for depreciation, user costs, and the various types of stocks can be derived in a way that is as consistent as possible with the System of National Accounts.

1.3. What the Manual does not cover

This *Manual* does not deal with the measurement of capital formation *as such*. The *1993 SNA* and its revision enlarged the asset boundary by introducing new classes of fixed assets, such as mineral exploration, computer software and entertainment, literary and artistic originals and research and development. There are both practical problems and conceptual questions about the valuation of some of these new assets, and these specific issues are only dealt with relatively briefly here.

The *Manual* is somewhat eclectic in the choice of non-produced assets that are explicitly dealt with. The bulk of the text deals implicitly or explicitly with produced assets because they constitute the backbone of capital measurement and they are the first

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candidates for measures of capital inputs into production. Land, although mainly a non-produced asset, does get special attention in the *Manual* whereas other non-produced assets such as natural resources get a less extensive treatment. There is no strong conceptual justification for this choice except that land has long been treated as a source of capital services in economics and should therefore be recognised as such. To a lesser extent, this is the case for other non-produced assets. On purely practical grounds, providing a complete guide to measuring non-financial balance sheets would not have been feasible within the time frame of the write-up of the *Manual*. Also, there is a well-developed body of international guidance concerning environmental assets, in particular in the form of the International Handbook on Integrated Environmental and Economic Accounting (United Nations *et al.* 2003) to which the reader will be referred where appropriate.

Price indices for assets are required for the measurement of capital stocks and of volume investment. Constructing price indices for fixed assets is particularly difficult because many capital goods are unique so that it is not possible to observe price changes from one period to the next. Another problem is that an important part of capital goods – for example communications and computing equipment – is subject to large technological improvements which are sometimes difficult to capture. Important measurement issues arise also in the area of price indices for dwellings and land. These issues are referred to but not treated in detail because they are seen as price index problems and are not specific to capital stock measurement.

PART I

Capital Stocks and Capital Services – Concepts

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Chapter 2

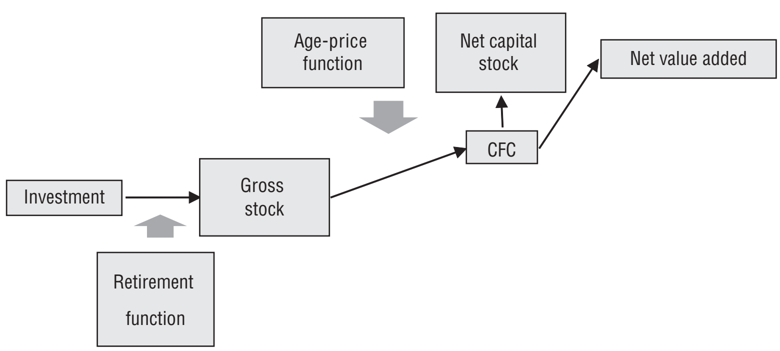
Introduction

One of the main objectives of the present *Manual* is to present an integrated and consistent approach towards capital measurement that encompasses different measures of capital stocks (gross, net and productive stock) alongside with the relevant measures of economic flows (investment, depreciation and capital services).

Capital stock featured in two places in the 1993 SNA, as part of compilation of balance sheets and as a tool to derive estimates of depreciation or consumption of fixed capital (CFC). How is gross capital stock estimated? Basically by cumulating gross fixed capital formation (GFCF) year by year and deducting retirements. Because it makes no sense to aggregate expenditures undertaken in different years without adjusting for the difference in prices between those years, all capital stock figures are in "constant prices". These prices may be the prices of the current year, in which case past expenditures are adjusted to the current price level or may be expressed at the prices of a given year, usually the one which is the base year for constant price national accounts.

Retirements are calculated by postulating a life length or more precisely a retirement function that is applied to investment flows. When these investment flows, corrected for retirement are cumulated, one obtains the gross capital stock (Figure 2.1). Consumption of fixed capital or depreciation is calculated by superimposing a pattern of decline in value over this time. This is called an age-price profile or age-price function. The relevant factor for each cohort of assets is applied so that the aggregate stock figure reflects both the chosen price level and also the fact that similar assets of different ages have different values. This gives rise to the net or wealth capital stock.

Figure 2.1. **Capital measures in the 1993 SNA**



Once net capital stock figures on a consistent basis exist for two successive years, it is possible to calculate the difference between them and after deducting new investment and allowing for disposals, this is what appears as the estimate of CFC or depreciation as currently recommended in the SNA. All these calculations need to be carried out in constant prices.

In the 1993 SNA, there was no explicit link between capital stock and value added except the entry of consumption of fixed capital to explain the difference between gross value added and net value added. Yet it has always been recognised that operating surplus is income deriving from the use of capital in production just as compensation of employees is income deriving from the use of labour. There is increasing interest in exploring exactly how different levels and types of capital stock influence the level of operating surplus. This has led to more attention being paid to capital services because of its application to productivity studies. Capital services can be integrated with national accounts practice of determining depreciation in a way which allows for deeper analysis and possible improvements in the underlying data on capital stock.

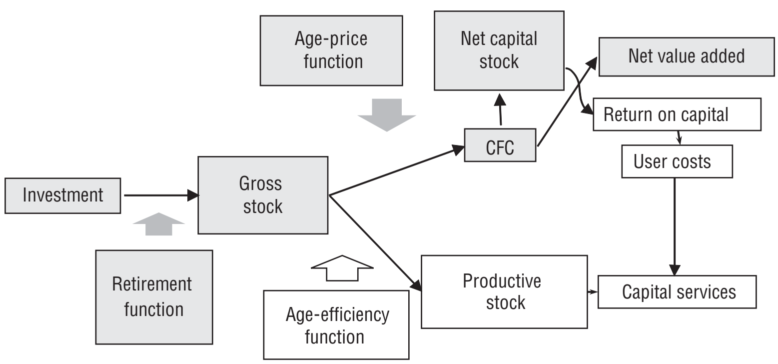
Capital services and their price, the user costs of capital do not replace well-established measures like the net and the gross capital stock – they complement them.

Whereas the introduction of costs of capital services into the accounts has been of interest in itself, they should also be internally consistent with measures of the net capital stock so that the volume and price measures of capital services, depreciation and net income aggregates in the national accounts as well as balance sheets are fully integrated. This allows researchers and statistical offices to produce consistent indicators of multi-factor productivity (see OECD (2001a)) which are of significant analytical interest.

Figure 2.2 illustrates the additional elements that capital services bring into the picture. One important element is the age-efficiency profile or age-efficiency function which depicts an asset's loss in productive efficiency as the asset ages. When past investment flows are corrected for retirements and for the loss in productive efficiency, their cumulative value is the productive stock. Capital services, the flow of productive services from capital assets to production, are proportional to the productive stock and can be derived from the former. Finally, the price of capital services – its user costs or rental price – is estimated by combining information on the required return to capital, on depreciation and on revaluation. Given the price of capital services – the user costs – and the quantity of capital services derived from the productive stock, the total value of capital services can be computed. All this will be dealt with in much greater detail below but it should be underlined here that the total value of capital services brings together again the price and quantity side of capital measurement. Consistency between these two aspects of capital is therefore required.

Thus, capital services are not simply an add-on to measures of the net capital stock – they are its analytical counterpart that comes along with the two basic roles of capital – a measure of wealth and income and a measure of the contribution of capital to production.

Figure 2.2. **Integrated set of capital measures**



The different measures of capital stocks and flows are directly related to these purposes, as shown in the table below. A more detailed description will be delivered later but a number of indications can be given immediately:

- The net capital stock measures the (market) value of capital, and is therefore a measure of wealth. Its evolution over time is governed by flows of investment and depreciation. A more telling terminology for the net stock is the "wealth stock". The "net" language distinguishes the depreciated capital stock from the un-depreciated or gross stock. More on the net/wealth stock can be found in chapter Chapter 6.
- Table 2.1 shows no entry for the gross capital stock. This is because the gross stock, if computed at all, constitutes an intermediate step towards calculating the net and the productive stock rather than a stock measure in its own analytical right. However, the gross stock is a well-known statistic and more will be said in section 3.2. Chapter 4.
- The productive stock exists for each type of capital used in production. Past investment for every group of assets is cumulated after correcting for the efficiency loss that has occurred since it was new. The productive stock is first of all a vehicle to derive measures of capital services, the flow of productive services provided by capital during one period. Commonly, the assumption is made that the flow of capital services is in a fixed proportion to the productive capital stock – by implication, the rate of change of capital services can be read from the rate of change of the productive capital stock. The productive stock is discussed at greater length in Chapter 7.
- Despite two distinct perspectives, income/wealth and production/productivity, the two spheres are linked. For example, the depreciation profile is not independent from the efficiency profile and depreciation measures not only enter the net capital stock, they are also part of user costs that form the basis for aggregation weights of the productive stock.

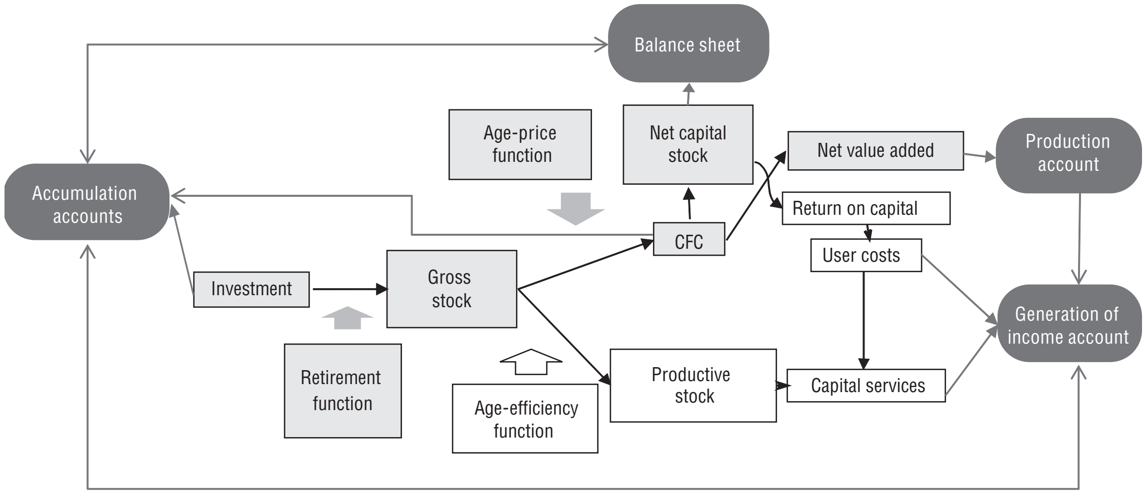
Figure 2.3 showed the various elements of an integrated system of capital measures. It is useful to go further and place this integrated system in the broader context of a system of national accounts, noting that capital services have not been recognised in the 1993 SNA and are not a compulsory part of the 2008 SNA. The basic links are shown in Figure 2.3. Stocks and flows of capital and investment appear in transaction accounts (production account and generation of income accounts), in accumulation accounts and in balance sheets. While most of these links have existed in the 1993 SNA, the proposed recognition of the value of capital services and their break-down into capital services prices and volumes in the generation of income accounts are new and described in greater detail in

Table 2.1. **Two aspects of capital**

	Income and wealth perspective	Production and productivity perspective
Basic flow	Investment	Investment
Aggregation across assets of different age based on	Depreciation profile (Age-price profile)	Age-efficiency profile
Resulting stock for each class of assets	Net capital stock by asset type	Productive stock by asset type
Derived flow	Depreciation	Capital services by type of asset
Aggregation across different classes of assets based on	Market prices	Capital service prices
Resulting stocks	Total net capital stock	Productive stock for each type of asset
Derived measure	Balance sheet entry, national wealth, net measures of income	Capital services, multi-factor productivity

Section 16.1.1. A more detailed example of a system of stock and flow measures of capital that is fully integrated into a system of national accounts is given in Jorgenson and Landefeld (2006).

Figure 2.3. **Capital measures in a system of accounts**



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Chapter 3

How asset values are determined

3.1. Concept

The central economic relationship that links the income and production perspectives to each other is the net present value condition: in a functioning market, the *stock value* of an asset is equal to the discounted stream of future benefits that the asset is expected to yield, an insight that goes at least back to Walras (1874) and Böhm-Bawerk (1891). Benefits are understood here as the income or the value of capital services generated by the asset.

In what follows, we shall consider a single asset, although this is clearly unrealistic: no firm, and much less a statistical agency will measure capital by looking at individual pieces of machinery or equipment. The typical case is to consider classes of assets, although an attempt is normally made to keep these classes of assets as homogenous as possible. For the moment, however, consider a single asset that is new, *i.e.* of age zero.

3.1.1. Income perspective

The value of this asset at the beginning of period t, P_0^t, to its owner corresponds to the discounted stream of future incomes generated by the asset. A subscript has been used to signal the age of the asset, in the present case zero because this is a new capital good. The flow of income for this asset will be labelled c_s^{t+s} where the superscript 't+s' indicates the period when the income arises and where the subscript 's' indicates again the age of the asset. A discount factor is needed as well to reflect the fact that people prefer immediate income to income in the future. The discount factor is labelled (1+r), where r is the nominal rate of return that the asset holder expects the asset to yield. Economic reasoning would suggest that this is the opportunity cost of the funds tied up in the asset: how much would an investor have earned (risk adjusted) if the funds had been invested elsewhere? At a minimum, the nominal rate of return should reflect the financing costs for the asset, for example the interest that the asset owner has to pay for a loan taken out to purchase the asset. Typically, however, the nominal rate of return will be higher than the interest rate paid on financing but there is no need to dwell on this distinction here. With the above remarks in mind, the fundamental equation relating the stock value of an asset to future income is:

$$p_0^t = c_0^t/(1+r) + c_1^{t+1}/(1+r)^2 + c_2^{t+2}/(1+r)^3 + \ldots + c_T^{t+T}/(1+r)^{T+1}. \qquad (1)$$

The relationship (1) has been formulated with nominal benefits and a nominal discount rate. Alternatively, it could have been expressed with real benefits and a real discount rate. In this case, a general deflator such as the consumer price index would be used to express future income flows and the rate of return r^t would be adjusted for the rate of general inflation. Consistency is important here and it is incorrect to combine nominal future income with a real discount rate or vice versa.

Further, the net present value formula (1) assumes that income payments are received at the end of each year. National accounts conventions suggest that benefits should be measured as evenly spread throughout the accounting period. This complication will be considered in the implementation part of the *Manual*. For the present conceptual exposition we ignore the complication as it does not affect the main conclusions.

Some more explanation on the income flows f may be useful. For an owner-user of an asset, the income generated by the asset corresponds to the profits that the asset generates when used in production. In more precise accounting terms, it corresponds to the extra gross operating surplus that the owner can expect from the use of the asset in production. Thus, the income flow for an asset should be 'gross' in the sense that it is not corrected for, *i.e.* inclusive of, depreciation, the value loss of the capital good as it ages. The income flow for an asset is 'net' in the sense that the extra proceeds from sales that were possible because the capital good generated additional output, are corrected for average labour costs and intermediate inputs per unit of capital.

3.1.2. Cost perspective

In competitive markets, there are no expected residual profits above and beyond the costs of capital input. The implication is that gross operating surplus[1] – whatever is left over once labour and intermediate inputs have been paid – will be equal to the cost of capital input. Thus, gross operating surplus per asset – the income flow generated by it – can also be given a cost interpretation: more specifically, it corresponds to the unit user cost of the asset. The cost perspective also permits interpreting unit user costs as the price of capital services: a capital good of a particular type and of a particular age supplies one unit of age-and asset-specific capital services. The price for these services is c_s^{t+s} – a price that the owner-user 'pays to himself'.

The cost perspective can be developed directly by examining the costs that a firm would have to incur if, at the beginning of a period, it bought an asset, used it in production during that period and sold it at the end of the period. The following elements would be considered in computing these costs: *(i)* the purchase price of the asset at the beginning of the period – if it is a new asset, this would be p_0^t; *(ii)* the sales price of the asset at the end of the period, noting that the asset is now one year old: p_1^{t+1}; *(iii)* a discount rate r to reflect the fact that financial capital is bound in the asset while in usage during the period. Combining these elements, the costs for using the asset are $p_0^t(1+r)-p_1^{t+1}$. These are in fact the unit user costs, or the price of capital services for the asset (see Chapter 8 for an in-depth presentation), which had been labelled c_0^t. It is not difficult to show (see Section 19.1) that the net present value relationship (1) follows from the reasoning about the cost of using a capital good during one period: $c_0^t = p_0^t(1+r)-c_1^{t+1}$.

When the sequence $\{c^t\}$ is interpreted as a sequence of unit user costs or capital services prices, equation (1) can also be interpreted as a rule for cost allocation over time: the value of a new capital good has to be distributed over accounting periods because of its nature as an investment good. This allocation in time should be such that costs in future periods match capital services that are provided by the asset in each period and measures for quantities and prices of capital services fulfil exactly this role.

Another important link can be established now that c_0^t has been interpreted as the price for the capital services of a new asset in year t: when compared to the price of capital services of another asset of the same type but of different age, say one year, it is plausible to state that the ratio of capital services prices c_0^t/ c_1^t should reflect the relative efficiency in production of the new compared to the one year old asset.

3.1.3. Market perspective

The net present value relation (1) can also be formulated for the stock value of an asset that is not new, *i.e.* for an asset with age greater than zero. For some used assets, there are markets, for others there are no markets. If a used asset market exists, and if an asset is offered for sale at a price that does not seem likely to generate a satisfactory rate of return, there will be no demand for that asset. If an asset is offered at a price that seems likely to generate a very high rate of return, there will be more demand than supply for the asset. In the first case, the price will be bid down, and in the second case the price will be bid up until the rate of return rises or falls to a "normal" level. Equation (1) can, therefore, also be given an interpretation of how asset prices are determined in a market economy.

Equation (1) is central for understanding the conceptual framework of this *Manual*. The net present value formula provides the link between stock measures, depreciation, and capital services: the value of the (net) stock of a particular age s enters via the price of the asset p_s^t; depreciation is part of the gross operating surplus term per unit of capital c_s^{t+s} that reflects income. This in turn equals unit user costs which constitute the price of capital services.

3.2. Relationship between capital service and asset prices for a single asset – a numerical example

This Section uses a simple numerical example to convey the main ideas behind a consistent set of capital measures. Box 3.1 spells out the numerical assumptions. The example starts out with Table 3.1 which shows how equation (1) can be used to calculate the price of an asset both when it is new and at every stage in its lifetime. Several assumptions are made to construct this example.

A 6-month old car may have lost none of its productive efficiency and yet it can only be sold at a 20% discount on the second-hand market. This distinguishes the age-efficiency from the age-price profile.

We take a cost perspective here (see Section 3.1.2 above) although nothing particular hinges on this, and we could equally have chosen a market or an income perspective for illustration. The first column in Table 3.2 shows the (future) service years of the asset. The perspective taken is from the beginning of year 1, looking ahead until the end of the asset's service life. The cost per unit of capital services that the asset is expected to provide each year is shown in the third column and corresponds to the sequence of c_0^t, c_1^{t+1}, c_2^{t+2} etc. in the net present value calculation (1). There are several ways to compute the evolution of these prices of capital services, given the data in Box 3.1 and only one option is presented here. Two factors impact on the change in the price of capital services: the rate at which the productive capacity of an asset declines as it becomes older, and the rate at which asset prices develop. The first effect is captured by the *age-efficiency profile*, shown in the second column of the table. Thus, during the first year of operation, the asset runs at 100% of its productive capacity, during the second period the figure is 88%, and so forth. The age-efficiency profile has been depicted as linear here and whether this is correct or not is an empirical issue.

The second effect that bears on the price of capital services is general changes in asset prices. Those were assumed to rise by 2% per period. The two effects can now be combined to yield the sequence of prices of capital services shown in the third column. By assumption it is $ 10 at the end of the first year (or equivalently, at the beginning of the second year). At the beginning of the third year, the price of capital services has fallen to $ 8.93, the product of a decline in efficiency to 88% and a 2% rise in asset inflation: $\$ 10*0.88*1.02 = \$ 8.93$. At the beginning of year 4, the capital service price is $\$ 10*0.75*1.02^2 = \$ 7.80$ and so on.

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Box 3.1. Numerical example

In the following chapters, a numerical example will be used that is based on the following assumptions about a fixed asset:

- Service life of 8 years
- Discount rate 5 %
- Price of capital services for a new asset, payable by the end of the first year is $ 10
- For simplicity, no general inflation
- Price of new asset is expected to rise by 2% per year
- Productive services of the asset decline by a constant amount over its service life (linear *age-efficiency* pattern)

Because the costs for capital services accrue in different years, their present value has to be obtained by discounting each year's rental by the discount factor (1+r), taken as 1.05 in this example. The fourth column of Table 3.1 shows the value of capital service prices, discounted to the beginning of year 1. This example assumes that payments are due at the end of each year and so the first year's cost of $ 10 is valued at $ 10/1.05 = $ 9.52 at the beginning of year 1; the payment of $ 8.93 expected at the end of the second year (or at the beginning of the third year) is worth only $ 8.93/1.05^2 = $ 8.10 at the beginning of year 1; the payment of 7.80 expected at the end of year 3 is worth only $ 7.80/1.05^3 = $ 6.74 etc. The total of these discounted capital services prices gives the value of the asset at the beginning of year 1, *i.e.* $ 40.12.

Table 3.1. Relationship between capital service prices and asset value in year 1

Year (t)	Age-efficiency	Price of capital service at beginning of period	Price of capital service discounted to beginning of year 1
1	100.0%		
2	87.5%	10.00	9.52
3	75.0%	8.93	8.10
4	62.5%	7.80	6.74
5	50.0%	6.63	5.46
6	37.5%	5.41	4.24
7	25.0%	4.14	3.09
8	12.5%	2.82	2.00
9	0.0%	1.44	0.97
10		0.00	0.00
Price of asset beginning of year 1			40.12

So far, we have considered the valuation of the asset at the beginning of the first year. Next, consider the same type of calculation one year later, *i.e.* at the beginning of year 2 and then two years later and so forth. This is captured in Table 3.3 below. The first four columns are identical to Table 3.1 but the fifth column shows the asset value at the beginning of the second year. For example, the capital service price of $ 8.93 prevailing in period 3 is the same as before but because time has moved on, it is now only discounted by one period: $ 8.93/ 1.05 = $ 8.50. The asset value at the beginning of the second year is then $ 32.12; the value at the beginning of the third year is $ 24.81 and so on. This sequence of asset values can be considered the price history of the asset, expressed in current prices of each period.

Table 3.2. **Relationship between capital service prices and asset value in all years**

			Price of capital service discounted to beginning of year							
Year (t)	Age-efficiency	Price of capital service at beginning of period	1	2	3	4	5	6	7	8
1	100.0%									
2	87.5%	10.00	9.52							
3	75.0%	8.93	8.10	8.50						
4	62.5%	7.80	6.74	7.08	7.43					
5	50.0%	6.63	5.46	5.73	6.02	6.32				
6	37.5%	5.41	4.24	4.45	4.68	4.91	5.15			
7	25.0%	4.14	3.09	3.24	3.41	3.58	3.76	3.94		
8	12.5%	2.82	2.00	2.10	2.21	2.32	2.43	2.55	2.68	
9	0.0%	1.44	0.97	1.02	1.07	1.13	1.18	1.24	1.30	1.37
10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Price of asset beginning of year			40.12	32.12	24.81	18.24	12.52	7.74	3.98	1.37

With the price history at hand, an important link can be established – that between the age-efficiency profile and age-price profile. To show this link, a matrix is constructed below with the history of asset prices in the main diagonal (Table 3.3). Each line stands for a different year in the life of the asset and each column epitomises the asset's age.

Table 3.3. **Price history of asset**

	Age of asset								
Year (t)	0	1	2	3	4	5	6	7	8
1	**40.12**								
2	40.92	**32.12**							
3	41.74	32.77	**24.81**						
4	42.57	33.42	25.30	**18.24**					
5	43.43	34.09	25.81	18.61	**12.52**				
6	44.29	34.77	26.32	18.98	12.77	**7.74**			
7	45.18	35.47	26.85	19.36	13.03	7.89	**3.98**		
8	46.08	36.18	27.39	19.75	13.29	8.05	4.06	**1.37**	
9	47.01	36.90	27.94	20.14	13.56	8.21	4.14	1.39	**0.00**

It can now be seen that the diagonal entries, the price history of the asset, combine two effects:

- a (vertical) movement in time (from year 1 to 2 etc.) that reflects the general change of the price of the asset class in question. For example, the new asset at the beginning of year 1 has a price of $ 40.12; after one year, its value has dropped to $ 32.12. The first effect can be read by comparing vertically the price of a new asset in year 1 ($ 40.12) to the price of a new asset in year 2 ($ 40.92). The difference reflects the 2% change in new asset prices underlying the present example.
- a (horizontal) movement in the age of the asset (from being new – age zero – to being one year old etc.) that reflects the value change because the asset has become older. In the example at hand, the age-effect is given by the horizontal movement from $ 40.92 to $ 32.12 – that is by the price difference of a new and a one-year old asset at the beginning of year 2. In percentage terms, the relative price of a one year old asset compared to a new asset is $ 32.12/$ 40.92 = 78.5%, the relative price of a two year-old asset compared to a new asset is $ 24.81/$ 41.74 = 59.4% and so forth. These price comparisons of assets of different

age for a given year constitute the *age-price profiles* of assets and are directly linked to depreciation. In particular, the line for year 9 shows the entire age-price profile of the asset.

From the above discussion it should be apparent that the age-efficiency profile and the age-price profile of a class of assets come in pairs, and although they may be different, they are not independent of each other. This is important for empirical implementation where the starting point is either an age-price profile from which a consistent age-efficiency profile is derived or an age-efficiency profile from which a consistent age-price profile is derived. The two avenues are presented in detail in Part II of this *Manual*.

Table 3.4. **Linear age-efficiency and corresponding age-price profile**

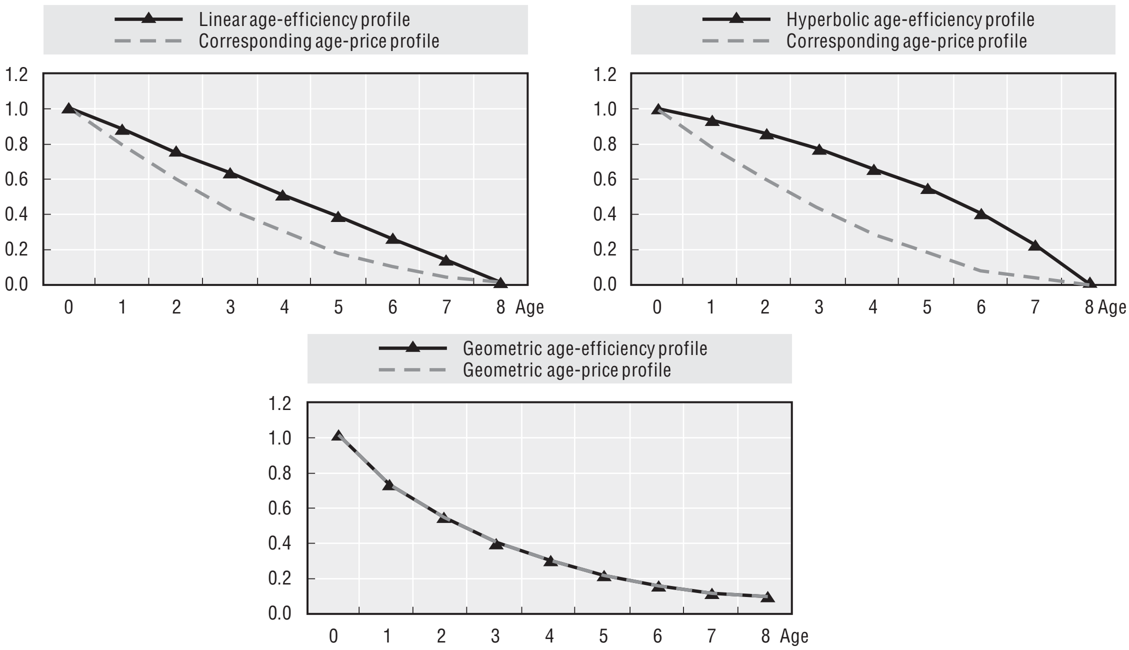
	Age								
	0	1	2	3	4	5	6	7	8
Age-efficiency profile	1.00	0.88	0.75	0.63	0.50	0.38	0.25	0.13	0.00
Age-price profile	1.00	0.79	0.59	0.43	0.29	0.17	0.09	0.03	0.00

The age-price and the age-efficiency profiles for the numerical example are shown in Table 3.4. The age-efficiency profile is taken directly from the first column of Table 3.1, and is based on the assumption of linearly efficiency decline. The age-price profile has been derived via Table 3.3, by comparing – for a given year – the price of capital goods of different ages with the price of a new capital good. One notes immediately that the two profiles are not identical. This can also be seen from the first graph in Figure 3.1: the linear age-efficiency profile gives rise to a convex-looking age-price profile. Other types of age-efficiency and age-price profiles are of course possible and indeed, the linearly declining efficiency profile may not be the most plausible approximation to the typical pattern of efficiency loss of an asset as it ages.

Two particular cases are worth mentioning here and are depicted graphically in Figure 3.1. The first case is a particular version of a hyperbolic age-efficiency profile where an asset's productive efficiency declines at a slow rate in the first years of its service life and at increasingly faster rates towards the end of the asset's service live. A hyperbolic age-efficiency profile gives rise to a convex age-price profile. The second special case arises when the age-efficiency or the age-price profile declines at a constant rate. It can be shown that in this case, the age-efficiency and the age-price profile are identical and both decline at the same rate. This constitutes significant practical advantages in implementing and computing capital measures and has been used in a vast majority of empirical studies of capital measures and depreciation.

The numerical example used here *assumed* a discount rate of 5% to put the calculations in place. In other words, the discount rate has been taken from outside, as an exogenous variable. As will be discussed later in this *Manual*, this is but one way of obtaining a discount rate or rate of return. In particular, a widely-used approach towards measuring the rate of return is computing it *endogenously* (see Section 8.3). It is worth flagging at this point already that an endogenous computation of the rate of return is difficult to reconcile with non-geometric age-efficiency and age-price profiles[2]. Thus, when rates of return are computed endogenously, it is best to combine them with geometric age-price and age-efficiency profiles.

Figure 3.1. **Age-efficiency and corresponding age-price profiles**



Notes

1. Taxes on production and mixed income are ignored for the moment.
2. There is an issue of simultaneity: if age-efficiency and age-price profiles are not geometric, and the starting point for computations is an age-efficiency profile, a rate of return is needed to derive the age-price profile. But to compute an endogenous rate of return, an age-price profile is needed. Conversely, if the starting point for implementation is an age-price profile, the age-efficiency profile is required to compute an endogenous rate of return.

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Chapter 4

Asset Retirement and the Gross Capital Stock

To this point, only a single asset has been considered. This is unrealistic because in practice, data exists only on classes and cohorts of assets. A *class* of assets brings together similar assets, for example in line with a product classification. A *cohort* of assets exists when many units of the same asset are invested during a particular accounting period. Even when identical assets are purchased at the same point in time, it is unlikely that they are all retired at the same moment.

4.1. Gross capital stock

The stock of assets surviving from past investment and re-valued at the purchasers prices of new capital goods of a reference period is called the *gross capital stock*. The gross capital stock is called gross because it has traditionally been thought of as the value of assets before deducting consumption of fixed capital. Thus, the gross capital stock ignores decay of assets and considers past investments "as new" – only retirement is taken into account.

Apart from being the conventional starting point for calculating consumption of fixed capital and the net capital stock, the gross capital stock has been regularly used in analysis. Closer inspection of its analytical application shows, however, that it has been used as a proxy for the productive capital stock (see below) rather than in its own conceptual right. For example, the gross capital stock has been widely used as a broad indicator of the *productive capacity* of a country, or it has been compared with value added to calculate *capital-output ratios*; finally, the gross capital stock has sometimes been used as a measure of *capital input* in studies of multifactor productivity. One of the first OECD publications on the matter (Ward 1976), proposes an efficiency-adjusted gross capital stock which is equivalent in concept to the productive capital stock.

Only in the special case where all assets keep their full productive efficiency until they disintegrate ("one-hoss-shay" pattern) would the gross capital stock provide an indication of the importance of capital in production. There are a number of assets that conceivably show such a pattern: certain buildings may be part of the category, and structures such as parking lots or warehouses. Even this observation must be qualified, however, in the sense that it only holds for a single type of asset. Further, when gross stocks of different types of assets are aggregated to yield an industry-wide or economy-wide gross stock, aggregation proceeds with weights that reflect "as new" market prices. This constitutes a fundamental difference to the aggregation procedure employed for the productive stock and for capital services which is based on a different set of weights, reflecting the user costs of capital.

4.2. Retirement profile and asset lives

The gross capital stock can be estimated in several ways. By far the commonest is the perpetual inventory method which involves accumulating past capital formation and deducting the value of assets that have reached the end of their service lives. To this end, a retirement or mortality profile is required to model the retirement process of a cohort

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Box 4.1. **Valuing capital stocks**

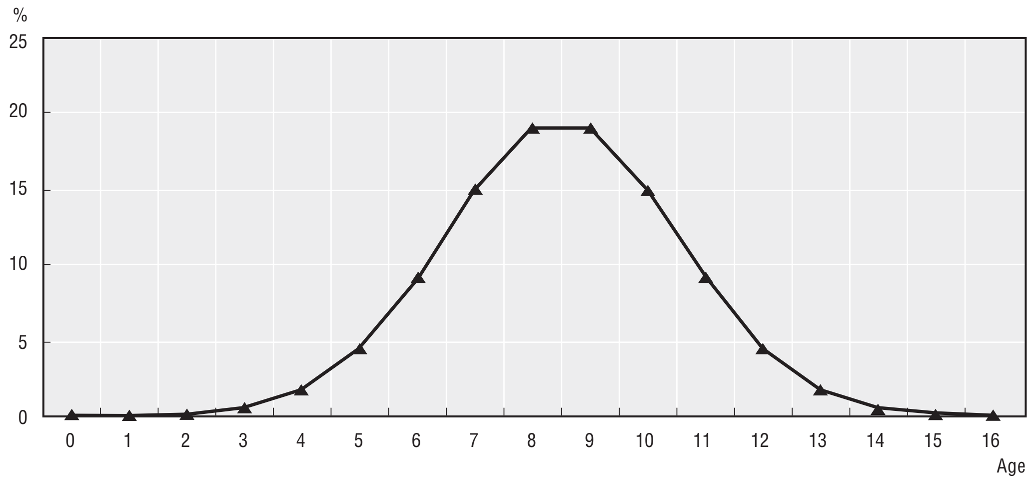
Assets can be valued at two kinds of prices:

- **Historic prices**, which means that the assets are valued at the prices at which the assets were originally acquired. Historic valuation implies that different vintages cannot be aggregated because each is on a different price basis. Valuation at historic prices is the usual procedure in company accounts. This is done because historic prices can be objectively verified by examining the invoices relating to asset purchases. Commercial accountants may also prefer historic prices because they tend to give a conservative valuation of assets. These advantages, however, are offset by the fact that assets which have been acquired at different dates are being valued at different prices so that when prices are rising/falling assets acquired more recently are implicitly given a higher/lower weight than those acquired in earlier periods. Capital stocks valued at historic prices cannot be compared with national accounting or other economic statistics that are expressed at prices of a single period.
- **Prices of a reference period**, which means that the assets are valued at the prices of a particular period. Meaningful aggregation of assets of different age to a stock requires that a vector of prices be applied which distinguishes between assets of different age and of different types but which refers to the same period or to the same point in time. The reference period can be any period, either the present accounting period or a past period. Note that the distinction between "current" and "constant" prices is not helpful in the case of stock measures: measures of flows can usefully be expressed at current prices (no deflators required) or at constant prices (deflator required). Stock measures, on the other hand, can never be constructed without price indices. Even when stocks are valued with prices of the current period, it is necessary to re-value to the present period all assets of an earlier vintage. This *Manual* avoids therefore the distinction between "current" and "constant" prices in relation to stocks and will refer to stocks valued at prices of a particular reference period, be it the most recent one or a period in the past. Valuation at prices of the current period is sometimes referred to as valuation at current "replacement" cost, but the qualifier "replacement" raises questions about what exactly is being replaced. For this reason the word "replacement" is not used in this *Manual*.

of assets over time. A key parameter in the retirement profile is the average service life of the cohort. Part II of this *Manual* lists alternative mortality profiles and describes ways how to estimate service lives. For the present purpose of demonstrating the concepts, we shall simply use a normal retirement distribution as shown in Figure 4.1. It depicts the marginal probability of retirement of a cohort of assets, with the highest probability of retirement around eight years of age, the average service life for the example at hand. The area under the retirement distribution sums to 100%, *i.e.* after around 16 years it is almost certain that all assets of the cohort will have retired. Retirement distributions can be truncated to fix a maximum service life, and in the present example this could be set at 16 years.

The retirement function can be expressed in a cumulative way, *i.e.* by adding up the successive retirement probabilities over the service life of the cohort. The result is best explained by looking at Table. It shows a sequence of investment in the same asset class over a period of 16 years. The fifth column represents the probability of survival of assets that were purchased during these 16 years. Note that the probability of survival is just

Figure 4.1. **Example of retirement distribution**



one minus the probability of retirement. Suppose that the current (latest) year is year 16. Then, the survival probability for investment goods purchased in year 16 is one, *i.e.* there is certainty of survival of the first period. There is a probability of approximately 84% that assets which were bought 8 years are still in service. But there is only a 0.6% probability for the 16 year old cohort to be still around. With this survival pattern at hand, the gross capital stock can be computed, based on the perpetual inventory method. The first column in Table shows investment expenditure over the past 16 years, at historical prices. With the capital goods price index (third column), these data are converted into comparable units, valued at prices of year 16 (fourth column). Next, the survival pattern is used to weight past cohorts by their survival probability with the result shown in column six. Upon adding up this last column, one obtains the gross capital stock valued at prices of period 16.

Table 4.1. **Retirement profile and gross capital stock**

Year (t)	Investment at historical prices	Price index (new) capital goods	Investment in prices of year 16	Survival pattern	Investment in prices of year 16, weighted with retirement pattern
1	500	1.000	672.9	0.0060	4.0
2	800	1.020	1055.6	0.0225	23.8
3	1000	1.040	1293.6	0.0666	861
4	600	1.061	760.9	0.1584	120,6
5	500	1.082	621.7	0.3083	191.7
6	700	1.104	853.3	0.4998	426.4
7	750	1.126	896.3	0.6912	619.6
8	900	1.149	1054.5	0.8411	886.9
9	1200	1.172	1378.4	0.9330	1286.0
10	1000	1.195	1126.2	0.9770	1100.3
11	1100	1.219	1214.5	0.9936	1206.7
12	1200	1.243	1298.9	0.9984	1296.9
13	1100	1.268	1167.3	0.9995	1166.8
14	1000	1.294	1040.4	0.9997	1040.1
15	900	1.319	918.0	0.9998	917.8
16	800	1.346	800.0	1.0000	800.0
Gross stock 31/Dec/year 16 at average prices of year 16					11173.6

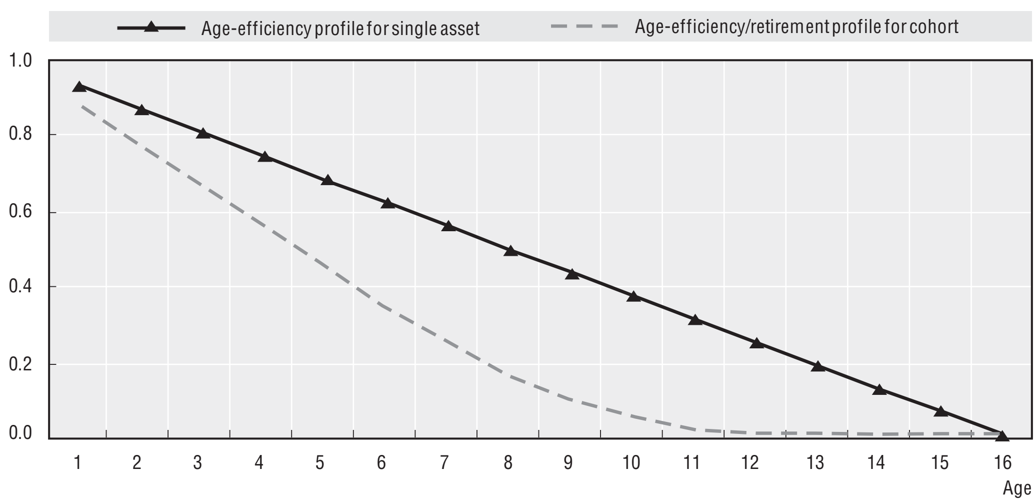
4.3. Combined age-efficiency/retirement profiles

Retirement distributions also have to be taken into account when age-price functions are derived from age-efficiency functions as was shown in section 3.2. It means that the age-price profiles derived there are age-price profiles *conditional on the survival of the asset*. If an age-efficiency profile is constructed for an entire cohort, the retirement distribution has to be taken into account which amounts to constructing a combined age-efficiency/retirement profile. From this cohort age-efficiency profile a cohort age-price profile can be derived, in line with the methods above. The resulting age-price profile then takes survival probabilities of assets into account. The price of an asset adjusted for the probability of survival will be lower than the price of an asset without such an adjustment, *i.e.* conditional on survival. Alternatively, a retirement profile can be combined with an age-price profile to yield an age-price function for a cohort. From this combined age-price/retirement profile, the corresponding age-efficiency profile can be derived. Note that in general the two avenues do not yield the same results. This is shown more formally in Annex 4.

Even when depreciation profiles for a single asset are linear, depreciation profiles for an entire cohort turn out to be of convex shape. Reasoning in terms of a single asset is thus not a good guide to the depreciation profile of a whole cohort.

If one starts on the age-efficiency side, an age-efficiency/retirement profile for a cohort of assets is computed by attaching a probability weight to different age-efficiency indices. For example, at the end of the first year of service there is a certain probability that some assets will retire. Thus, their age-efficiency profile has been falling extremely rapidly and become zero. There is a second set of assets whose age-efficiency has been falling slightly less rapidly than the first group because they are likely to retire at the end of the second period. Then there is a third group with an expected retirement at the end of the third period and with a corresponding age-efficiency profile and so on. For every point in the maximum service life of the cohort, a combined age-efficiency/retirement profile is computed by weighting each age-efficiency profile by its retirement probability as given by the retirement distribution. For a full exposition see Sections 13.2, 13.3 and Annex 4 of this *Manual*.

Figure 4.2. **Age-efficiency profile for single asset and for cohort of assets**



A central point is that this procedure implies that the age-efficiency profile for the cohort *as a whole* is different from the age-efficiency profile of an individual asset. Figure shows this difference for the linear age-efficiency function used in the numerical example in this chapter and for a lognormal retirement function. Despite the fact that the profile for an individual asset is linear, the age-efficiency/retirement profile for the cohort as a whole is convex. The conclusion is that a geometric age-efficiency/retirement profile may be a good approximation for a family of age-efficiency/retirement profiles for entire cohorts. As geometric efficiency and depreciation patterns immensely facilitate computational procedures for capital stocks and capital services, this is an important practical consideration.

For the remaining discussion in Part I of this *Manual*, the distinction between age-efficiency profiles for a single asset and for an entire cohort of assets will be maintained, in particular for the discussion of depreciation and the net stock.

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Chapter 5

Depreciation or Consumption of Fixed Capital

5.1. Concept and scope

Depreciation is the loss in value of an asset or a class of assets, as they age. Depreciation is a flow concept and as such shares key features such as principles of valuation with other flows in the national accounts. Economically, depreciation is best described as a deduction from income to account for the loss in capital value owing to the use of capital goods in production.[1] The meaning of the value loss in production explains also why "Consumption of fixed capital" (CFC) has been used as a synonym for "Depreciation" in the 1993 SNA. Similarly, in the United States national accounts, the term "Capital consumption" has been employed.

Depreciation measures, while of interest in themselves, have as a primary purpose to move from various "gross" measures of economic flows to the corresponding "net" variable, in particular for production and income (net domestic product, net value added) and a number of demand variables such as net investment. This is more than a simple additional accounting line because net measures have a particular role to play in analysis. In particular, net measures permit analysis that is closer to a welfare perspective[2] than gross measures which tend to reflect a supply-side perspective. The "net" aspect is also of particular relevance in conjunction with stock measures. As explained in Chapter 6, the net capital stock is a measure of wealth which provides another link to economic welfare. To measure the net capital stock of many assets, measures of depreciation are indispensable.

An important purpose of measuring depreciation is to move from gross to net measures in the accounts so that the welfare-relevant variable "net income" can be examined.

Consumption of fixed capital is a cost of production. The general definition of CFC is given in the 2008 System of National Accounts, in Chapter 6:

> *"Consumption of fixed capital is the decline, during the course of the accounting period, in the current value of the stock of fixed assets owned and used by a producer as a result of physical deterioration, normal obsolescence or normal accidental damage. […] Losses due to war or to major natural disasters that occur very infrequently […] are not included under consumption of fixed capital. […] The values of the assets lost in these ways are recorded in the other changes in the volume of assets accounts. […]Consumption of fixed capital is defined in the System in a way that is intended to be theoretically appropriate and relevant for purposes of economic analysis. Its value may deviate considerably from depreciation as recorded in business accounts or as allowed for taxation purposes, especially when there is inflation."*

Some clarifications are needed.

- First, a decline in value during the accounting period can be understood as the sum of two components, as has already been indicated in Section 3.2. One component is the price change that reflects the price movement of the asset class under consideration, *given a particular age* (and measured, for example, by comparing the price of a new asset at the beginning of the period with the price of a new asset at the end of the period). Another component is the price change that reflects the ageing of the asset *given a*

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particular price level for the asset class (and measured, for example, by comparing the price of a new asset with the price of a one-year old asset). Whether only the latter measure should be used to capture depreciation or whether also the former price movement should be included in a measure of depreciation, has be subject to debate and will be discussed further in the section on "depreciation and obsolescence". At this point it is sufficient to signal that the present *Manual* captures depreciation as the price change due to ageing, thereby controlling for the overall movements in asset prices. This fits with the idea in the national accounts that economic flows within a period should be measured with regard to a given set of average prices of this period, also spelled out in the SNA: "*Consumption of fixed capital must be measured with reference to a given set of prices,* i.e. *the average prices of the period*".

- Second, "normal accidental damage" refers to the kinds of accidents that are commonly encountered when assets are used in production. Accidental damage includes cases where the asset has been so badly damaged that it has to be prematurely scrapped. Transport equipment is particularly vulnerable to damage of this kind and when service lives are estimated for such assets they must reflect the probability of premature scrapping through accidental losses.

In this *Manual*, the terms "consumption of fixed capital" and "depreciation" are used interchangeably because they reflect the same concepts. National accountants use the former, whereas economic analysts are more attuned to the latter.

- Third, the above definition implies, without explicitly stating so, that "abnormal" or unexpected obsolescence is also excluded from consumption of fixed capital. Abnormal obsolescence here means unforeseen obsolescence and it may occur either because of unexpected technological breakthroughs or changes in the relative prices of inputs. Relative prices can change following events on product or factor markets, for example shifts in consumer taste. Other reasons are of a technological nature: the introduction of electronic calculators in the 1960s is an example of an unforeseen development, which resulted in a sudden and sharp fall in the value of the existing stock of electromechanical calculators. The 1973 oil-shock is an example of a drastic shift in relative input prices, which may have led to premature replacement in some countries of inefficient oil-using equipment by more efficient models or by assets using other energy sources. Premature scrapping of assets, which arises from unforeseen obsolescence, is treated in the same way as losses of assets due to wars or natural calamities and is shown in the account for "Other changes in the volume of assets".
- Fourth, the calculation of consumption of fixed capital should take into account the observed values of second hand assets when they are actively traded. How information on second hand markets can be used to determine depreciation profiles is discussed in Chapter 15. However, there are many assets for which there are no or no representative second hand markets, making empirical measurement of depreciation profiles difficult. In such cases, depreciation patterns could be considered a way of allocating fixed capital formation expenses over the service life of the asset. Such an allocation should be forward, not backward looking and should be proportional to the expected income flows generated by the asset over its lifetime.[3]

5.2. Measuring depreciation

The measurement of depreciation is directly associated with the age-price profile of an asset or of a cohort of assets. The rate of depreciation of an s-year old asset is the difference in the price of an s-year old asset and an s+1 year old asset, expressed as a proportion of the s-year old asset. In this calculation, both the price of the s-year old asset and the price of the s+1 year old asset are thereby measured as average prices of the accounting period. Thus, in the example of the price history of an asset in Table 3.3, depreciation rates are measured by comparison of values across lines. For example, the depreciation rate for a one-year old asset is (40.92-32.12)/40.92, or about 21%, the depreciation rate for a two year old asset is about 24%. Note that in this numerical example, rates of depreciation are accelerating. This is a direct consequence of the fact that the age-price function was consistently derived from the assumed linear age-efficiency function.

Table 3.3 is based on the efficiency and price profiles for a single asset. The discussion in the preceding Chapter on retirement showed, however, that realistically, age-efficiency and age-price profiles for entire cohorts should be used, which reflect retirement distributions. Thus, just like the age-price profile for a single asset can be consistently derived from the age-efficiency profile for a single, an age-price profile for an entire cohort can be derived from an age-efficiency profile for an entire cohort. The computation is exactly as in Table 3.3 for a single asset.

The transition from the single asset perspective to the cohort perspective is shown in Table 5.1. The first column depicts the age of investment goods. The table is best read starting with the third column that replicates the age-efficiency function in the case of a single asset with service live of eight years – the same pattern that was summarised in Table . When moving from a single asset to a cohort, other asset lives must be considered to reflect the heterogeneity of capital goods within a cohort. The second and fourth column in Table 5.1 show examples of age-efficiency functions for different service lives – 1 year and 16 years. For the cohort of assets at hand, 8 years have been considered the average service life and 16 years the maximum service life. To construct an age-efficiency profile for the cohort *as a whole*, a probability-weighted average of the age-efficiency functions associated with different service lives is constructed. How exactly this is achieved and which possibilities there are for calculation is explained in detail in Section 13.3. For the simple example at hand, it suffices to say that the result is a combined age-efficiency/retirement profile for the cohort as a whole which is shown in the second column from the right. Finally, the last column in Table 5.1 represents the age-price profile that corresponds to this combined age-efficiency/retirement profile. It has been derived from the combined age-efficiency/retirement profile in precisely the same way an age-price profile for a single asset has been derived from an age-efficiency profile for a single asset (Tables 3.1 to Table). The age-price profile for a cohort is the starting point for the calculation of depreciation and of net stocks.

Depreciation rates and depreciation profiles are different ways of presenting the age-price profile of an asset, with exactly the same information contents.

Before moving on to show how depreciation is calculated, it is noted that in Table 5.1, age-price profiles for a cohort have been derived from the age-efficiency profile. This is one way of constructing a consistent set of capital measures. Alternatively, the starting point could be age-price profiles for individual assets. For example, statistical offices have often used a linearly-declining age-price function, *i.e.* constant absolute values of depreciation over an asset's lifetime. One notes that if the

Table 5.1. **Age-efficiency and age-price profiles for a cohort**

Age of investment good	Age-efficiency profile for single asset with service life of					Age-efficiency/ retirement profile for cohort	Age-price profile for cohort
	1 year	….	8 years	….	16 years		
15	. .		. .		0.06	0.00	0.00
14	. .		. .		0.13	0.00	0.00
13	. .		. .		0.19	0.00	0.00
12	. .		. .		0.25	0.01	0.00
11	. .		. .		0.31	0.02	0.01
10	. .		. .		0.38	0.05	0.02
9	. .		. .		0.44	0.09	0.03
8	. .		0.00		0.50	0.16	0.07
7	. .		0.13		0.56	0.24	0.11
6	. .		0.25		0.63	0.34	0.18
5	. .		0.38		0.69	0.45	0.27
4	. .		0.50		0.75	0.56	0.38
3	. .		0.63		0.81	0.67	0.50
2	. .		0.75		0.88	0.78	0.65
1	0.00		0.88		0.94	0.89	0.82
0	1.00		1.00		1.00	1.00	1.00

starting point is a particular depreciation or age-price pattern, a consistent (and generally non-linear) age-efficiency profile has to be derived. For a more detailed discussion, the reader is referred to Chapter 10.

We now continue the description of depreciation measurement by introducing *depreciation rates*. Depreciation rates are shown in the third column of Table and are simply a different way of expressing the age-price profile for the entire cohort that was derived in Table 5.1: for every age, the depreciation rate shows the difference in value between successive ages as a percentage of the younger asset. Thus, the depreciation rate for a one year old asset is the price difference between a one year-old and a two year-old asset expressed as a percentage of the value of the one year old asset – 20.3% for the example at hand.

For purposes of computation another transformation is useful, namely to compute *depreciation profiles based on new asset values*. The latter reflect the value loss of an asset as it ages, expressed as a percentage of the value of a *new* asset, as shown in Table. For a new asset, depreciation rates and depreciation profiles coincide (18.4%) but for other ages, they are different. For example, the 16.5 % depreciation profile for a one year old asset is computed as the depreciation rate for a one-year old asset multiplied by one minus the depreciation rate for a new asset, *i.e.* 0.203*(1-0.184)=0.165. Similarly, for a two-year old asset, one obtains 0.225*(1-0.203)*(1-0.184)=0.147 etc. The sole purpose of transforming "normal" depreciation rates into depreciation profiles based on new asset values if one of computational convenience, as will presently be discussed, and to be able to establish links to the existing practice of computing CFC in the national accounts.

There are two, equivalent ways of computing the level of depreciation – one that uses the rates of depreciation directly and one that operates via the net or wealth capital stock.[4] Consider the second operation first. It obliges us to anticipate that, under the perpetual inventory method (described at greater length in Chapters 6 and 10), the net stock for a particular type of asset is constructed by cumulating past

Table 5.2. **Depreciation rate and depreciation profile**

Age of investment good	Age-price profile for cohort	Depreciation rate	Depreciation profile
15	0.000	1.000	0.000
14	0.000	0.825	0.000
13	0.001	0.775	0.000
12	0.002	0.723	0.001
11	0.006	0.668	0.004
10	0.015	0.608	0.009
9	0.034	0.546	0.018
8	0.066	0.484	0.032
7	0.114	0.425	0.049
6	0.182	0.372	0.068
5	0.269	0.325	0.088
4	0.377	0.286	0.108
3	0.504	0.253	0.127
2	0.651	0.225	0.147
1	0.816	0.203	0.165
0	1.000	0.184	0.184

flows of investment with the age-price function as a weighting pattern. This is simulated in the first six columns of Table: the year for which depreciation is to be computed is year 17 and the second column lists investment expenditure of a particular asset type during the years 1 to 17. Investment is valued at average prices of year 16 – a reference year that has been chosen arbitrarily. Column three exhibits the combined age-price/retirement profile that applies at the end of year 16: investment (*i.e.* gross fixed capital formation – GFCF) during year 16 gets a weight of 1; GFCF during year 15 gets a weight of 0.816 and so on. Column four exhibits the age-price/retirement profile from the perspective of the end of year 17 – year 17 investment enters with a coefficient of 1, year 16 investment with a coefficient of 0.816 and so on. In column five, past investment flows are weighted with the age-price profile that applies at the end of year 16, and in column six, past investment flows are weighted with the age-price profile that applies at the end of year 17. Summing up columns five and six yields the net stocks at the beginning (column 5) and at the end (column 6) of year 17, valued at average prices of year 16.

To compute depreciation, the total change in the wealth stock between the beginning and the end of period 17 is readily computed as 125 currency units. This difference can be broken down into investment and depreciation (all measured on the same price basis), and it is easily established that depreciation during period 17 has to be $ 1051.5, given a flow of investment of $ 1176.5 and the change in the wealth stock of $ 125. As everything has been expressed in prices of period 16, depreciation of period 17, expressed in current prices of period 17, is obtained by multiplying through with the price change of investment goods between periods 16 and 17.

There is a second, equivalent way to compute depreciation and it uses directly the depreciation profile shown in Table. More specifically, the depreciation profile is applied directly to the series of past investment. This computation can be seen in the 7th and 8th column of Table. The sum of the weighted investment flows equals 1051.5, the value of depreciation in year 17, expressed in prices of year 16.

Table 5.3. **Computing depreciation**

Year (t)	Investment in prices of year 16	Age-price profile		Past investment weighted by age-price profile		Depreciation profile	Past investment weighted by depreciation profile
		year 16	year 17	Year 16	Year 17		
1	672.9	0.000	0.000	0.0	0.0	0.000	0.0
2	1055.6	0.000	0.000	0.1	0.0	0.000	0.1
3	1293.6	0.001	0.000	0.7	0.2	0.000	0.6
4	760.9	0.002	0.001	1.5	0.4	0.001	1.1
5	621.7	0.006	0.002	3.7	1.2	0.004	2.5
6	853.3	0.015	0.006	13.1	5.1	0.009	8.0
7	896.3	0.034	0.015	30.3	13.8	0.018	16.6
8	1054.5	0.066	0.034	69.2	35.7	0.032	33.5
9	1378.4	0.114	0.066	157.3	90.4	0.049	66.9
10	1126.2	0.182	0.114	204.5	128.5	0.068	76.1
11	1214.5	0.269	0.182	326.9	220.6	0.088	106.3
12	1298.9	0.377	0.269	489.4	349.6	0.108	139.8
13	1167.3	0.504	0.377	588.5	439.8	0.127	148.7
14	1040.4	0.651	0.504	677.2	524.5	0.147	152.6
15	918.0	0.816	0.651	749.4	597.5	0.165	151.9
16	800.0	1.000	0.816	800.0	653.0	0.184	147.0
17	1176.5		1.000		1176.5		
				4111.9	4236.9		**1051.5**
During year 17:							
Change in wealth stock in prices of year 16					125.0		
Of which investment in prices of year 16					1176.5		
Of which depreciation in prices of year 16					**–1051.5**		

5.3. *Price and volume of depreciation*

The calculations above were all carried out for a particular type of assets, and the price-volume split is straight forward by applying the appropriate (quality-adjusted) price index of the asset class under consideration. Splitting aggregate depreciation (*i.e.* the sum of depreciation across all assets) into a price and volume component is slightly more complex and will be addressed in Section 8.3.3.

5.4. *Depreciation and obsolescence*

It was mentioned earlier that, along with physical deterioration, depreciation should include "normal" or "foreseen" obsolescence. The question how to define obsolescence, how to measure it and how to ensure that it is part of depreciation measurement has recently been discussed (Hill 2000, 2003, Diewert 2005, Ahmad *et al.* 2005, Schreyer 2005, Diewert and Wykoff 2006) with different proposals for the measurement of depreciation.

A representative definition of obsolescence from the literature is "…the loss in value of existing capital because it is no longer technologically suited to economic conditions or because technically superior alternatives become available" (Hulten and Wykoff 1981 p. 255). Obsolescence is typically described as a value phenomenon, not one that affects the physical services provided by a capital good. However, the borderline between value effects and physical effects can be blurred:

- Conceptually, obsolescence also comprises complex cases induced by relative price changes of other inputs so that the asset under consideration is no longer suited to economic conditions. An energy-intensive machine may become obsolete if energy costs rise relative to other inputs or a coal mine may become obsolete if the price for coal becomes uncompetitive. Such obsolescence will translate into the shortening of economic service lives of assets and affects the value of the asset as well as the overall flow of services it delivers. Diewert and Wykoff (2006) have labelled downward shifts in the price of specialised capital due to shifts in demand *disembodied obsolescence charge* since it can occur even if no new, improved models of the capital input appear on the market.

- When obsolescence is linked to the introduction of new, improved models, there is a case of *embodied obsolescence charge* in the terminology of Diewert and Wykoff (2006). Because embodied obsolescence is directly linked to quality change, the use of quality-adjusted price indices is a tool by which the volume of assets with different characteristics can be made comparable. For example, when investment data for successive years is used to construct measures of depreciation, quality-adjusted price indices are applied for deflation. This implies that the volume investment of older vintages is scaled down relative to new ones because time series of investment are converted into standard efficiency units. Thus, even though the absolute productive efficiency of an old capital good may be unchanged, quality improvements in newer capital goods lead to a reduction in the volume measure for the old capital good, when expressed in new equivalent efficiency units.

At the risk of oversimplifying the debate, a main issue has been whether depreciation measures should only comprise the difference in value between assets of different age at a given period ("cross-section depreciation") or whether the depreciation measure should also include expected downward adjustments in real asset prices between periods. The inclusion of the second element, advocated for example by Hill (2000), was motivated by the idea that secular falls in real asset prices are indicative of embodied technical change that makes assets relatively cheaper over time. This is an expression of obsolescence and should therefore be part of the depreciation measure, as depreciation should reflect obsolescence. On the other hand, important strands of the economic literature on depreciation[5] have always defined and measured depreciation excluding declines in real asset prices.

One of the conclusions from the debate was that there may be no single "correct" measure of depreciation but that different analytical questions may give rise to different notions of depreciation. One way to look at depreciation is as the value of assets lost due to their use in production or the means that need to be set aside to keep the productive capacity of an economy intact. Another way to look at depreciation is as the amount of wealth that is lost to owners of assets because the latter are used in production *and* because there is a long-term downward trend in real asset prices. The latter interpretation would call for an inclusion of real price drops into measures of depreciation, the former interpretation would call for an exclusion of real price drops from depreciation while treating them as a real holding loss, *i.e.* as a wealth effect. Put differently, if depreciation is there to measure the value of investment needed to keep the productive stock of an economy intact, falls in real asset price should not enter the calculation. If depreciation is there to measure the value of investment needed to keep the purchasing power of capital owners' wealth stock intact, real asset prices should be considered (Schreyer 2005).

In the event, the question about what to include in a measure of depreciation is a question about what net income (or other net measures in the national accounts) is

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supposed to measure, much more than a question about obsolescence. Diewert (2006a) traces this discussion about net income back to a debate between Pigou (1924, 1941), Clark (1940) and Hayek (1941). Deducting depreciation inclusive of expected declines in real asset prices from gross income yields a net income measure that corresponds to income from a wealth perspective. Diewert's (2006a) net income measure adjusted for "wear and tear and revaluation" is similar but more general because it allows for (expected) real capital losses as well as (expected) capital gains. Deducting depreciation exclusive of expected declines in real asset prices from gross income yields a net income measure that corresponds to income from a production perspective.

The present *Manual* uses a notion of depreciation that does *not* encompass the changes in relative prices of assets. There are several reasons for this.

- The first reason is that it keeps the supply side and production perspective of the economy separate from the demand and consumer side. A measure of depreciation that captures the discounted value of capital used up in production and the investment needed to keep the productive capacity of the economy intact fits into a supply-side perspective. A consumer or demand side perspective[6] can easily be added by considering wealth effects arising with the ownership of productive assets but it seems better to keep these effects separate rather than lumping them together in the first place.
- The second reason is that present practice in OECD countries' national accounts corresponds to a notion of depreciation that excludes wealth effects. Also, if one wanted to bring real wealth effects into measures of depreciation, there is a question whether such effects should be integrated asymmetrically (capturing only expected real holding *losses*) or symmetrically (allowing also for real holding *gains*).

However, we reiterate that different analytical questions may give rise to different treatment of relative price changes for capital goods. In particular, for the analysis of wealth effects and associated welfare considerations, it is meaningful to account for real price changes. Net income would then decline in the presence of expected holding losses and rise in the presence of expected holding gains.

5.5. *Determining depreciation parameters*

5.5.1. *Derived from age-efficiency profiles*

There are several approaches towards deriving depreciation rates in practice. The first option is to start from information or assumptions about assets' service lives and about their age-efficiency profile and from there derive the age-price profile and depreciation rates, very much along the lines shown in Tables 3.1 to 3.4. A more detailed discussion of age-efficiency profiles can be found in Chapter 6 and a formal description of how to derive depreciation parameters from the age-efficiency profile can be found in Part II of this *Manual*.

5.5.2. *Direct determination of age-price profiles*

The second option – frequently used by statistical offices – is to start from information or assumptions about assets' service lives, and make an additional assumption about the functional form of the age-price profile. In many instances, the assumption has been that depreciation follows a linear pattern. The third option is to derive depreciation parameters through empirical information on used asset prices that can be exploited econometrically.

Options two and three are also described more formally in Part II of this *Manual*. Some general points can be made here.

First, when a linear pattern for the age-price or depreciation profile is assumed, no allowance is made for a retirement distribution in the computation of the profile. The retirement profile has to be built into the computation by adjusting the age-price profile for retirement or by multiplying past investment vectors through by their survival probability (see Section 13.3). This amounts to making use of the elements of the gross capital stock. The total amount of depreciation for a particular period, valued at average prices of this period, is then obtained by applying the vector of depreciation parameters to the vector of past investments where each investment has been adjusted for its probability of survival.

Second, when a pattern of constant percentage decline in asset values is chosen for the age-price profile ("geometric pattern"), a simple method to obtain geometric coefficients is the double-declining balance method where the rate decline is given by the following expression: $\delta^i = 2/\overline{T}^i$ where $\overline{T}^i$ is the average service life of asset type i. At the same time, there are no broad-based empirical results that would generally support that value. For further discussion of the declining balance method see Chapter 12.

A preferred way to obtain the parameters for geometric models of depreciation is from econometric studies of used asset prices or from asset disposal surveys. Although the empirical basis is not very broad, these results provide much better foundations for depreciation estimates than simple assumptions. The principles of such studies are described in Chapter 12.

Notes

1. See Triplett (1996) for a comprehensive discussion of the interpretation of depreciation.
2. The first on to establish a formal, model-based link between net domestic product and economic welfare was Weitzman (1976). However, the basic fact that net variables are more relevant for discussions about welfare than gross measures has long been around in the economics profession (see Marshall, 1890 and Pigou 1924 for example).
3. The amounts so allocated are not a complete measure of the cost of capital – they ignore price changes and interest rates, just as the part of annuity that corresponds to the reimbursement of the principal of a loan is an insufficient statistic for the monthly cost of the loan. Note also that the System of National Accounts (Chapter 6) explicitly states that "unlike depreciation as usually calculated in business accounts, consumption of fixed capital is not, at least in principle, a method of allocating the costs of past expenditures on fixed assets over subsequent accounting periods". In other words, depreciation is a forward-looking measure that is determined by future, not past, events.
4. The words "net stock" and "wealth stocks" are used interchangeably in this *Manual* (see Chapter 6).
5. For a representative summary of such work, see Jorgenson (1996). Some authors (Ahmad, Aspden and Schreyer 2005) have argued that expected obsolescence should be part of depreciation but that the inclusion of real asset price changes is neither necessary nor sufficient to capture them. Diewert (2006c) came to a similar conclusion when he showed how increases in the prices of another factor of labour could lead to an early retirement of an asset, implying a type of obsolescence that is not necessarily dependent on real asset price changes: "What causes these non standard forms of obsolescence is some sort of non-separability of capital from other factors of production" (Diewert in a comment on the discussion). Jorgenson (1999) argued that there was no need to separately account for obsolescence. He writes: "[…] there is no role for the concept of 'obsolescence' in the new definition [of depreciation], since all asset prices are defined in terms of constant quality price indices, like those employed for computers by BEA. Purchasers of assets anticipate quality change, but this information is included in the prices of assets, so that no separate accounting for obsolescence is required". This seems to be very close to Diewert's and Wykoff's (2006) point about embodied obsolescence charges.

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6. For certain products such as computers, the difference between a supply side and a consumer perspective are potentially large because computers suffer from rapid drops in real prices. Thus, depreciation charges might differ and so will net income, reflecting two different notions of income, as explained above. At the same time, if obsolescence is the reason for rapid drops in real prices, the economic service lives of computers are likely to be short which will tend to reduce the difference between the two measures of depreciation and income. For empirical evidence on obsolescence for computers see Geske, Ramey and Sharpiro (2007) who state (p.14): “Once obsolescence is taken into account, age-related depreciation of personal computers that were resold is negligible”.

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Chapter 6

Net ("Wealth") Capital Stock

6.1. Concept

The stock of assets surviving from past periods, and corrected for depreciation is the *net or wealth capital* stock. The net stock is valued as if the capital good (used or new) were acquired on the date to which a balance sheet relates. The net stock is designed to reflect the wealth of the owner of the asset at a particular point in time. Hence, the notion of “wealth” stock which seems more telling than ‘net’ stock because there are other types of “net” capital measures, for example the productive stock is ‘net’ of efficiency losses of capital goods due to ageing. The net stock is the measure that enters balance sheets of institutional sectors.

6.2. Measurement

Broadly speaking, there are three avenues to measure the net stock:

- through direct application of the perpetual inventory method, as the sum of past investments, weighted by a combined age-price/retirement profile;
- derived from gross stock and depreciation;
- from company surveys.

6.2.1. Direct application of the perpetual inventory method

The starting point for any computation of the net stock is the age-price/retirement profile for a particular asset group. This profile can either be directly determined from empirical observations about depreciation patterns or it can be derived from combined age-efficiency/retirement patterns described earlier in this *Manual*.

Net stocks capture the wealth aspect of capital – they are the right entries for balance sheets.

With the age-price/retirement profile in hand, the perpetual inventory method can be applied to yield a measure of the net stock, as shown in Table. As in earlier tables, the second column features investment at historical prices which is transformed into prices of year 16 (column four) by applying the investment price index from column three. Next, the combined age-price/retirement pattern from Table 5.1 is applied to weigh the vector of past investments. Thus, investment of the current period 16 gets a weight of one, implying that its entirety features in the net stock, investment from period 15 is equipped with a weight of about 81%, and so forth until investment from 16 years earlier which basically fetches a zero weight. The last column shows the so-weighted investment series which are then added up to yield the net stock of 4111.9 currency units at the end of year 16, valued at prices of year 16.

The net capital stock at prices of year 16 in Table was calculated using the *year average prices* of the asset if the investment deflator in column three relates to mid-periods. In the SNA balance sheets however, the net capital stock must be valued at *year-end* prices because all entries in the closing balance sheets refer to the market values of assets and liabilities at the end of each year. Thus, to use the net capital stock at current prices shown in Table as a balance sheet entry, it must be multiplied by the ratio of end-year to year

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Table 6.1. **Computing the net stock**

Year (t)	Investment at historical prices	Price index (new) capital goods	Investment in prices of year 16	Age-price profile for cohort	Investment in prices of year 16, weighted with age-price profile for cohort
1	500	1.000	672.9	0.000	0.0
2	800	1.020	1055.6	0.000	0.1
3	1000	1.040	1293.6	0.001	0.7
4	600	1.061	760.9	0.002	1.5
5	500	1.082	621.7	0.006	3.7
6	700	1.104	853.3	0.015	13.1
7	750	1.126	896.3	0.034	30.3
8	900	1.149	1054.5	0.066	69.2
9	1200	1.172	1378.4	0.114	157.3
10	1000	1.195	1126.2	0.182	204.5
11	1100	1.219	1214.5	0.269	326.9
12	1200	1.243	1298.9	0.377	489.4
13	1100	1.268	1167.3	0.504	588.5
14	1000	1.294	1040.4	0.651	677.2
15	900	1.319	918.0	0.816	749.4
16	800	1.346	800.0	1.000	800.0
Net stock end of year 16 at average prices of year 16					**4111.9**

average prices. End-year prices are not usually calculated directly but are obtained by averaging December/January or fourth/first quarter prices if these are available or by averaging year-average prices for adjacent years.

Year-average prices are, however, the correct price basis for valuing depreciation, both at current and constant prices. Depreciation is a flow that occurs regularly throughout the year. Ideally it would be valued at the prices prevailing each moment that it occurs, but as this is not practical, the average of prices throughout the year – or failing that mid-year prices – are an acceptable approximation. Thus, the net stock at year-average prices is useful in the context of measuring depreciation, as shown in Chapter 5.

6.2.2. Derivation from gross stock and depreciation

For assets in a balance sheet, the System of National Accounts recommends valuing them by writing-down the current purchasers' or basic prices of new assets by the accumulated consumption of fixed capital of these assets. This corresponds to what is described under the present section. Because this method is entirely equivalent to the "direct application of the perpetual inventory method" described above, both these approaches constitute measurements recommended by the SNA.

A second way, thus, of computing the net stock consists of adjusting measures of the gross capital stock for cumulative depreciation. This presupposes that the depreciation measures are available. As has been shown in the Chapter on depreciation, there are several, equivalent ways of deriving depreciation measures. One is by comparing net stocks and deducting gross fixed capital formation. This method can of course not be used in the present case because it implies a circularity - that the net stock is known to derive the net stock. In other words, it is not possible to compute both the net stock and depreciation indirectly – at least one of them has to be computed by directly applying age-price or depreciation profiles to time series of investment.

6.2.3. Company surveys

Because the net stock is conceptually similar to balance sheet items in company accounts, information from companies can in principle be used to gauge the level of the net stock of fixed assets. As described in greater detail in Chapter 12 several practical issues have to be overcome before company information is usable for the national accounts. One important issue is valuation – data on company assets may be valued at historical costs whereas national accounts balance sheet items have to be valued at current prices. Another question is whether the depreciation patterns used by companies to derive net values of assets are broadly compatible with national accounts principles, in particular whether the depreciation pattern approximates a loss in market value of the asset. Sometimes fiscal considerations or fiscal rules such as accelerated depreciation influence the value of a company's net stock without being representative of market values.

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Chapter 7

Productive Stock and Capital Services

7.1. Concept

The stock of a particular type of assets surviving from past periods, and corrected for its loss in productive efficiency is the *productive capital* stock[1]. Thus, productive stocks are directly related to the quantity and production aspect of capital. Productive stocks constitute an intermediate step towards the measurement of capital services. The assumption is made that the flow of capital services – the actual capital input into production – is proportional to the productive stock of an asset class. If the factor of proportionality is constant, the rate of change of capital services will equal the rate of change of the productive stock[2]. The same rate of change constitutes the volume component when it comes to splitting the change in the total value of capital services at current prices into a price and a volume component. A different way of seeing the productive stock of a particular type of asset is as the embodied volume of current and future capital services. The concept of a productive stock is only meaningful at the disaggregate level of a particular type of asset. Once each asset's productive stock is combined with the corresponding capital service price (per unit of the productive stock), the resulting value represents the flow of capital services. This is the relevant variable for aggregation across different types of assets.

7.2. Computing productive stocks

The productive capital stock for a single asset is measured through direct application of the perpetual inventory method, as the sum of past investments, weighted by an age-efficiency profile. The age-efficiency pattern (see also Chapter 3.2) describes the change in an asset's productive efficiency as the asset ages. Typically, the age-efficiency profile is expressed relative to the productive efficiency of a new asset[3]. By applying the age-efficiency profile to quantities of past investment, all vintages are expressed in new-equivalent efficiency units. The computation of the productive stock via addition of efficiency-adjusted investments of past period implies complete substitutability of past vintages, once adjusted for efficiency differences. This is more stringent an assumption than strictly necessary[4] but has some practical advantages. Triplett (1997) discusses this assumption with the example of trucks:

> *"The assumption that old trucks can be represented as some smaller quantity of new trucks (that is, reduced proportionately by deterioration) implies somewhat unrealistic conditions about the way trucks and other inputs combine in the production process. One can think of the deteriorated truck as equivalent to a lower quality truck (compared to a new one). In the quality change literature, the assumption that permits expressing improved trucks as 'more' unimproved ones is termed 'repackaging'. The repackaging assumption and its limitations are discussed in Fisher and Shell (1972)"*

The productive stock for a single (type of) asset may or may not coincide with the net stock of a single (type of) asset. The two stock measures are identical if the age-efficiency profile is identical with the age-price profile. Such an identity holds for geometric age-efficiency and age-price profiles and has been discussed earlier in this *Manual*. A more important difference between the productive stock and the net capital stock arises, however, in the process of aggregation. Net capital stock measures are aggregated on the basis of market prices and there is a clear meaning to the 'level' of the net stock. Over time, an index of the net capital stock can be considered a weighted average of the index of net stocks for different types of assets, where each asset's share in the total market value of assets figures as weight. Productive stocks for each type of asset, on the other hand, are not aggregated *as such*. Rather, by attaching user costs to them, the transition is made to capital service flows which are then aggregated. Over time, an index of capital services is a weighted average of an index of productive stocks by type of asset, where each asset's share in total user costs figures as weight. Usually, an index of the net capital stock evolves quite differently from an index of the productive stock, *i.e.* from an index of capital services. In many empirical applications, the productive stock has risen faster than the net stock. This happens, for example, when there is a shift in the composition of investment towards more short-lived capital goods such as information technology equipment and when real investment in these goods grows faster than investment in other goods. Short-lived capital goods are marked by high depreciation and holding losses, *i.e.* elements that tend to raise these assets' user costs share relative to their share in market value. The consequence is that fast-growing components of the productive stock get a higher weight than under the net stock calculation and the overall productive stock moves faster than the overall volume of the net capital stock.

Productive stocks measure the stock of assets, corrected for efficiency loss and retirement. They are seen as the stocks that generate flows of capital services, the input of capital into production

Table 7.1 continues the numerical example introduced earlier and shows how the productive stock for a single asset can be computed under the perpetual inventory method. Investment at historical prices is put on a comparable basis by applying the price index of new capital goods so that the time series of investment is expressed in prices of period 16. Then, use is made of the combined age-efficiency/retirement pattern introduced in Section 4.3. This profile serves to weight the vector of constant price investment, the

Table 7.1. **Computing the productive stock for a single (type of) asset**

Year (t)	Investment at historical prices	Price index (new) capital goods	Investment in prices of year 16	Age-efficiency profile for cohort	Investment in prices of year 16. Weighted with age-efficiency pattern
1	500	1.000	672.9	0.0001	0.1
2	800	1.020	1055.6	0.0005	0.5
3	1000	1.040	1293.6	0.0021	2.7
4	600	1.061	760.9	0.0071	5.4
5	500	1.082	621.7	0.0197	12.2
6	700	1.104	853.3	0.0459	39.2
7	750	1.126	896.3	0.0914	81.9
8	900	1.149	1054.5	0.1580	166.6
9	1200	1.172	1378.4	0.2434	335.6
10	1000	1.195	1126.2	0.3420	385.1
11	1100	1.219	1214.5	0.4478	543.9
12	1200	1.243	1298.9	0.5570	723.5
13	1100	1.268	1167.3	0.6674	779.1
14	1000	1.294	1040.4	0.7782	809.6
15	900	1.319	918.0	0.8891	816.2
16	800	1.346	800.0	1.0000	800.0
Productive stock end of year 16 at (current) prices of year 16					5501.6

result of which is shown in the last column of the table. Summing up the column yields the productive capital stock at the end of period 16, and valued at period 16 prices. The same type of calculation, carried out for a sequence of years, provides the basis for measuring the flow of capital services provided by the asset group. As was mentioned above, aggregation across assets proceeds with user costs weights. The nature of user cost weights is discussed in the next section.

Notes

1. One could also say that the productive stock equals a hypothetical stock of that consists solely of new goods and which yields in the current period the same level of services as the actual stock does.
2. Schreyer, Bignon and Dupont (2003) made explicit the distinction between the flow of capital services and the productive stock for a particular type of asset, by introducing a constant factor of proportionality that indicates the number of (unobserved) units of capital services per unit of productive stock. The distinction is not made here. Strictly speaking, the price of capital services (unit user costs) that is described later in this Manual should therefore be read as the price of capital services per unit of productive stock.
3. Nothing hinges on this practice. The productive stock could be expressed in efficiency units of any vintage and calculations for the total value of capital services and the quantity index of capital services would still yield identical results.
4. Diewert and Lawrence (2000) show how more general aggregation procedures with superlative index numbers can be used to aggregate quantities across different vintages. Thereby, perfect substitutability between vintages is not required.

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Chapter 8

User Costs

8.1. Concept

In a production process, labour, capital and intermediate inputs are combined to produce output. Conceptually, there are many facets of capital input that bear a direct analogy to labour input. Capital goods are seen as carriers of capital services that constitute the actual input in the production process. For purposes of productivity and production analysis, then, capital services constitute the appropriate measure of capital input. At present, however, the national accounts provide no measure of the value, price or volume of capital services.

Consumption of fixed capital or depreciation is sometimes thought of as reflecting the full costs of using fixed assets. That this is a misconception can easily be shown by taking the case where fixed assets are not owned by a firm but rented from another unit who owns the capital good. The owner's price charged for the rental will comprise not only depreciation (consumption of fixed capital), but other elements as well, for example an item reflecting financing costs of capital, lest the asset owner would make a permanent loss from renting out the asset.

In practice, many fixed assets are owned by their users and to measure the costs of capital services to owner-users, an imputation has to be made that brings together various elements of rentals to determine a price that the owner "charges to himself". As often, imputing unobserved values raises conceptual and empirical issues and one objective of the present *Manual* is to provide guidance on the choice of these elements.

The idea that the production account does not explicitly identify the total values of capital services from fixed assets but instead records them within value-added or operating surplus is not, of course, new. The impetus to separately identify these capital services now however, largely reflects the increased interest in growth accounting and productivity analysis (OECD 2001a, Harper *et al.* (2003), Jorgenson and Landefeld 2006).

A major impetus behind recognising capital services measures in conjunction with the national accounts is to lend more structure to gross domestic income, and in particular, to enable a price-volume split of the income accruing to capital. Deflated gross domestic income can also be seen as a volume measure of labour and capital inputs and, when compared to deflated gross domestic product yields a measure of multi-factor productivity.

8.2. Interpreting and measuring user costs

If there are rental markets, observed rentals could provide a first approximation to the user costs of capital for owner-users of the same assets. However, rental markets are far from complete or representative. There is another reason why market rentals may differ from user costs of capital: for a lessor, the rental does not constitute the net benefit that he gets from letting a capital good during one period. The lessor has to cover other costs such as labour and overheads associated with the leasing service. These costs have to be reflected in the rental which therefore constitutes a measure of turnover but not of operating surplus, or benefit, to the lessor. However, it is this benefit that is relevant for the

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owner-user in his evaluation of the costs of capital. Consequently, even if there were pervasive rental markets, observed rentals would constitute only a first approximation to the user costs for owners of assets[1].

Various components have to be added up to approximate the cost of capital services. A simple method for deriving a formula for the cost of using an asset is the following argument (Diewert 1974). Suppose the owner of an asset wants to determine the minimum price (before adding on costs of associated labour and overheads) at which he is willing to rent the asset during one period of time. In the simplest case, three main cost elements have to be considered: *(i)* the cost of financing or the opportunity cost of the financial capital tied up through the purchase of the asset; *(ii)* depreciation, *i.e.* the value loss due to ageing; *(iii)* revaluation, *i.e.* the expected price change of the class of assets under consideration.

Suppose that one deals with an asset that is new at the beginning of the accounting period. Then, unit user costs – the user costs per unit of capital – can be presented as a share of the purchase price of a new asset where the percentage share is made up of three (approximately) additive components: a nominal rate of return; a rate of depreciation for a new asset; and a nominal rate of asset price change. It should be noted that in general unit user costs are time and age-dependent: they apply during a particular accounting period for an asset with a particular age.

Section 3.1 introduced the income perspective, the cost perspective and the market perspective as three different ways of describing capital services and their prices. Depending on the perspective, it may be more or less appropriate to reason in terms of "unit user costs", "prices of capital services" or "rentals". In the present *Manual*, the first two notions are used interchangeably, and with a situation in mind where owners of capital goods are also their users. The terms "rental" or "rental price" are used for situations where owner and user are different and a market transaction takes place where capital goods are leased between different economic units.

In many instances, it will be easier to work with real rates of return and with real changes in asset prices. If r^{*t} stands for the real rate of return (*i.e.* the nominal rate of return corrected for a general inflation) that applies during period t, if i^{*t} is the real anticipated change in asset prices, if $(_0$ stands for the depreciation rate of a new asset, and if $p_0{}^t$ is the purchase price of a new asset at the beginning of period t, the unit user cost $c_0{}^t$ for a new asset is approximately given by

$$c_0{}^t \approx p_0{}^t \, [r^{*t} - i^{*t} + \delta_0] \qquad (2)$$

A full development of this derivation and different variants of user cost expressions can be found in Part III of this *Manual*. We note, however, at this stage that an approximation to (2) can often be obtained by setting the anticipated real holding gains term i^{*t} equal to zero. Such an approximation will be reasonable if the asset price changes are not too far from general price changes. The resulting user cost formula simplifies to:

$$c_0{}^t \approx p_0{}^t \, [r^{*t} + \delta_0] \qquad (3)$$

Thus this *simplified unit user cost* depends only on the period t real interest rate r^{*t}, the depreciation rate $(_0$, and the beginning of period t asset purchase price $p_0{}^t$. The main advantage over the other, preferred, formula (2) is that it is not necessary to estimate anticipated real holding gains and thus formula (3) is more *reproducible*, since different investigators will have different techniques for forming expected or anticipated holding gains. At the same time, if relative asset prices show marked trends, the use of (3) may introduce a bias into the weighting structure of different assets' capital services flows. Baldwin and Gu (2007) note on the matter of holding gains in the user cost expression:

> *"There is little disagreement that, on theoretical grounds, capital gains should be included in the rental price of capital. A lessor of capital will charge a lower price if a capital gain is expected by the end of the holding period or a higher price if a capital loss is expected.*
>
> *Nevertheless, there is some disquiet among practitioners when it comes to including a term for capital gains and losses. Giving rise to unease among practitioners is the size of volatility of the actual capital gains and the source thereof. And volatility in capital gains is not likely to be matched in the short run by changes in the marginal product of capital because of long gestation periods for capital projects.*
>
> *It is also not clear whether there are ways that holding-period gains arising from differential rates of asset inflation can be harvested – especially for investment goods. This concern revolves around the level of transaction costs that must be incurred in selling investment goods. If there is no inexpensive way to realise capital gains, changes in asset prices derived from price indices are not a very useful way to measure the capital gains component of the rental price of capital. It is therefore not clear that the actual asset price series provide accurate estimates of the rate of return that should be expected from capital gains".*

The simplified user cost formula, due essentially to Walras (1954), says that the user cost of capital is equal to the anticipated real interest rate plus the anticipated depreciation rate times the beginning of the period stock price of the asset.

The user cost formula as presented above constitutes the costs of using an asset of a particular age for one accounting period – for an owner-user this cost can be understood as a price internal to the firm. Multiplying the unit user cost by the number of capital goods of corresponding age and summing up across all capital goods gives rise to a measure of total user costs.

Three main elements of user costs were identified above: a return on capital, depreciation and revaluation or holding gains and losses. Chapters 5 and 12 of this *Manual* deal with the concept and measurement of depreciation, respectively. Chapter 16 discusses at some length the empirical choices for rates of return. What remains in the present conceptual part of the *Manual* is to discuss some of the conceptual aspects of the rate of return and of the revaluation term.

8.3. Rates of return – conceptual considerations

The choice of the rate of return is an important element in the construction of user costs. In a functioning capital market, the expected rate of return to capital corresponds to the risk-adjusted market return. A useful way of approaching the rates of return in the private sector and under market conditions is as the *opportunity costs of holding durable goods rather than financial claims* (Jorgenson and Yun 2001). The opportunity cost interpretation of rates of return or of user costs (see Box 3) can be brought to a more general level and can be applied in a market and in a non-market context.

When there is a functioning capital market, it follows that, *ex-ante*, or over longer periods, one should not expect a higher rate of return on fixed assets than from an alternative investment with comparable risk. The actual, *ex-post*, rate of return, on the other hand may vary between investments of similar risk, although such variations should not be systematic. This reasoning can be applied to individual types of assets and to industries. Different types of assets can carry different degrees of riskiness. For example,

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investment in an office building may be less risky than investment in research and development. In principle, this should be reflected in the *ex-ante* rate of return to each type of asset. However, assets are not only used in isolation but they are combined with other assets and other factors of production in economic units, such as establishments or enterprises. Units with similar activity form an industry and activities in different industries may differ in their riskiness, because different industries use different combinations of assets and because the economic environment in which different industries operate may not be identical. A financial investor who plans to buy shares in a company will do so if the risk-adjusted expected return from this investment is at least equal to investments of similar risk elsewhere on the market. But the investment, and therefore the rate of return concerns the business operation as a whole and therefore all assets equally. *Ex-ante*, therefore, the rate of return should be the same for different types of assets in the same economic unit or the same industry.

From an *ex-post* perspective, there is no immediate reason to assume that all assets have produced the same risk-adjusted rate of return. In particular, an asset's realised rate of return does not necessarily equal the firm's overall profit rate. This point has been made by Triplett (1997) and Oulton (2007). At the same time it is hard to envision how one would define a single asset's realised rate of return unless there is a unique asset with identifiable cash flows. But when multiple assets are used jointly (see also the argument with regard to risk in the preceding paragraph), it is unclear how one would conceptualise, let alone measure each asset's rate of return.

We conclude that first, the *ex-ante* or expected return has to be distinguished from the *ex-post* or realised return. Second, the expected rates of return may vary between industries where such differences reflect the combination of assets used in the industry as well as purely industry-specific circumstances. Our third conclusion here is that in general, the expected as well as the realised rate of return *of a particular asset* are hard to conceptualise and to observe.

The choice of a suitable rate of return is also linked to the following national accounts question: should the estimate of the value of capital services explain gross operating surplus, the capital part of gross mixed income and relevant taxes on capital exactly? Or is the estimate of capital service independent so that there is another element of value-added not explained by remuneration of labour and capital? The issue was first raised by Diewert[2] (1980) and then more extensively examined by Harper, Berndt and Wood (1989). The discussion takes us back to the distinction between *ex-ante* and *ex-post* measures:

- Under an *ex-pos*t approach, realised rates of return are applied, and there are two avenues of implementation. By far the most frequent approach is the endogenous, ex-post approach: a period-to-period internal rate of return is computed by imposing the condition that the estimated value of capital services exactly correspond to gross operating surplus plus the capital element of gross mixed income. Alternatively, an exogenous ex-post rate of return could be imputed from financial market information such as a rate on corporate debt.
- With an ex-ante approach, the rate of return is chosen such as best to reflect economic agents' expectations about the required return from investment. It is unlikely that there is exact equality between the value of capital services and gross operating surplus plus the capital element of gross mixed income. This is an inconvenient feature from the standpoint of national accounting.

8.3.1. Endogenous and exogenous rates of return

Having made the distinction between different rates of return, is there any conceptual reason to prefer one over the other? Or should a mixed approach be put forward as suggested by Oulton (2007)? The *endogenous,ex-post* option is frequently used in empirical research. It assumes that gross operating surplus plus the capital component of mixed income exactly exhausts the costs of capital services. Given the value for costs of capital services, for the capital stock and depreciation, there is only one unknown variable, the internal rate of return and the equation can be solved to yield a rate of return.

This procedure brings with it several advantages:

- From a theoretical perspective, it is consistent with a fully competitive economy and production processes under constant returns to scale.
- From a practical viewpoint, computation is straightforward, and results can be of analytical interest in themselves. Endogenous rates are produced by a system that is fully integrated. Such a system produces rates that fully use all the information in the system. Combined with the capital stock estimates, they generate data on rates of return, how they differ across industries and over time. If the statistical system is relatively coherent and accurate, they provide the information that is required by capital theory to help estimate the differences in rates of return across industries – because the estimates are produced at the industry level.
- There is an issue surrounding the role of a statistical agency. If an agency produces a rate of return from its system, others can compare it to what they decide is the "real" cost of capital and infer whether markets are operating monopolistically or are otherwise imperfect. If an agency picks the rate of return exogenously that is appropriate for calculating the "real" cost of capital, it is directly involved in estimating the "monopolistic" surplus. The latter is not a product that can be regarded as having the quality required for the purpose at hand. Using an endogenous rate avoids this issue[3].
- Finally, the fact that the costs of capital services exactly exhaust gross operating surplus plus the capital component of mixed income and taxes on capital avoids interpreting any difference term between the value of capital services and gross operating surplus that may show up otherwise.

At the same time, the choice of an endogenous, *ex-post* rate raises other questions. In particular, some assumptions are needed to justify the use of an endogenous, *ex-post* rate (Schreyer 2008):

- The set of assets has to be complete in the sense that all assets are observed by the statistician who compiles the national accounts. The national accounts provide no indication as to exactly which factor of production is remunerated through gross operating surplus. Fixed assets are certainly among them but they are not necessarily the only ones. Inventories and most natural resources used in production are considered sources of capital services. In addition, the business literature offers a wealth of discussions about the importance of intangible assets, and there are good reasons to argue that such assets account at least for part of gross operating surplus. If an endogenous rate is computed on the basis of those fixed assets that are measured in the accounts, but if there are other, unmeasured assets that provide capital services, the resulting rate may be liable to bias. On the other hand, it will hardly ever be possible to be truly exhaustive in the set of underlying assets, just as business accounts are not exhaustive in the scope of assets. Then, the endogenous rate can be interpreted as a rate conditional on a particular scope of assets with the understanding that the rate may change if the scope of asset changes[4].

- An assumption of perfect foresight has to prevail so that the ex-post rate of return on each asset (implicitly observed by the national accountant as the firm's profit rate) equals the ex-ante rate of return, otherwise it could not be assumed that the (risk-adjusted) ex-post rate is equalised across assets.
- When the value of capital services exactly equals operating surplus, and when the latter is negative, the implication is negative user costs for some assets. Even for positive gross operation surplus, the endogenous rate of return may turn out to be negative. While *"[…] low or negative profits in any given year is part of the business cycle, and holding assets with an unexpected large jump in prices is entirely consistent with rational economic behaviour in the actual world…"* (Jorgenson *et al.* 2005, p. 167), this still constitutes a problem when user cost weights are employed in the aggregation process of capital services. That having said, negative user costs may also occur under an *ex-ante* approach. A case in point are assets that undergo large appreciations such as land and this may require a special treatment whether an *ex-ante* or an *ex-post* approach is pursued (see Section 18.1).

Despite these considerations, the *ex-post*, endogenous approach has stood the test of time, and has also been proposed as integral part of future developments in the United States national accounts (Jorgenson and Landefeld 2005). There is also a simplified version of the approach, suggested by Diewert, Mizobuchi and Nomura (2005) in the form of 'balancing real rates': real rates of return are computed endogenously but under the simplifying assumption that *real* holding gains or losses are zero for each type of asset (see Box 8 and the discussion of the simplified user cost approach around equation (3)). 'Real' is to be understood as a nominal rate deflated by a general price index such as the consumer price index. Setting real asset price changes to zero reduces the occurrence of negative user costs that may arise when there are large increases in asset prices, for example for land. At the same time, trends in relative asset prices *are* part of the price of capital services and ignoring them may lead to a bias in the resulting prices.

We now examine the exogenous rate of return which can come in its ex-post or *ex-ante* version[5]. Its advantages are that in several respects the theoretical assumptions needed are less restrictive than for the endogenous method. Schreyer (2007) showed that exogenous rates can coexist with occurrences of non-observed assets, imperfect competition and non-constant returns to scale[6].

However, there are also several disadvantages to the exogenous model.

- First, and foremost, a choice has to be made as to exactly which rate should be chosen. When rates are allowed to vary between industries or sectors, the problem is compounded because in principle, a rate has to be chosen that reflects industry-specific risk. Theory provides little guidance as to the specific choice of market rates. From a practical perspective, it may be difficult to identify exogenous rates of return at all for certain countries when financial markets are under-developed or under strong regulatory constraints. When the ex-ante version of the exogenous rate is chosen, the additional question arises how to model expectations.
- Second, there may also be occurrences of economically meaningless negative user cost if the expected nominal return plus depreciation is lower than the expected nominal asset inflation rate. If such expectations materialised, there would be a question of why

the asset owner would continue to hold onto it since there would be no economical rationale for doing so.[7]

- Third, if there are systematic differences between the endogenous and the exogenous rates for particular industries or for the economy as a whole, this requires explanation. While this may be an interesting terrain for analysis, it complicates life for the statistician who needs to communicate on these differences which is not always straight forward.

Oulton (2007) suggests a hybrid approach where first an *ex-post*, endogenous rate is computed and then the *ex-ante* rate is chosen as the trend of the ex-post rate of return. This proposal has the advantage that it avoids the problem of selecting an exogenous rate of return while preserving the *ex-ante* nature of the calculation.

Eventually, the question of exogenous versus endogenous and *ex-ante* versus *ex-post* rates is only as important as their empirical effects. On this matter, evidence is mixed. Oulton (2007) reports that effects on industry-level growth rates of capital services are small on average, although in the case of some important industries such as finance and business services the difference is substantial. Harper, Berndt and Wood (1989) find that the choice of approaches does make a difference empirically although none of their methods is truly an *ex-ante* method in the sense that it would combine expected rates of return with expected asset price inflation. Biatour, Bryon and Kegels (2007) examine the effects of methodological choices for Belgium data and while they find effects of *ex-ante* versus *ex-post* parameters on measures volume growth of capital services, these effects are comparatively contained and more important in the short term than over longer periods. Schreyer (2007) computes total economy capital services measures for several countries at the aggregate level using both methods and finds marked differences in results. However, his economy-wide results are likely to be biased for the endogenous method because of the convention of zero net operating surplus for non-market producers (see also below).

Baldwin and Gu (2007) compute twelve different measures to test robustness of Canadian productivity results with regard to different ways of computing user costs. They find that the inclusion or exclusion of a real revaluation term in the user cost formula is an important element that affects the resulting multi-factor productivity measures significantly more than moving between *ex-ante* and *ex-post* formulations for the rate of return. Finally, sensitivity tests with the artificial dataset presented in the Annex to this *Manual*, also show relatively modest impact of the ex-post/ex-ante choice on average capital services growth rates. Thus, although the evidence is not fully conclusive, it would appear that the issue should not be overstated with regards to its effects in practice.

Productive stocks measure the stock of assets, corrected for efficiency loss and retirement. They are seen as the stocks that generate flows of capital services, the input of capital into production.

Data constraints will also influence the choice between methods. The endogenous approach requires that, at a minimum, a breakdown of production into market and non-market sectors is available and that the scope of assets included in the calculation is relatively complete. If one of these conditions is not fulfilled, the resulting endogenous rate of return is likely to be biased. For example, if the assets that enter the computation of capital services exclude land, non-labour income is divided by an incomplete stock of assets, which may lead to an upward bias of the endogenous rate of return. Or, if market producers cannot be distinguished from non-market producers, non-labour income will be underestimated (because the national accounts do not allow for a return on government-owned assets) and the resulting rate of return may be upward biased. In these cases, an exogenous (*ex-ante*) rate may be preferable to an endogenous computation. Because more hinges on data quality, the careful construction of the design of measurement and data examination is key to applying an endogenous approach.

A more general point is that data and practices that are perfectly reasonable for one use may be more problematic for other uses. Or that precision is more important in one area than in another. For example, some decision have much more of an impact on the estimate of the *level* of capital stocks than on their *growth rates*. For instance,Baldwin and Gu (2006) addressed the question how productivity measures are affected by alternate methods or assumptions on the growth of capital or capital services. They found that for growth rates that are an input into productivity estimates, alternate techniques and data bases yield approximately the same results. For example, the use of endogenous and exogenous rates of return yield about the same productivity growth rates but only if the exogenous rate is calculated in an appropriate way that recognises that private capital costs are not the same as government rates. Similarly, choosing different estimation techniques of depreciation rates yields about the same growth in capital services but only if the endogenous rate is used. In contrast, estimates of the levels of productive capital are very much affected by these decisions and have large impacts on the wealth balance sheets. Thus, attention should be paid to the differences in the sensitivity of the different statistical products that are produced.

8.3.2. Rates of return for non-market producers

The discussion so far has implicitly dealt with the market sector because there was a presumption of a measure of operating surplus which would form the basis for the computation of a rate of return. There is no net operating surplus for non-market producers, however. Their value of output is based on the costs of inputs, and the System of National Accounts uses the convention that the cost of capital is measured by the consumption of fixed capital alone. No imputation is made for net operating surplus, *i.e.* for financing or opportunity costs of capital and for expected holding gains or losses. By implication, it is not possible to identify the price and volumes of capital services for assets used by non-market producers in production.

Many reasons for this convention are of a practical nature. Identifying an interest rate to be applied to measure net operating surplus for non-market producers is difficult in practice. It also implies an additional imputation in the national accounts and statistical agencies are – rightly – reluctant to multiply imputations in measurement because they bear an element of subjectivity. It has also been argued that different statistical agencies would deal in different ways with such an imputation, leading to reduced international comparability of national accounts data. Unlike the measurement of capital services for market producers which essentially involves a split of capital income into a price and volume index of capital services but without any effect on main aggregates, the imputation of capital costs for non-market producers has immediate implications for the level and growth rate of measured GDP. This makes such an imputation all the more delicate and requires specifically robust and transparent methods that may not be at hand to date.

A more conceptual reason has also been put forward: non-market producers such as general government are by their very nature economic units that operate not-for-profit. Imputation of a "rate of return" or net operating surplus would be counter to the nature of a not-for-profit operation and hence, a zero rate of return and zero net operating surplus are appropriate.

Others have, however, argued that there should be a positive return for assets non-market producers[8]. One argument is that government units do use net return measures when deciding upon public investment. Another argument is that for non-market producers, the issue is not so much about a net return to investment in the sense of profits from capital investment but about an accounting for cost that is as comprehensive as possible. Financing costs for investment exist undoubtedly for non-market producers who take out loans or issue bonds for that purpose. These financing costs are part of the user costs of capital. When no direct financing costs arise, because investment is paid directly out of tax revenues, there are opportunity costs (see Box).

Another argument in favour of attributing costs of financing to government capital is in terms of symmetric treatment of private and public assets. The imputation of a zero net rate for government assets and the existence of a positive rate for privately owned assets imply that as soon as assets change owners and move, for example, from the non-market to the market sector, they generate a higher return and more income. Put differently, the level and growth rate of GDP becomes dependent on the institutional arrangements between public and private sector. This is all the more relevant as the increasing number of new arrangements such as public private partnerships, outsourcing of government activities and so forth have significantly blurred the borderline between market and

Box 8.1. **Opportunity costs – a basic notion in economics**

"The concept of opportunity cost expresses the basic relationship between scarcity and choice. If no object or activity that is valued by anyone is scarce, all demands for all persons and in all periods can be satisfied. There is no need to choose among separately valued options […] In this fantasised setting without scarcity, there are no opportunities or alternatives that are missed, foregone or sacrificed. Once scarcity is introduced, all demands cannot be met. […] Scarcity introduces the necessity of choice […] Choice implies rejected as well as selected alternatives. Opportunity cost is the evaluation placed on the most highly valued of the rejected alternatives or opportunities. It is that value that is given up or sacrificed in order to secure the higher value that selection of the chosen object embodies." (James M. Buchanan, 1998, p. 719).

Approaching user costs of capital from a perspective of opportunity costs, implies therefore looking for the highest valued alternative that the funds tied up in fixed assets could generate. In a functioning market, theory suggests that the price mechanism equates marginal opportunity costs. Thus, there would always be a financial security with the same risk as the investment in a fixed asset. This provides the rationale for turning to expected rates of return on financial markets as a way of estimating the *ex-ante* return on fixed assets. Empirically, the problem consists in identifying financial assets with the same risk as the investment in the fixed asset.

There is a vast literature on how to measure the opportunity costs of investment in a non-market context (see Drèze and Stern 1987 for an overview). Measuring the opportunity costs of investment requires identifying the maximum value sacrificed for the investment at hand. Such an alternative use could be in terms of consumption or in terms of private investment in which case the households' discount rate or the market sector's rate of return would be the appropriate rates of discount for public investment. Several authors have therefore suggested using a weighted average of the market and the household rate of return.

Box 8.1. **Opportunity costs – a basic notion in economics** *(cont.)*

The interpretation of user costs from an opportunity cost perspective makes it particularly difficult to accept a zero rate of return on government assets. The implication is that the funds used by government have no alternative use. Also, a zero discount rate means that no difference is made between benefits from investment projects that arise in the near future and those that arise in distant future. This can lead to implausible results. Alternatively, if opportunity costs are positive but government used a zero discount rate to evaluate investment, there would be substantial over-investment in public capital.

non-market production. Against this argument has to be held, however, that also among market producers, the expected rate of return may vary as a function of the risk premium associated with the business operation. The risk premium involved in government operation is likely to be small and in this sense, the rate of return to the same type of asset could vary depending on the institutional unit where it is employed. However, even a zero risk premium does not imply zero costs of financing.

Note also that any effort towards developing output-based measures of government production (Atkinson 2005) has to be accompanied by as complete measures for government inputs as possible. Otherwise, productivity measures for government – one of the main reasons for which output-based measures of production are developed in the first place – would be biased because of the insufficient weight attributed to capital input.

Should there be recognition of the financing costs in the user costs for government-held assets? Many economic arguments would suggest so. However, choosing the appropriate rate of return is difficult and requires simple and robust measures to maintain the usefulness and the comparability of national accounts.

At the same time, there is the practical issue of which rate of return to choose for government producers and there are indeed many possibilities. Starting with a look at what economic theory has to propose on this matter, the reference point would appear to be the extensive literature on cost-benefit analysis for projects undertaken by government. The choice of the appropriate discount rate in such studies is crucial for their results and has been studied extensively. We shall refer to Drèze and Stern (1987) for a survey of the theory of cost-benefit analyses, including a survey of the approaches towards discount rates. At the core of cost-benefit studies is the notion of opportunity costs which has also been used in this *Manual* to characterise the nature of user costs for economic agents in general. It is thus only consistent that the concept of opportunity costs also applies to the public sector. In so doing, the question has to be answered whether public investment displaces private investment or private consumption or both. If corporate investment is displaced then the rate(s) of return for the market sector (see above) constitute(s) the opportunity cost to public investment; if private consumption is displaced then the households' rate of return constitutes the opportunity cost to public investment. In some cases, both corporate investment and household consumption will be reduced due to public investment – directly or via taxation – and the rate of return for non-market investment would thus have to be approximated by an average of the rate of return in the market sector and the rate of return in the household sector. This is, for example, Sandmo and Drèze's (1971) suggestion (averaging interest rates for consumers and producers) to measure the discount rate in cost-benefit analyses. For a similar approach, see also Baumol (1986), and Jorgenson and Landefeld (2006) who set the rate of return for the non-market sector as a weighted average of the rate of return in the corporate sector and the household sector (although their approach rests on an *ex-post* calculation).

A practical problem associated with the above approach is that it may be inapplicable when basic data are sparse or of poor quality. A solution that is broadly in line with the theoretical considerations about opportunity costs, and which is simple and potentially applicable for a large number of countries is to apply a discount rate for households in the form of a *social time preference rate*. This approach draws on the large literature for cost-benefit assessment of government projects and their discount rates and has been applied in both developed and developing countries. The social time preference rate (see for example Marglin 1963 or Kula 1984) reflects the value that society attaches to present, as opposed to future consumption. It has the merit of relatively straightforward calculation and demonstrated empirical applicability in OECD and in non-OECD countries. Further discussion on measuring the social rate of time preference is provided in Section 16.3.3.

Empirical uncertainties remain, however and we conclude the conceptual considerations on the rates of return for government with a statement by Moulton (2004):

> *"In summary, this proposal [to impute rates of return to government-held assets] carries both potential risks and benefits. As with any imputation, adding an imputed rate of return carries the risk of making the accounts less useful as an indicator of cyclical activity. A programme to create an expanded production account for the government sector as described above, including measures of multifactor productivity, would necessitate the estimation of a net return. As part of such a programme, developing improved measures of changes in volume of government output should also be considered a priority along with improved imputation of the services of government capital inputs. The statistical agencies of several countries have recently undertaken interesting work on volume measures of government output, but much remains to be done in this area." (Moulton, p. 169).*

8.3.3. Rates of return for the household sector

The household sector, another non-market producer, enters the considerations here because it is responsible for an important type of non-market production: house owners provide dwelling services to themselves. In their capacity as producers of dwelling services, households use assets (structures and land) which constitute an important part of inputs into this process. The household sector is also a user of consumer durables and some researchers (e.g., Jorgenson 1995) have systematically included those as part of investment and as sources of capital services. In the present *Manual*, however, we stick to the convention of the System of National Accounts and treat consumer durables as final consumption goods while noting that there is no economic reason to do so.

The production of housing services for their own final consumption by owner-occupiers, on the other hand, has long been included within the production boundary in national accounts. The value of owner-occupied housing is determined in one of two ways: either as a rental equivalent, *i.e.* "at the estimated rental that a tenant would pay for the same accommodation, taking into account factors such as location, neighbourhood amenities, etc. as well as the size and quality of the dwelling itself" (1993 System of National Accounts, paragraph 6.89). Or, as an alternative, a user cost approach is implemented where capital services and maintenance expenditure are estimated to provide a value for the housing services provided by the household sector. This is described in greater detail in Section 18.1.2.

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The user cost approach explicitly requires the choice of a rate of return. In practical applications, this is taken as a long-run real rate, very much along the lines of the *ex-ante* approach outlined for the market sector. For example, Eurostat (2001) suggests a 2.5 percent real rate in the estimation of user costs for owner-occupied housing in the then candidate countries to the European Union. One can think of more sophisticated, country-specific approaches in selecting the household rate of return but when the rental market is not representative for the market of housing services as a whole as has been the case in many European candidate countries, the user cost approach is the only feasible approach towards measuring owner-occupied housing. The same situation holds for many developing and emerging economies. The real rate of return used in these calculations constitutes the household rate of return which in turn could serve as an element in determining the rate of return for government assets if such a rate is imputed for analytical purposes. A reasonable measure of the household real rate of return is the social time preference rate described in the section above and discussed at greater detail in Part II of this *Manual*.

The rental equivalent approach towards owner-occupied housing *implies* a certain rate of return, which can be computed by equating the average value of rentals to a user cost expression, and controlling for depreciation and real holding gains.[9] In practice, this is more difficult because independent calculations of rental equivalents and user costs have shown very different patterns. Again, we refer to the discussion in Section 18.1.2. But at this point, two useful conclusions arise from this short discussion of owner-occupied housing. First, when measures of owner-occupied housing are based on a user cost approach, it is consistent to use the underlying rate of return for households also as an element for the estimate of the rate of return for government. Second, the approach towards owner-occupied housing in the national accounts is an opportunity cost approach and hence consistent with the more general opportunity cost approach towards the user costs of capital adopted in this *Manual*.

8.4. Revaluation – conceptual considerations

The second item in expression (2) for unit user cost was a real revaluation term – the expected price change of the asset, corrected for a measure of overall inflation. While it is clear that revaluation is an entry in the capital accounts – it marks one of the items needed to go from opening to closing balance sheets – questions have been raised regarding the appearance of holding gains and losses as part of the price of capital services. In particular, two issues tend to arise in conjunction with this revaluation term.

To pose the first question correctly, we have to jump ahead in our considerations of capital measurement and foreshadow the fact that the value of capital services approximately (sometimes exactly) corresponds to gross operating surplus (GOS). GOS is part of gross income and as such should not include holding gains or losses. The question then arises whether the presence of real holding gains/losses in the user cost term does not mean that a revaluation item has now been introduced into a measure of income?

The answer to this question is no and lies in the negative sign that precedes the revaluation term i^{*t} in in expression (2). To see why, remember that the rate of return r^{*t} is the rate of profitability that an investor or shareholder would expect from the use of the asset in production. The total return is this rate times the stock of the asset under consideration. There would be three main elements that determine the rate of return for the shareholder: *(i)* profits out of 'normal' business operations (*i.e.* out of ongoing production), captured by GOS; *(ii)* real holding gains or losses associated with the asset, labelled HGL; *(iii)* depreciation, D.

Total return = GOS + HGL – D (4)

This presentation is consistent with an income term, GOS, that does *not* include real capital gains or losses, otherwise there would be double counting of the latter. The formulation *is,* however, consistent with the interpretation of GOS as profits from ongoing production activity, excluding revaluation effects. Only after adding capital gains and after subtracting depreciation do we get to the net return that is relevant for financial markets and investors. Of course, expression (4) is only a simplified way of representing user costs of capital but entirely consistent, for example with expression (2).

The second question in conjunction with real holding gains and losses takes us back to the discussion about depreciation and obsolescence. How should real revaluations be treated when gross income is transformed into net income? Should the amount subtracted from gross income include real holding losses or not? In Section 5.4, it was concluded that a case could be made for a measurement of net income (measured as net operation surplus, NOS) in one of two ways:

NOS = GOS – D = Total return – HGL (5)

NOS'= GOS – [D – HGL] = Total return (6)

In the first version, shown in expression (5), net income corresponds to the profits from normal business operations (GOS) which excludes price changes but which has been corrected for depreciation. Net operating surplus then equals (Total return – HGL), *i.e.* the *expected net return from normal business operations*. Under the second version, shown in expression (6), net income corresponds to GOS minus a combined measure of depreciation and capital gains/losses which equals the expression for the total return that financial markets require. Thus, NOS' will be reflective of real holding gains or losses. Net income will differ between the two options and correspond either to a notion of income where the productive capacity of the capital stock is kept intact or to a perspective where the capital owner's wealth is kept intact – for more discussion see Section 5.4.

Notes

1. Section 18.1. discusses the measurement of user costs for owner-occupied houses. There is empirical evidence that the actual costs of renting a dwelling can be quite different from the user costs associated with the owner ship of houses. Diewert (2008) describes how in this context an opportunity cost approach could be interpreted as the maximum of user costs and the rental equivalent price (see Section 18.1.)
2. "Which r should be used? If the firm is a net borrower, then r should be the marginal cost of borrowing an additional dollar for one period, while if the firm is a net lender, then r should be the one period interest rate it receives on its last loan. In practice, r is taken to be either (a) an exogenous bond rate that may or may not apply to the firm under consideration, or (b) an internal rate of return. I tend to use the first alternative, while Woodland and Jorgenson and his co-workers use the second. As usual, neither alternative appears to be correct from a theoretical a priori point of view, so, again, reasonable analysts could differ on which r to use in order to construct a capital aggregate." Diewert (1980; 476-477).
3. Another example pointed out by Statistics Canada is that when a statistical system is developed, it needs to build systems that are not overly sensitive to imprecision. If the exogenous approach is taken, exogenous rates of return need to chosen correctly. And then depreciation rates need to be chosen correctly. Errors that are made in the estimate of each can be additive in the exogenous system. The endogenous system has the advantage that it is less sensitive to errors in estimating the depreciation rate – because errors in estimating the depreciation rate will be offset in the estimates of the rate of return. How important this advante is of course depends on the relative difficulty of estimating the depreciation parameter.

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4. In practice, the scope of assets matters. Diewert and Lawrence (2000), measuring total factor productivity growth for Canada, showed that neglecting land and inventories decreased the TFP growth rate by about 20%. In a similar study for Japan, Nomura (2004) showed that the Japanese TFP growth fell from 1.54% per year over the period 1960-2000 to 0.80% per year when land and inventories were omitted.
5. There is thus no assumption of perfect foresight and this helps to deal with the question of expectations: the level of capital services is what the entrepreneur expects when making decisions about the use of assets in production. If the costs of capital services turn out to be less than gross operating surplus, the entrepreneur has made some pure profit or some of the gross operating surplus pertains to non-measured assets. Further, when there is an expected rate, it reflects the conditions (in particular the implicit prices of capital services) that producers are facing when deciding about production and investment.
6. Another advantage of an *ex-ante* rate is that it may provide a means of splitting mixed income between income to labour and income to capital. In principle, if there are independent estimates for the cost of capital services of those institutional units whose income is mixed, it is possible to sort out the share of labour and capital remuneration. Such information could be compared against plausible estimates of the labour income of self-employed. Obtaining the empirical information on capital stocks and capital services by institutional unit may be difficult but at least there is a possibility of advancing on the analysis of mixed income.
7. By way of example, consider the total return R to a piece of land during one period. Say that the price of land is P^O at the beginning and P^1 at the end of the period, let F be the rental and r the discount rate so that: $R=P^1/(1+r)-P^0+F$. R cannot be negative ex-ante if anyone is supposed to buy the asset. It is also apparent that R with F<0 (a negative user cost) is smaller than R with F=0 or F>0. Thus, a rational asset owner would always withdraw the land from the rental market or from use in production if this generated a negative F. Furthermore, a functioning rental market would bid F up to be non-negative. Negative ex-ante user costs could also be an indication for misspecification of *ex-ante* variables. As explained by Harper, Berndt and Wood (1989) negative rental prices tend to occur when *ex-ante* exogenous rates of return are combined with *ex-post* rates of asset price change in the same user cost expression.
8. For example, in a review of the government sector of the U.S. national accounts by the U.S. National Research Council, Slater and David (1998) argue that: "The assumption of zero net return is implausible. If net return were really zero, it would imply substantial overinvestment in public capital. In fact, however, serious shortages of many types of public infrastructure, ranging from schools to transportation systems, are widely perceived to exist. If this perception is correct, it follows that the net return to many existing public investments and to properly directed additions to that capital stock is a positive return. Some recent studies suggest that the return is, in fact, quite high (for a review and an extensive bibliography, see Gramlich, 1994). The lack of a net return measure in the national accounts is not due to a belief that the net return is actually zero, but to the difficulties of estimating the return. Returns to private investment can be measured by the costs of obtaining capital to finance this investment. Expressed another way, market prices for business output must (in equilibrium) cover the costs of interest on funds borrowed to finance investment plus a return to business owners equal to what could be obtained on alternative uses of their capital. Since most government output is not sold at market prices, equivalent measures of the net return to government investment are not directly available. However, a substantial body of research on alternative ways to measure the return on public investment is available (Gramlich, 1994). Several possible measures of net return have been suggested, including: the discount rate established by OMB for evaluating costs and benefits of proposed federal capital projects; the municipal bond rate; the rate of return on comparable private business activities; and the development of valuation measures of public output independent of the costs of inputs, thus permitting application of techniques used to compute private rates of return."
9. This is perfectly symmetric to the endogenous approach towards computing the rate of return to the market sector where gross operating surplus is used to compute a rate of return.

PART II

Measuring Capital Stocks and Capital Services – Implementation

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Chapter 9

Scope of Capital Measurement and Classifications

9.1. Scope

Most but not all of the stock and flow measures considered in this *Manual* relate to "produced", non-financial objects (fixed assets and inventories) that are included in gross capital formation as defined in the national accounts. Produced non-financial assets come into being via the production process or as imports.

Table 9.1 gives the full listing of non-financial assets recognised in that system. For a treatment of other natural resources such as subsoil assets, the reader is referred to the *Handbook on Integrated Environmental and Economic Accounting* (United Nations *et al.* 2003) and to Section 18.3. Note that two items related to non-produced assets are part of the produced assets. These are major improvements to land and costs of ownership transfer on non-produced assets.

All assets in the classification are relevant for balance sheets of the economy and should, to the extent possible, be recognised there. When it comes to measuring capital services, the situation is less clear. There is agreement that all fixed assets should be considered sources of capital services. The discussion about inventories is less clear-cut although in the end, their inclusion was decided in the context of the revision of the 1993 SNA. There is also general agreement that land constitutes a source of capital services and should thus be recognised in the measures of capital services. The main difficulty with land as a source of capital services lies in the implementation of capital services measures in the presence of land markets with price bubbles which may produce results that are hard to interpret such as negative user costs of capital (see Section Chapter 17). In addition to land, there are other natural resources and non-produced assets that are used in production and that constitute a source of capital services. However, measurement problems are sometimes severe for these assets and due to practical considerations, they are often excluded from capital services measures.

According to national accounts conventions consumer durables are not treated as assets:

> *"…consumer durables are not treated as fixed assets. The services these durables produce are household services outside the production boundary of the System. If, for example, a washing machine were to be treated as a fixed asset, the production boundary would have to be extended to include all laundry services, whether undertaken by machine or by hand. As it stands, the production boundary restricts laundry services to those services provided to other units but includes services provided by both machine and by hand. However, owner-occupied dwellings are not treated as consumer durables but are included within the asset boundary. The owner-occupiers are treated as owners of unincorporated enterprises producing housing services for their own consumption" (2008 SNA, paragraph 10.31).*

Consumer durables are thus not specifically dealt with in this *Manual*, although it is well understood that their treatment as capital goods may be analytically useful as long as corresponding adjustments are made to production measures as well.

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Economic analysts and policy makers have also been interested in measuring what is generally called “intangible” assets (see for example, Corrado, Hulten and Sichel 2005). These include R&D and other assets in relation to innovation, human capital, advertising and organisational assets. While interesting from an analytical viewpoint, they are a long way off from recognition as assets in the national accounts, given the many measurement issues and given some conceptual issues associated with them, one exception being R&D which is now considered as an intellectual property asset.

9.2. Classifications

This chapter deals with the classifications used for publishing capital stock statistics. Three classifications contained in the SNA are relevant – the Classification of Assets, the Classification of Institutional Sectors, and the International Standard Classification of All Economic Activities. These are used in different combinations for the gross and net capital stocks and the two flow measures covered in this *Manual* – depreciation and the volume index of capital services.

The net capital stock, capital services and depreciation appear as entries in the SNA and this determines the classifications to be used. Both are to be classified by the institutional sector that owns the assets. This is the appropriate classification for the net capital stock, which is needed for the Balance Sheets of the system and for depreciation, which appears in the Production Account, in the Distribution and Use of Income Accounts and in the Accumulation Accounts.

The classification of non-financial produced assets, as given in the SNA, is designed to distinguish among assets on the basis of their role in production. The single most important difference to the treatment of assets in other classifications such as the Central Product Classification is the treatment of costs of ownership transfer. As spelled out in more detail in Chapter 14, according to the national accounts, costs of ownership transfer are allocated to the asset that is subject to ownership transfer whereas such costs are treated separately under product classifications.

Capital stock statistics also serve a number of analytic uses, such as calculating capital-output ratios or rates of return on capital and studying capital and multifactor productivity. For these purposes, it is usually preferable to classify assets according to the kind of activity of the owner and by type of asset. This involves a cross-classification by the ISIC and by the Classification of Assets.

9.2.1. Classification by type of asset

The part of the national accounts Classification of Assets covering non-financial assets is given in Table 9.1 Revised classification of non-financial assets above. Most countries that now compile capital stock statistics use an asset breakdown for publication purposes that is less detailed than this and the standard questionnaire that is used by the international organisations to collect annual statistics according to the SNA requires an even less extensive breakdown. In contrast, the United States Bureau of Economic Analysis (BEA) publishes capital stock statistics broken down into over 80 asset types.

The accuracy of capital stock statistics is determined to an important extent by the accuracy of the price indices used to revalue assets. In general, the greater the level of investment detail for which separate deflators and depreciation rates are available, the

Table 9.1. **Revised classification of non-financial assets**

Produced assets	Fixed assets	Dwellings		
		Other buildings and structures	Non-residential buildings	
			Other structures	
			Land improvements	
		Machinery and equipment	Transport equipment	
			ICT equipment	
			Other machinery and equipment	
		Weapons systems		
		Cultivated assets	Animal resources yielding repeat products	
			Tree, crop and plant resources yielding repeat products	
		Costs of ownership transfer on non-produced assets		
		Intellectual property products	Research and development	
			Mineral exploration and evaluation	
			Computer software and databases	Computer software
				Databases
			Entertainment, literary or artistic originals	
			Other intellectual property products	
	Inventories	Materials and supplies		
		Work in progress	Work in progress on cultivated assets	
			Other work in progress	
		Finished goods		
		Military inventories		
		Goods for resale		
	Valuables	Precious metals and stones		
		Antiques and other art objects		
		Other valuables		
Non-produced assets	Natural resources	Natural land	Natural land under buildings and structures and associated surface water	
			Natural land under cultivation and associated surface water	
			Natural recreational land and associated surface water	
			Other natural land and associated surface water	
		Subsoil assets	Coal, oil and mineral gas reserves	
			Metallic mineral reserves	
			Non-metallic mineral reserves	
		Non-cultivated biological resources	Natural forests	
			Other crop and plant resources	
			Wild stocks of fish and aquatic mammals	In national waters including Exclusive Economic Zone
				Outside Exclusive Economic Zone
		Water resources	Aquifers	
			Other	
		Other natural resources	Radio spectra	
			Other	
	Contracts, leases and licences	Third party property rights	Marketable operating leases	
			Permissions to use natural resources	
		Entitlement to future goods and services on an exclusive basis	Of nominated legal persons	
			Of future production	
	Goodwill and marketing assets			

more reliable will be the estimates of stocks and consumption of fixed capital; this is one of the reasons why BEA uses a very detailed asset classification. With the same consideration in mind, Eurostat (2001) suggests a minimum level of detail appropriate for the deflation of gross fixed capital formation in its handbook on price and volume measures in national accounts; each class of assets in this classification is thought to be relatively homogeneous as regards price movements. Note that communications equipment and computers are separately distinguished because the behaviour of prices for these goods is so different from that of other assets. Note also that this classification still follows the 1993 SNA classification of assets before revision and is therefore not an exact subset of the revised classification shown in the table above.

For many analytical purposes, investment data that is cross-classified by asset and industry or institutional sector constitutes key information. Similarly, sectoral balance sheets should provide the necessary asset breakdown for comparison between sectors and over time.

9.2.2. Classification by institutional sector

The SNA identifies five institutional sectors: non-financial corporations, financial corporations, general government, households and non-profit institutions serving households. These five sectors are further broken down to give a total of 36 sub-sectors at the most detailed level.

The level of detail to be used for classifying the net capital stock and consumption of fixed capital depends on the degree of sector detail that is used in the balance sheets (for net stock) and in the non-financial accounts (for depreciation). The few countries that compile balance sheets at the present time mostly classify stocks according to the five institutional sectors, but with some breakdown of general government by level – central, local, social security funds, for example. A similar breakdown is used by most countries for the non-financial accounts; although the financial corporations sector is sometimes broken down to distinguish between depository institutions and other financial institutions.

The annual national accounts questionnaire used by the international organisations to collect national accounts statistics calls for the non-financial accounts to be sub-sectored as follows and this determines the institutional sector detail for classifying consumption of fixed capital: non-financial corporations, financial corporations, central government, state government, local government, social security funds, households and non-profit institutions serving households.

In practice many countries cannot distinguish non-profit institutions serving households separately from the household sector. Some countries will also find the breakdown of government too ambitious and will only be able to provide estimates for general government as a whole.

9.2.3. Classification by kind of activity

For most kinds of analytic studies, capital stocks and flows will need to be classified by kind of activity. As a general rule, the more detailed the activity breakdown, the more useful will the statistics be for such purposes. However, practical considerations limit the amount of detail that can be shown. For example, if the PIM is used, the kind of activity breakdown cannot be more detailed than the kind of activity classification used for collecting statistics on gross fixed capital formation. If the latter is very detailed, transfers of used assets between producers in different kinds of activities will affect reliability and reduce the amount of detail that can reasonably be shown. A classification that may be useful for countries starting capital stock statistics is given in Table 9.2.

The annual national accounts questionnaire calls for capital stock statistics to be broken down by 17 kinds of activities. These are the 17 tabulation categories of the ISIC (revision 3). It would be possible to make this list more useful by distinguishing the principal activities within manufacturing (which is a single tabulation category) and by grouping some of the categories covering service activities.

Table 9.2. **Suggested activity classification for capital stock statistics**

ISIC Tabulation Categories	Description
A + B	Agriculture, hunting, forestry and fishing
C	Mining and quarrying
D	Manufacturing (*with 4 or 5 important activities separately identified*)
E	Electricity, gas and water supply
F	Construction
G + H	Wholesale and retail trade, repair of vehicles and household goods, hotels and Restaurants
I	Transport, storage and communications
J + K	Financial intermediation, real estate, renting and business activities
L	Public administration, defence and social security
M, N + O	Education, health and social work, other community, social and personal service activities

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Chapter 10

The Perpetual Inventory Method – Overview

The perpetual inventory method (PIM) is the most widely used approach towards measuring stocks and flows of fixed assets. It rests on the simple idea that stocks constitute cumulated flows of investment, corrected for retirement and efficiency loss. The basic sequence of implementation is shown in the figure below.

- Two entry points exist into the computation process: by defining the age-efficiency profile for each type of asset (starting point A) or by defining the age-price/depreciation profile for each type of asset (starting point B). The next step is to define a retirement profile with its parameters, among them the average and the maximum service life.
- The retirement profile is combined with the age-efficiency profile (path A) or with the age-price profile (path B) to yield an age-efficiency/retirement profile for a cohort or an age-price/retirement profile for a cohort. In the case of geometric depreciation, the two profiles coincide and the implementation process starts only here.
- Given the age-efficiency/retirement profile for a cohort, and given a rate of return, the age-price /retirement profile for a cohort can be derived and vice versa.
- The next step is to apply these profiles to time series of investment. The age-efficiency profile applied to investment series yields a measure of the productive capital stock. The age-price profile applied to investment series yields a measure of the net or wealth stock. The depreciation profile is just another way of presenting the age-price profile. Applied to the investment series, the depreciation profile yields a measure of the value of depreciation for a particular type of asset.
- The rate of depreciation for a new asset (taken from the depreciation profile), the real rate of return and the real rate of holding gains or losses form the basic data points to compute the unit user cost for a new asset.
- Multiplying the unit user cost for a new asset by the productive capital stock (also expressed in efficiency units of a new asset), yields a measure for the total value of capital services for a particular type of asset.
- The volume change in capital services is obtained by constructing a weighted average of the changes in the productive capital stock by type of asset. Each asset's share in total user costs constitutes the weights in this index.

On the wealth side of the calculations, the net stocks at the beginning and at the end of the period can be compared. Changes in the wealth stock consist of additions through investment, minus depreciation plus holding gains minus holding losses plus other net changes in volumes of the asset.

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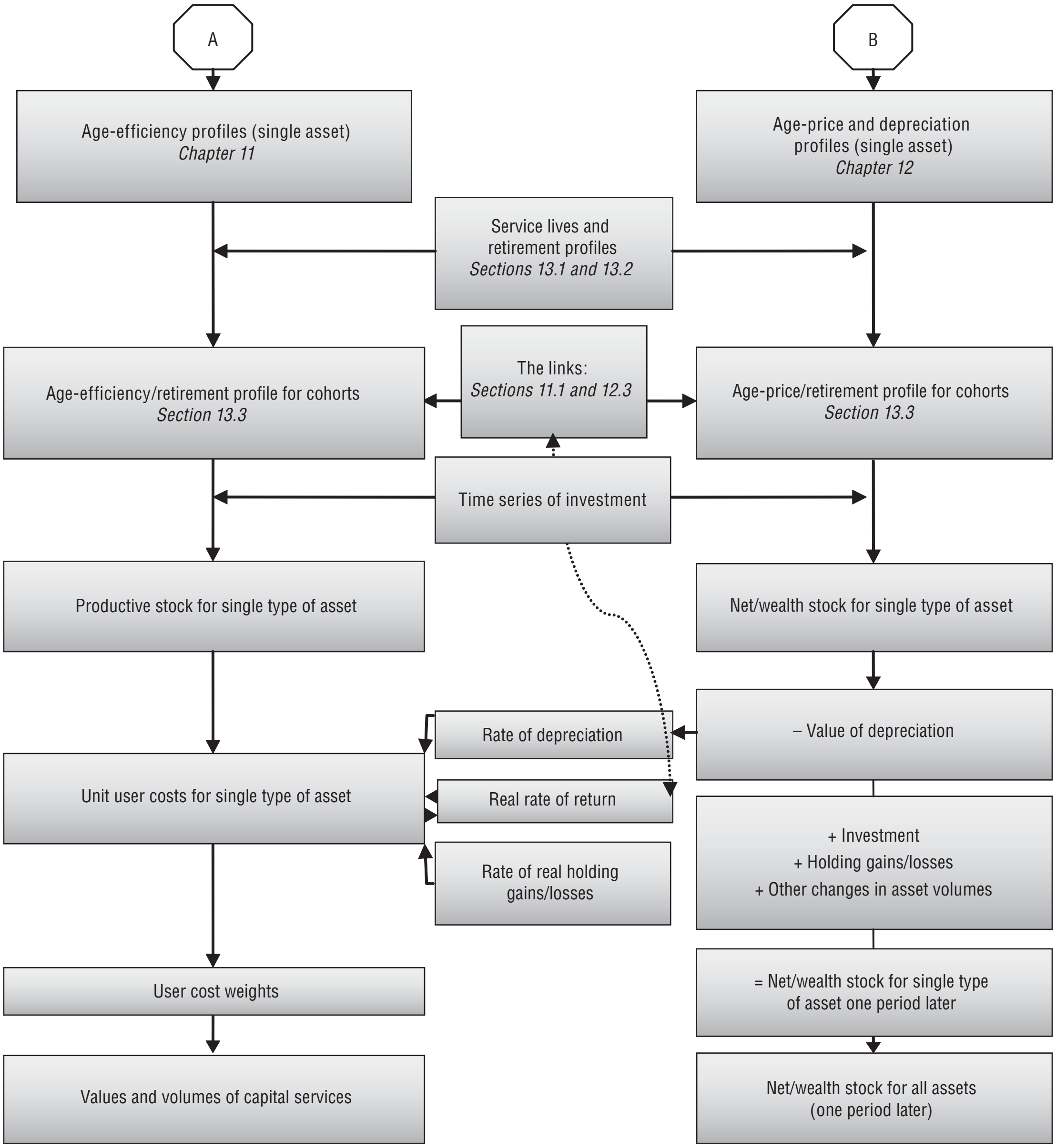
A
B
Age-efficiency profiles (single asset)
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Service lives and retirement profiles
Sections 13.1 and 13.2
The links:
Sections 11.1 and 12.3
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Section 13.3
Time series of investment
Productive stock for single type of asset
Net/wealth stock for single type of asset
Rate of depreciation
– Value of depreciation
Unit user costs for single type of asset
Real rate of return
Rate of real holding gains/losses
+ Investment
+ Holding gains/losses
+ Other changes in asset volumes
User cost weights
= Net/wealth stock for single type of asset one period later
Values and volumes of capital services
Net/wealth stock for all assets (one period later)

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Chapter 11

Age-efficiency Profiles

The age-efficiency profile of a single asset describes the time pattern of productive efficiency of the asset as it ages. The specific form of the age-efficiency profile is an empirical issue although solid empirical evidence is scarce and often replaced by plausible assumptions. The age-efficiency function of a single asset reflects losses in efficiency due to wear and tear as well as certain effects on service lives. For example, if obsolescence affects an asset's economic service life – *e.g.*, because secular rises in energy prices or real wage increases make it unprofitable to use an asset after a certain number of years – this may affect the maximum service life, a parameter of the age-efficiency function. Obsolescence could then imply retirement of an asset, which amounts to an unchanged age-efficiency function up to the point of retirement and a drop to zero at this point.

The age-efficiency function for a single asset (of a particular type) can be represented by $g_n(T)$ where n is an index for age that runs from zero (a new asset) to T, the retirement age of the asset. The age-efficiency parameter is always a non-negative measure between unity and zero. Because the efficiency of a new asset has been set to equal one, every $g_n(T)$ represents the relative efficiency of an asset of age n compared to a new asset. In principle, the age-efficiency function can take various shapes but for practical purposes, three functional forms merit mentioning: hyperbolic, linear and geometric.

Hyperbolic age-efficiency profiles have, for example, been used by the U.S. Bureau of Labor Statistics (1983), the Australian Bureau of Statistics (ABS 2000), Statistics New Zealand, Mas *et al.* (2006) and the OECD (Schreyer *et al.* 2003). Hyperbolic decline takes the form:

$$g_n \text{ (hyperbolic)} = \frac{T - n}{T - b \cdot n} \qquad (7)$$

where b≤1 is a parameter that shapes the form of the function. Typically[1], the hyperbolic profile shows a form where assets lose little of their productive capacity during the early stages of their service lives but experience rapid loss of productive capacity towards the final stage of their service lives.

"The efficiency reduction parameter b is set to 0.5 for machinery and equipment and 0.75 for structures – the same parameter values as used by the BLS. The higher value for other buildings and structures redistributes efficiency decline to occur later in the asset's life, relative to machinery and equipment, the efficiency decline of which is distributed more evenly throughout the asset's life. For computer software, b is set to 0.5. For livestock, b is also set to 0.5. Clearly, a more accurate age-efficiency function and age-price function could be assumed by recognising that livestock are immature for a number of years before they begin service as mature animals. However such improvements compromise model simplicity and the improvements from doing so would be quite small. For mineral exploration, b is set to 1, implying that there is no efficiency decline in exploration knowledge. The opposite is the case for artistic originals, where b is set to 0, implying straight-line efficiency decline." (ABS 2000)

For completeness, and because it has been used in the numerical example in Chapter 3.2, we also present a **linear age-efficiency profile**, g_n(linear):

$$g_n\text{(linear)} = 1 - n/T. \qquad (8)$$

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Here, productive efficiency declines by a constant absolute amount every period. The linear function is simple in presentation but not necessarily the most plausible form of efficiency loss of an asset. An important point to retain is also that a linear age-efficiency profile is not normally compatible with a linear age-price profile. How age-price and age-efficiency profiles are connected has already been shown in Chapter 3.2 and will be explained more systematically below. But the implication is that the widely-used linear age-price profile and the associated linear depreciation pattern do not follow from a linear age-efficiency profile.

The age-efficiency function above has been formulated for a single asset. When an entire cohort is concerned, account must be taken of the fact that not all assets of the same cohort will retire at the same time – there is a retirement distribution around an average service life. Section 13.3 and Annex 4 describe how a retirement distribution is combined with an age-efficiency or an age-price profile to yield an age-efficiency or an age-price profile for an entire cohort. This step is unnecessary when geometric profiles are employed. They combine age-efficiency and retirement functions directly. Furthermore, geometric age-efficiency and age-price profiles coincide so there is no need for a lengthy derivation of one from the other.

The **geometric age-efficiency profile** constitutes the most frequently used profile in empirical applications. It postulates that efficiency for a cohort declines at a constant rate δ. The concept goes at least back to Matheson (1910) although he applied it in the context of depreciation, *i.e.* to describe losses in value rather than efficiency (see below). Geometric efficiency profiles have been used widely by Jorgenson (1995) and many other researchers.

$$g_n(\text{geometric})=(1-\delta)^n. \qquad (9)$$

Because δ is also the rate of geometric depreciation, empirical estimates of rates of depreciation provide also the parameters for the age-efficiency function (see Chapter 12 for empirical methods of determining depreciation parameters).

11.1. Deriving age-efficiency profiles from depreciation profiles

When there is information about the age-price or depreciation profile, the age-efficiency profile can be derived. Given an age-price profile for a cohort, as well as the associated depreciation rates, and given a real rate of return r^*, a consistent age-efficiency profile can be computed. It should be noted that the link between the age-efficiency and the age-price profile is established at the level of the entire cohort, *i.e.* starting with a combined age-efficiency/retirement function that combines information about the retirement distribution and about the age-efficiency profile for a single asset (see Section 13.3 and Annex 4).

Note

1. It should be noted that the hyperbolic function does not necessarily yield age-efficiency profiles that are concave to the origin. Harper (1982) gives examples of hyperbolic functions that are convex to the origin.

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Chapter 12

Age-price and Depreciation Profiles

In this document, consumption of fixed capital or depreciation has been defined as the loss in value of an asset due to physical deterioration (wear and tear), and due to normal obsolescence. Depreciation is a value concept, to be distinguished from quantity concepts such as the age-efficiency function that capture losses in an asset's productive efficiency. There are several ways of determining depreciation parameters. They include:

- Start from empirical information about assets' service lives, and make an additional assumption about the functional form of the depreciation pattern. The various approaches towards assessing service lives empirically are described in Section 13.1;
- Use information on depreciation implicit in used asset prices and exploit it econometrically;
- Derive age-price and depreciation patterns from age-efficiency profiles;
- Use a production function approach and estimate depreciation rates econometrically.

4. The first two methods are by far the most common ones and will be described in some detail below. The production function approach will be described very succinctly.

12.1. Functional forms of the depreciation pattern

Straight line model of depreciation. A common model of depreciation is the straight line model. Given a service life for the durable, the age-price profile of the asset follows a pattern of linear decline:

$$p_n/p_0 = 1–n/T;\ n = 0, 1,\ldots T. \qquad (10)$$

The value loss of the asset between two consecutive vintages is a constant amount (1/T) of the initial asset value: $p_n–p_{n+1}=p_0/T$. The age-price profile translates directly into a sequence of depreciation rates, $\{\delta_n\}$, defined as the percentage loss in asset value due to ageing or $\delta_n = 1–p_{n+1}/p_n$ such that $\delta_n=1/(T-n)$. Consider the user cost price of an new asset under straightline depreciation. The simplified user cost expression is

$$\begin{aligned} c_n &= p_n(r^*–\delta_n) \\ &= p_n[r^*(1-n/T)–(p_n–p_{n+1})/p_n] \qquad (11) \\ &= p_n r^*(1-n/T)–p_0/T \end{aligned}$$

Under straight-line depreciation, this user cost term does not turn zero as the service life of the asset ends, that is when n approaches T. This implies an implausible case, namely a positive capital service value for an asset that is valueless.

The age-price profile (10) has been defined for a single asset. For practical applications, allowance has to be made for a retirement distribution. The transformation of the age-price profile for a single asset to the combined age-price/retirement profile for an entire cohort is described in Section 13.3.

Geometric or declining balance model of depreciation. Another common model is geometric or declining balance depreciation. Diewert (2005a) found that this approach dates back to Matheson (1910). As mentioned earlier, this method is computationally simple; it has been used in a large number of economic studies (see Jorgenson 1995, 1996 for a sample of influential papers) and is also gradually adopted by statistical agencies, among them the United States *Bureau of Economic Analysis*. The geometric model of depreciation δ (for an early application see Jorgenson and Griliches 1967) is characterised by

$p_n/p_0 = (1-\delta)^n$; n = 0, 1,(12)

The independence of the depreciation rate from the age of the asset generates a particularly convenient user cost formula. User costs are proportional to asset prices and in general, the factor of proportionality comprising the rates of return, of depreciation and of revaluation depends on the vintage of the asset because the rate of depreciation is age-dependent. Under a geometric model, the factor of proportionality becomes independent of the vintage of the asset. An important implication is that the value of depreciation does not have to be computed separately for every vintage but is obtained directly by applying the rate of depreciation to the net capital stock. Furthermore, the productive capital stock and the net capital stock coincide in the case of geometric rates because age-price and age-efficiency profiles coincide.

Another feature of geometric rates is that they typically combine the age-price and the retirement profile for a cohort of assets. As has been shown in Section 13.3, various age-price profiles for individual assets, when combined with retirement profiles for entire cohorts, generate profiles that are more or less convex to the origin so that the geometric model can be used as an approximation to a combined age-price/retirement pattern. Alternatively, when information from second-hand asset prices is used to estimate geometric rates econometrically, a specific adjustment is made to account for retirement patterns and for the fact that observed prices are only prices of surviving assets (see next Section).

In the absence of econometric estimates of geometric depreciation rates, δ has sometimes been estimated with the 'declining balance method' and on the basis of information about average service lives of a group of assets. Hulten and Wykoff (1996) made the following suggestion for converting an average service life of a cohort, T^A, into a depreciation rate. They propose a two-step procedure based on the 'declining balance' formula $\delta = R/T^A$ where R is an estimated declining-balance rate. Under the double declining balance formula, R is chosen to equal 2, but generally it is preferable to turn to empirical results for the shape of the geometric depreciation pattern. Hulten and Wykoff, in their empirical studies found an average value of R that is less than 2. Their results served as the basis for the geometric depreciation rates used by the United States Bureau of Economic Analysis (see Fraumeni 1997).[1] Baldwin *et al.* (2007), on the other hand, report econometric estimates of declining balance rates in the range between 2 and 3.

Overall, the parameters for geometric models of depreciation are best derived from econometric studies of used asset prices. Although the empirical basis is not very broad, these results provide much better foundations for depreciation estimates than simple assumptions. The principles of such studies are described below.

12.2. Empirical estimates of age-price profiles from used asset prices

12.2.1. Concept

Econometric studies of depreciation use price observations on new and used assets for several periods (for a more extensive survey of depreciation studies see Jorgenson 1996). Most approaches can be traced back to the work of Hall (1971) who put forward an econometric model of vintage price functions. Major empirical work in the field was conducted by Hulten and Wykoff (1981). Examples of more recent work are Oliner (1993), Geske, Ramey and Shapiro (2007), and Doms, Dunn, Oliner and Sichel (2004). In simplified form, these models can be characterised as follows

$$\ln P^{n,v,t} = a + \beta D_n + \gamma D_v + \mu D_t + \varepsilon \quad (13)$$

Observations on prices of a particular class of assets are distinguished by the age n of the capital good, by its vintage (*i.e.* a particular model, described by a set of characteristics v) and by the time of purchase t. The coefficient μ in this regression will yield an estimate of the average price change of the class of assets under consideration, while controlling for the age and for the characteristics of the models in the sample. In other words, μ is an estimate for a constant-quality price index for new assets, very much thekind of price index discussed in the context of deflating investment expenditure as a first step towards constructing measures of capital stocks.

The coefficient β, attached to the age variable, represents the percentage change in prices when age moves by one unit, holding characteristics and time constant. The economic effect measured by β captures what has been labelled "decay" by some authors (see Triplett 1998 for a discussion), *i.e.* the loss in value due to wear and tear as a capital good is used and as it ages. It is a pure age effect in the sense that it is measured while quality characteristics are held constant. β is also the parameter liable to picking up the 'lemons' effect, first identified by Akerlof (1970). Used assets trade at a discount when buyers cannot assess the quality of the goods offered for sale when they assume that vendors attempt to sell deficient goods.

This issue has also been discussed by Hulten and Wykoff (1981): they question whether assets traded on second-hand markets are representative of the entire asset stock, including the large majority of assets that remain in the possession of their original owners until they are scrapped. If the lemon problem is pervasive, the prices from second hand samples will not representative. Even if most second hand assets are in fact not lemons (*i.e.* not defective), so long as some prospective buyers fear that there may be some defective ones among the assets on offer, prices will be depressed and the prices of assets traded on second-hand markets will understate the market values of assets not so traded. An additional point is that there may be an inverse relationship between the lemons effect and the age of an asset. If an asset is put on the market while it is still relatively new, prospective buyers may be more suspicious about possible defects than if an asset is traded towards the end of its normal service life. The opposite suggestion has also been made, namely that used assets are usually put on the market in order to raise finance and so firms will sell their best assets rather than their worst ones. Attempts to determine the validity of these and other theories about the extent to which second-hand assets are representative of the total asset stock are inconclusive.

The coefficient γ captures the effects of product characteristics, *i.e.* product quality on prices. Obsolescence is directly associated with product characteristics: a new model of a class of assets may have new features or more of certain characteristics than an old model and this will typically depress the price of old models even if they are physically unchanged *as such*. Because expected obsolescence is considered part of depreciation in the national accounts, the obsolescence-related effects should be reflected in measures of depreciation. However, as Oliner (1993) has shown when investment data has been deflated with constant quality price indices – as is typically the case – only β should form the basis for empirical estimates of rates of depreciation because quality change has already been captured by the constant-quality deflator.

A related approach uses information from surveys on asset disposals, implemented recently, for example in Japan (Nomura 2008). Under Nomura's approach, prices are collected in a disposal survey. Firms provide information on the purchase price of an asset (gross book value at historical prices) and on the price at which an asset was sold. Nomura (2008) then uses a price index of new assets to express the acquisition cost in prices of the current period, adjusted by a trade margin and corrected for transport costs so as to obtain a valuation at purchasers' prices. Given ratios between disposal and acquisition prices by type of asset, an age-price profile can be estimated econometrically, assuming a constant geometric depreciation profile and weighting observations on values for disposed but surviving assets by the corresponding survival probability and weighting observations on values for disposed and discarded assets by one minus the survival probability. Depreciation rates and parameters of the survival function are both estimated empirically.

Box 12.1. **Depreciation rates based on Japan's Capital Expenditure and Disposal Survey**

The Japanese surveys on capital expenditures and disposals, conducted in 2005 and 2006, collected about 260 000 observations on disposal of assets from business accounts of private corporations. About 26 000 transactions relate to sales of assets with information on the sales price. The Japanese survey has some unique characteristics. First, the collected data provides fairly complete information on the characteristics of disposed assets, and on the time of their acquisition and disposal. With each data point on disposal, an identifier distinguishes between a second-hand sale of the asset for continued use and a discard of the asset for scrapping. Second, the Japanese survey has an impressive number of asset details – more than 600 at the most detailed level. This renders asset types more homogenous than in the case of a smaller number of asset types. Third, the acquisition and disposal periods were investigated monthly, thus also capturing the profiles of assets with relatively short service lives.

Table 12.1. **Depreciation rates for Japan**

			Manufacturing	Non-manufacturing	Total	Canada*	United States*
A		Building and construction	0.108	0.109	0.109	0.083	0.032
	A-1	Dwellings owned by firms	0.101	0.100	0.101		
	A-2	Plants for manufacturing	0.107		0.107	0.090	0.030
	A-3	Warehouses	0.090	0.090	0.090	0.075	0.030
	A-4	Office buildings	0.103	0.103	0.103	0.070	0.030
	A-5	Hotels, stores and restaurants	0.129	0.111	0.111	0.100	0.030
	A-6	Other buildings	0.106	0.126	0.122	0.070	0.030
	A-7	Electric power plants		0.122	0.122	0.090	0.020
	A-8	Water supply and sewage facilities		0.131	0.133		
	A-9	Communication and broadcasting facilitites		0.104	0.104	0.120	0.020
	A-10	Other construction	0.145	0.147	0.146	0.130	0.020
B.		Machinery and equipment	0.189	0.199	0.195	0.200	0.018
	B-1	Buildings accompanying facilities	0.141	0.136	0.138		
	B-2	Machinery	0.183	0.182	0.182	0.148	0.155
	B-3	Transport equipment	0.254	0.218	0.222	0.193	0.170
	B-4	Other machinery and equipment	0.224	0.260	0.243	0.194	0.168
Regrouped		Computers and photocopying machines	0.364	0.363	0.363	0.450	0.500
		Communications equipment	0.322	0.310	0.313	0.230	0.140

Note: For a rough comparison, the estimates for Canada and the United States for similar asset categories were derived as simple averages of these countries' more detailed depreciation rates.

Source: Nomura (2008).

12.2.2. Empirical evidence

Many studies of second hand asset prices have been made in the United States, perhaps because second-hand asset markets are more developed in that country. It is not certain that the age-price profiles identified for assets in the United States are also typical for other countries, although the studies carried out elsewhere, in Canada, United Kingdom and Japan, for example, have found similar age-price profiles.

Box 12.2. Depreciation rates based on Statistics Canada's Capital Expenditure and Disposal Survey

When statistical offices regularly compile data on capital expenditure *and* capital disposal, this can be a very good source of information for the estimation of age-price and depreciation profiles (see Section 13.1.1 for more discussion). The *Capital and Repair Expenditure Survey* (CES) conducted by Statistics Canada provides a good example for this approach. The survey covers about 80% of Canadian business investment with around 30 000 firms surveyed each year. The part of the survey dealing with capital expenditure is central to the estimation of gross fixed capital formation in Canada and as such a key input for the perpetual inventory method. However, the crucial information for estimation depreciation rates comes from those parts of the survey that deal with capital disposal.

The disposal database allows the direct estimation of depreciation rates for 36 major asset groups. The database contains individual data on the selling value of assets, on the age of the assets and on the corresponding gross book value. Another, interesting piece of information comes from a question on the expected service lives of new assets alongside with the investment value on new assets.

Traditionally, used-asset samples have not contained information on retirements, and price data has to be weighted by assumed survival probabilities. Such adjustments are not required when information on discards is included directly in the database. The basic variable used in recent studies on deprecation (Statistics Canada (2007), Patry 2005) is the ratio between the asset price when sold and its gross book value: P = SV/GBV. The book value, initially at historical prices, is expressed in prices of the selling year using investment goods deflators. Thus, the ratio P, along with information about the age of the asset when sold, permits estimating an age-price function which can readily be converted into a deprecation profile. A methodological challenge in this context has been to deal with the fact that the gross book value comprises not only the initial purchase value of the asset but also cumulative improvements that have been capitalized during the asset's service life.

The ex-post rates of depreciation can be compared with information from the survey on expected service lives. Expected service lives (T) can be translated into depreciation rates δ with the declining balance method given information about the declining balance rate DBR: δ = DBR/T. Statistics Canada obtain DBR econometrically and find that on the whole, ex-ante and ex-post depreciation rates were reasonably close.

One of the most interesting results from these studies is the comparatively high rate of depreciation and short service life that emerges for structures. For example, the authors find a 6% depreciation rate and an average service life of about 33 years for office buildings – considerably less than in many other countries and than in earlier studies for Canada. It emerged that over time, the service life of buildings has declined. This underlines the need for comprehensive and regular studies on depreciation patterns, lest there be a danger of ending up with biased values for depreciation and capital inputs.

Source: Statistics Canada (2007); Tanguy and Nakamura (forthcoming); Patry (2005).

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> **"This leads us to accept the geometric pattern as a reasonable approximation to [the age-price profile] of broad groups of assets".**
> **(Hulten and Wykoff 1996)**

Ideally, these studies should use actual transaction prices. A few studies have done this by using auction prices. This is often the case in studies of farm equipment because auctions are a common way of disposing of assets when farms go out of business. Other studies have tried to obtain transaction prices from second-hand asset dealers through surveys. Most studies, however, have been based on "list prices". These are the offer prices published by dealers and, because bargaining is common in asset markets, they may overstate actual transaction prices. In almost all cases, the first price in the age-price profile – the price of a new asset – is almost always a list price even when the subsequent observations are genuine transaction prices. Finally, at least one study (Lee 1978) has used insurance values. This was a study of fishing boats and because they run substantial risks of accidental loss, both owners and insurers have a shared interest in ensuring that insured values are realistic. This is not always the case for assets which face lower accident risks.

A significant source of bias, about which there is no dispute, arises from the fact that second-hand asset prices necessarily refer only to assets that have not yet been retired from the capital stock. Within the entire group of farm tractors of a given make, model and year of manufacture, there will be some whose second-hand prices are zero because they have been scrapped. A number of studies (Jorgenson 1996) have tried to correct for this bias by adding some (unobserved) zero prices to the set of prices that have been observed. It is usually assumed that the assets with zero prices were withdrawn from the stock following a bell-shaped mortality function such as the Winfrey "S3" curve. Hulten and Wykoff (1981) adjust used asset observations before they apply their econometric procedure. This permits integrating the effects of survival and consequently, the resulting depreciation rates combine the effects of retirement, decay, and obsolescence.

Three main conclusions about age-price profiles can be drawn from these studies:

- First, different kinds of assets exhibit a very wide range of age-price profiles. If price is plotted on the vertical axis and age horizontally, studies have found age-price profiles that are concave to the origin, that are horizontal lines, that fall in a straight line and that are convex to the origin. The studies have covered a wide range of industrial, agricultural and construction machinery, commercial and industrial buildings and transport equipment and it is therefore no surprise that they have not identified a single, standard pattern for the age-price profile of assets.
- Second, notwithstanding the above, by far the commonest age-price profile is a line which falls over time with some convexity towards the origin. This is almost always the case for machinery and equipment and is generally the case for buildings.
- Third, the downward sloping convex curve, which is most often detected in these studies, does not follow any simple mathematical law. Some of the studies have tested whether their observed age-price profiles follow one of two simple models – geometric (*i.e.* asset prices falling by a constant rate each year) or straight-line (*i.e.* asset prices falling by a constant amount each year). Statistical tests almost invariably reject both of these simple models, although straight-line is usually rejected more firmly than the geometric model. In summary, to quote Hulten and Wykoff's (1996) experience: "Although it is rejected statistically, the geometric pattern is far closer than either of the two other candidates. This leads us to accept the geometric pattern as a reasonable

approximation for broad groups of assets, and to extend our results to assets for which no resale markets exist by imputing depreciation rates based on an assumption relating the rate of geometric decline to the useful lives of assets."

12.3. Deriving depreciation profiles from age-efficiency profiles

When there is information or when assumptions have been made about the age-efficiency profile, the age-price profile and therefore the depreciation pattern can be derived. Age-price and age-efficiency profiles are related and a simple numerical example of how age-price profiles can be derived from age-efficiency profiles was given in Chapter 3.2. The conceptual link between the two profiles is the asset market equilibrium condition – the price of an asset equals the discounted value of its expected future rentals – because an important factor that shapes future rental prices is the age-related efficiency with which an asset will contribute to production. This age-efficiency pattern is mirrored by the relative user costs for assets of different age: $f_n/f_0=h_n$ where f_n/f_0 is the user cost of an n-year old asset relative to a new asset and where h_n is the age-efficiency/retirement profile. A more formal demonstration of this derivation is given in Annex 4.

It should be noted that the link between the age-efficiency and the age-price profile is established at the level of the entire cohort, *i.e.* starting with a combined age-efficiency/ retirement function that combines information about the retirement distribution and about the age-efficiency profile for a single asset (see Section 13.3). Given an age-efficiency profile for a cohort, and given a real rate of return, a consistent age-price profile can be computed. Note a possible circularity when the rate of return is computed endogenously and when the age-price profile is derived from the age-efficiency profile: a rate of return is needed to compute the age-price profile and hence depreciation. But the rate of depreciation is needed to compute the endogenous rate of return. One, tedious, way to deal with this situation is to solve a system of non-linear equations. A much simpler solution is to use an approximate and plausible real rate of return, such as 4% and solve for the age-price profile. The issue does not arise when rates of return are exogenous and/or when age-price and age-efficiency profiles are geometric.

12.4. Production function approach

The following description of the production function approach draws directly on Diewert (2005b) to whom we refer for a more extensive discussion and further references. The production function approach postulates the existence of a relation between output y^t produced during period t, quantities of non-durable inputs x^t, and quantities of durable inputs of different age $\{I^{t-n}\}$ such that

$$y^t = f\,[x^t, I^t+(1-\delta)I^{t-1}+(1-\delta)^2I^{t-2}+(1-\delta)^3I^{t-3}+\ldots+(1-\delta)^TI^{t-T}] \qquad (14)$$

Given observations on outputs and inputs, and given an assumption about the functional form of the production function, regression techniques can be used to obtain estimates of δ.[2] Empirical studies using the production function approach to estimate depreciation rates include Epstein and Denny (1980), Pakes and Griliches (1984), Nadiri and Prucha (1996) and Doms (1996). As Diewert (2006a) points out, it should be noted that the depreciation rates which are estimated using the production function approach may be different from the estimates that result from used asset studies. The latter approach incorporates the effects of deterioration and obsolescence (and are thus in line with the notion of depreciation in the national accounts) whereas the production function approach typically incorporates only the effects of physical deterioration.

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Econometric techniques, applied to models based on production theory, have also been used to estimate depreciation rates for research and development capital (Bernstein and Mamuneas 2006, Hall 2006) for which there is no possibility to use used asset prices to determine rates of depreciation. This is a useful way of introducing some objectivity into the difficult area of measuring R&D capital and depreciation.[3]

Notes

1. The Bureau of Economic Analysis uses a declining balance rate of 1.65 for most machinery and equipment and a rate of 0.91 for non-residential structures, based on Hulten and Wykoff (1981) and Wykoff and Hulten (1979).
2. Strictly speaking, the method produces estimates of the age-efficiency profile. However, due to the assumption of geometric rates, there is no difference between the age-price and the age-efficiency profile.
3. A caveat here is that typically, this approach relies on econometric estimates of depreciation given a rate of return. The latter is assumed, *i.e.* taken as an exogenous variable and the estimated results on depreciation rates may vary with the assumed rates of return. It is unclear whether, empirically speaking, this is an important effect or not.

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Chapter 13

Service Lives and Retirement of Assets

13.1. Service lives of assets

The accuracy of capital stock estimates derived from a PIM is crucially dependent on service lives – *i.e.* on the length of time that assets are retained in the capital stock, whether in the stock of the original purchaser or in the stocks of producers who purchase them as second hand assets. Note that the asset life is understood here as an economic notion,[1] and not as a physical or engineering notion of capital goods. This is important because it implies that asset lives can change over time simply due to economic considerations even if the asset remains physically unchanged. In fact, economic service lives are one avenue by which obsolescence manifests itself – the decision to retire is taken because a new and possibly more productive and/or cheaper asset appears, rendering the old model obsolete.

More precisely, the *average or mean service* life has to be distinguished from the *maximum service life* of a cohort of assets because the service lives of the same assets within a cohort are normally described by a retirement or mortality function, more of which below. The first section below looks at the sources that are available to estimate service lives, the next section considers evidence that service lives may be changing over time, and a final section looks at how errors in service life assumptions may affect reliability of capital stock estimates. Annex 1 shows the service lives used by several countries.

13.1.1. Sources for estimating service lives

The main sources for estimating service lives are asset lives prescribed by tax authorities, company accounts, statistical surveys, administrative records, expert advice and other countries' estimates.

> **For national accounts purposes, service lives are economic service lives which may be different from physical service lives.**

Tax lives. In most countries, the tax authorities specify the number of years over which the depreciation of various types of assets may be deducted from profits before calculating tax liabilities. Many countries – including Australia and Germany for example – make some use of them, either to estimate the service lives of assets for which no other source is available, or to provide a general credibility check on service life estimates obtained by other methods.

The interesting question is what sources are used to estimate tax-lives in the first place. In general, it appears that tax-lives are based on a variety of sources of differing reliability including expert opinion, ad hoc surveys of particular assets in particular industries and advice from trade organisations. In general, the accuracy of tax-lives will depend on the extent to which they are actually applied in tax calculations. Some governments use various systems of accelerated depreciation to encourage investment with the result that tax-lives become irrelevant to the calculation of tax liabilities, and neither tax collectors nor tax payers have any incentive to see that they are accurate and kept up-to-date. In several countries, however, tax-lives are based on periodic investigations by the tax authorities and can be assumed to be realistic.

Box 13.1. **Service lives for capital stocks in Germany**

The single most important source for service lives of assets in Germany are depreciation rules for companies as set by the German Ministry of Finance. Depreciation tables (*AfA Tabellen*) provide, by detailed asset type, information on the length of service lives for tax purposes. As these fiscal service lives reflect a principle of prudence, they tend to underestimate the true economic service lives and hence, the *Statistisches Bundesamt* for purposes of depreciation measurement, adjusts them upwards by between 20 and 100%. Adjustment factors are based on expert opinions from enterprises and industry associations. To a small extent, service lives are differentiated by industry. For example, it is assumed that lorries have a shorter service life in the construction industry than elsewhere.

Service lives for structures, in particular for dwellings and non-residential buildings, and service lives for intangible assets such as software are based on a series of other sources, and typically differentiated between different industries. For every vintage of investment, there is a different average service life, because every year the product, industry and sectoral composition of service lives may change. The table below shows examples of average service lives for types of assets as well as the spread of service lives for particular products within each asset category.

Type of asset	Average service life	Minimum and maximum service life of products within asset type
Buildings	66	15 – 150
Residential buildings	74	40 – 95
Streets	57	35 – 116
Equipment	12	5 – 30
Transportation equipment	11	8 – 25
Machinery and equipment	12	5 – 30
Metal products	18	14 – 22
Data processing equipment	5	5 – 9

Source: Schmalwasser and Schidlowski (2006).

In some cases, the statisticians have concluded that the pattern of tax lives across industries or asset types are fairly realistic but that there is a tendency for an overall bias in one direction or the other. They therefore apply an upward or downward correction factor before using them for their PIM estimates.

Company accounts. Company accounts often include information on the service lives that they are using to depreciate assets. Singapore and Australia have both made use of service lives reported in company accounts. The International Accounting Standards Committee has for some years been encouraging member countries to adopt common standards for company accounting and the Committee's rules require companies to report asset service lives used to calculate depreciation in their accounts. Company accounts could, therefore, become a better source of information in the future.

Company accounts almost always record stocks of assets at historic (or "acquisition") values, and while this is a disadvantage for many purposes; it does not necessarily prevent them from being used to estimate asset lives. Current price estimates of GFCF are, by definition, also valued at acquisition prices and are therefore consistent with stock estimates in company accounts. If the latter can be converted to a gross basis by adding back depreciation (which is also recorded at historic prices in company accounts) service lives can be estimated by comparing the gross stock in each year with the sum of investments during a varying number of previous years until finding how many years' cumulated investments most nearly equal each year's capital stock. This technique has been used in France, Italy and the United States.

Box 13.2. **Determining service lives from company data in France**

A systematic analysis of data from company information was carried out by Atkinson and Mairesse (1978) to determine the average service life of equipment in France. The researchers from the national statistical institute proceeded as follows. Atkinson and Mairesse compiled time series data for capital and investment for 124 French manufacturing firms for the period 1957-1975. The capital measure is the gross book value of fixed assets excluding land and buildings as recorded every year in the balance sheets, the investment variable is the corresponding value of the equipment flow. In line with accounting practice, all variables are at historical prices. With some extra estimates to generate long investment series, Atkinson and Mairesse construct a capital stock variable Ki,t*=σsϕ(s,σ)Ii,t-s based on past investments Ii,t-s for firms i=1,2,...; weighted by a retirement function ϕ(s,σ) whose parameters σ (which in turn determine the average service life) were as yet unknown. Subsequently, the authors employ an econometric procedure to estimate σ. More specifically, they estimate the non-linear function

S(σ) =Σi Σt(log Ki,t – log Ki,t*)2

which selects parameters σ on the criterion that they minimise the difference between the constructed capital stock Ki,t* and the capital stock measures from the company accounts Ki,t. The authors also test for different forms of the retirement function, such as a lognormal and a Weibull distribution. The data are treated by economic sector. The results indicate that the average service lives for manufacturing equipment goods for the period under consideration in France ranged between 16 and 21 years.

Statistical surveys. Two kinds of surveys are relevant to the estimation of asset service lives – those which ask producers about *discards of assets* during some previous accounting period and those which ask respondents to give the purchase dates and *expected remaining lives* of assets currently in use. The Netherlands has been carrying out a discards survey for some years (see Box) and the Czech Republic has recently added questions about discards to its annual capital expenditure survey. The United Kingdom, on the other hand, investigated the feasibility of a discards survey but concluded that very few respondents would be able to provide reliable information about assets that had already been discarded from the stock. There is also an indirect approach toward estimating service lives (see Box 13.3 on the Netherlands).

OECD (2001b) reports on several other surveys of this kind – *i.e.* surveys asking respondents about expected lifetimes. Korea and Japan have carried out large-scale investigations of capital stocks and asset service lives covering most kinds of activities. Canada, Italy and Spain have added questions about expected service lives to ongoing surveys of capital investment or industrial production. The United States carried out a number of industry-specific surveys in the 1970s with a view to updating the service lives used for tax purposes. A survey carried out in New Zealand on behalf of the tax authorities concentrated on 250 specified types of plant, machinery, transport and other types of equipment. For each asset type, a target group of producers was identified which could be expected to use that particular type of equipment and respondents were asked to report the year of purchase and expected remaining life of one individual asset of that type. By confining the investigation to a single asset the survey achieved a good response rate.

Box 13.3. **Service lives and discard patterns based on direct observations in the Netherlands**

Sources: the Netherlands count among the few countries where survey information is available on capital stocks and on capital discards. Combined with information from investment surveys, these sources are used to estimate service lives and retirement patterns by type of asset. Such direct observations only exist for manufacturing industries. Until 2003, capital stock surveys were conducted through on-site visits for manufacturing enterprises of 100 employees or more, with coverage of all two-digit ISIC industries, and relating to six types of assets. Surveys on discards have been conducted annually since 1991 for the same group of enterprises as the capital stock survey. Importantly, the survey on discards makes a distinction between scrapping an asset and selling it on the second-hand market.

Main features of method: for every type of asset and industry, the gross stock of a particular vintage minus the discard value of that vintage during the year is divided by the gross stock of the vintage at the beginning of the year. This ratio approximates, for every vintage, the probability of survival conditional on being in existence at the beginning of the period. Next, an assumption is made that the survival rates are generated by a Weibull probability density function which has been found to give a good approximation to the way in which a group of assets installed in a given year are discarded. The Weibull function (see also expression (16) below) has two parameters that characterise its shape. These parameters are then chosen such that the survival probabilities generated by the function are as closely as possible the empirical survival probabilities computed from the survey results. Given the parameters, the expected service life of each group of assets can be calculated.

The estimation of optimal parameter values is carried out for every asset/industry combination. A rule for the exclusion of outliers is applied to avoid unreasonable probability distributions. For the 1993-2001 period, capital survey data are available for two separate years for most industries and estimates were made for each year. Each survival distribution is checked for plausibility and some results are excluded because they do not pass visual inspection. When results are acceptable for both years of observation for the same industry/asset combination, an average is taken, otherwise the more plausible result makes it into the final selection. Some further quality checks are performed before the final set of retirement functions for each industry/asset is used in the national accounts. The results are shown in Annex 1 of this *Manual*.

Producers of capital goods need to know the age structure of the asset stock in order to forecast future demand. For this reason, trade associations and publishers of technical journals sometimes carry out surveys, which may provide information on service lives. Information from these sources does not seem to have been widely used by statistical agencies but it may well be that information on particular kinds of assets is available from trade and technical publications in some countries.

At the same time, some caution is also needed when using information from capital expenditure, and disposal surveys. Frequently, answers by respondents indicate how long the firm currently owning the asset has held it, but not including how long it had been held by a previous owner. This may occur regardless of the instructions to the respondent as the current owner may not have records on how old the asset was when purchased used. In addition, answers may refer to when the firm sold the asset to another user. This is not the same thing as scrapping or retiring it. Service life estimates from such surveys could be underestimated as a result. Clearly, depreciation should depend on the total life of an asset, not just on the life of the asset when held by a certain producer.

Administrative records. For some assets, government agencies maintain administrative records that can be used to estimate service lives. In almost all countries registers are kept of construction and demolition of dwellings and commercial buildings and vehicle registration records track the service lives of road vehicles. Aircraft and ships are often subject to similar controls. Regulatory bodies in power industries, railways and telecommunications are also a possible source of information.

Expert advice. Most countries appear to base at least some of their asset lives on expert advice. This may involve seeking advice from a panel of production engineers familiar with conditions in a representative cross-section of industries, or asking firms that produce capital assets for the normal service lives of different sorts of equipment. As already noted, producers of capital equipment need to have realistic estimates of the usual working lives of the assets they produce because sales to replace existing assets are a significant part of their total market. Asset-producers are therefore a potential source of reliable information on service lives.

Other countries' estimates. Most countries periodically review estimates used by other countries to ensure that their own estimates are not too far out of line with those of neighbouring or similar countries. Certainly, when countries first estimate capital stocks, they usually search the literature or contact other statistical offices to find out the service lives used elsewhere. There is a danger here that if countries systematically copy other countries service lives, an impression is created that there is a well-based consensus on the matter when in fact few, if any countries, have actually investigated service lives in their own countries. It should also be noted that asset service lives must be strongly influenced by country-specific factors such as the relative prices of capital and labour, interest rates, climate and government investment policies. Other countries' estimates may provide a broad credibility check but should not be adopted without question.

Implicit service lives in depreciation rates. When (constant) rates of depreciation are estimated with the help of econometric techniques an implicit statement is made about average service lives. Although the maximum service life of a geometrically depreciated asset tends towards infinity, the number of years after which an asset has lost 50%, 90% or 99% of its value can easily be calculated. More specifically if the relation $P_n=(1-\delta)^n P_0$ describes the geometric pattern of the price of an asset as it ages (its age-price profile) where n is the asset's age and δ is the rate of depreciation obtained from econometric estimates, then the number of years n^* by which a new asset will have lost X% of its value is given by $n^*=\ln(X/100)/\ln(1-\delta)$.

13.1.2. Ownership transfer costs

The cost of transferring ownership of assets is treated as gross fixed capital formation (see also Chapter 14). Because of this, costs of ownership transfer are also subject to consumption of fixed capital. In the revised System of National Accounts it is recommended that the costs of ownership transfer be written off over the period the asset is expected to be held by the purchaser, which may or may not correspond to the entire service life of the asset. Costs of ownership transfer on the disposal of an asset and also terminal costs (for example dismantling costs) should also be written off over the period the asset is held but recorded when they are actually incurred. When this cannot be followed for lack of adequate data, these terminal costs should still be recorded as gross fixed capital formation but written off as consumption of fixed capital in the year of acquisition.

Costs of ownership transfer may or may not be tied in with the asset itself. The capital services associated with the asset for which costs of ownership transfer are paid can, for example, be envisioned as the property rights from which the asset owner benefits while he/she holds the asset. That ownership transfer costs are investment for a separate asset is also reflected in the classification of non-financial assets where costs or ownership transfer show up as an asset category, at the same level as buildings or machinery and equipment.

As the average period during which assets are held by one owner is typically shorter than the asset's service life, one implication is that the service life over which costs of ownership transfer are written off, is inferior to the service life of the asset to which the costs relate. Also, it is not a matter of course that the deflator for the underlying asset is the appropriate price index for the costs of ownership transfer themselves. A general deflator such as the consumer price index might be more appropriate. Similarly, the shape of the age-efficiency and age-price profile may be different. Thus, in order to take account of these specific circumstances, costs of ownership transfer should be computed as a separate asset category. In practice, this may even turn out to be the only feasible option if statistical information on ownership transfer costs comes from different sources than information on gross fixed capital formation and if ownership transfer costs cannot be allocated to different types of assets.

13.1.3. Changes in service lives

There are good conceptual and empirical reasons why service lives may change over time. In practice, estimates of service lives are rarely updated in most countries. The "fixity" of service lives has been criticised because it is alleged that service lives are tending to fall over time. Two main reasons are given for this:

- It is argued that "product cycles" are becoming shorter. Consumer tastes in many countries may be changing more rapidly than in the past so that manufacturers are forced to introduce new versions and models more quickly and to bring new products onto the market more often than before. This could require producers to retool their production lines more frequently.
- It is also argued that many capital goods face much higher rates of obsolescence than in the past. This is particularly the case with computers and related equipment and may also be true for the increasing range of assets that incorporate computer technology; numerically-controlled machine-tools, communications equipment, and robotised production systems are examples.

As against this, some assets are certainly becoming more durable. Road vehicles and commercial aircraft are two examples. In addition, there has been considerable progress in recent year in the development of "flexible" production systems, which allow manufacturers to rapidly switch between alternative models without the need to retool. Shorter production cycles do not, therefore, necessarily imply shorter asset lives.

There have been few empirical studies relevant to the question of changes in asset lives. In Germany the Federal Ministry of Finance first began to publish tables of service lives to be used for tax purposes in 1957 and they have been regularly updated since then. The German *Statistisches Bundesamt* notes that officials of the Ministry of Finance are in regular contact with firms about changes in asset lives. The information obtained by the officials may be impressionistic rather than scientifically-based, but the *Statistisches Bundesamt* considers that it is nevertheless sufficiently well-founded to detect the direction of changes in service lives and the approximate size of such changes. Schmalwasser and Schidlowski (2006) report that service lives by type of product are revised about every 10 to 15 years. Note also that even if service lives at the most detailed product level remain unchanged, the average service life for a vintage may change if the product composition changes.

Most countries appear to keep asset lives fixed for their PIM estimates, but there are some exceptions. In the capital stock estimates of the United Kingdom, the lives of most assets are assumed to have been gradually declining since the 1950's and service lives of most types of long-life assets are reduced by just over 1% each year. The German *Statistisches Bundesamt* uses falling service lives for housing, farm buildings, motor vehicles and certain types of industrial equipment. Finland assumes that service lives for machinery and equipment were falling by 0.8% to 1% per year from 1960 to 1989 and at about half that rate since 1990.

Some of these reductions in asset lives are introduced not because the statisticians believe that service lives of particular kinds of assets are falling but rather that the asset groups identified in their PIM models are thought to contain increasing shares of shorter-lived assets. In particular, assets containing computerised components are generally assumed to have shorter lives than other types of equipment and the share of such assets in some asset groups is almost certainly rising in all countries. Thus, even in the absence of information about asset lives of *specific* assets, it may be right to assume declining service lives for *groups* of assets. Clearly the importance of this composition effect will depend on the degree of detail in the asset classification that is being used.

There are fewer examples of increasing service lives. In Germany the service lives of commercial aircraft are assumed to have been between 5 and 8 years prior to 1976 and 12 years for aircraft purchased since then. In the United States electric light and power equipment was assigned a service life of 40 years before 1946 and 45 years for all later years. Commercial aircraft are also assigned longer lives in later years – 12 or 16 years prior to 1960 and 15 or 20 years since then. Australia cites evidence from vehicle registration records that the service lives of road vehicles are increasing and this may be a fairly widespread phenomenon.

13.1.4. Effect of errors in service life estimates

Ideally, what is required for accurate implementation of the PIM is a set of service lives for narrowly-defined asset groups that are used in different sectors and kinds of activity. Moreover, this set of service lives should be updated regularly to reflect cyclical or longer-term changes in the lengths of time that assets remain in the stock. From the review of the sources above it is clear that the information actually available falls far short of this ideal.

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Service life estimates are generally available only for broad asset groups, there is limited information available on differences in lives of asset groups between sectors and kinds of activity and service lives are updated at rare intervals in most countries. This section considers how errors in service lives may affect levels and growth rates of capital stocks derived from the PIM.

The effect of errors in the average service lives used in the PIM can be gauged through "sensitivity studies" by running the PIM model with alternative estimates of service lives. Results of sensitivity studies for Canada and the Netherlands are described below.

Statistics Canada has estimated the gross capital stock in manufacturing with its standard PIM model but using service lives that increased from 0.5T to 1.5T, with T the average service life presently being used in Canada. The tests were run for the period 1950 to 1998. Predictably, changing service lives change the level of the capital stock in the same direction. Using the shortest lives (0.5T) reduced the level of the stocks by up to 50% and using the longest lives (1.5T) increased the level by up to 40%. With less extreme changes – 0.9T and 1.1T – the size of the stock is reduced by about 8% and raised by about 7%. Assuming that service lives used for PIM estimates are not usually wrong by more than 10%, the Canadian study therefore suggests that stock levels may have error margins of +/–8%.

Analytic studies often focus on growth rates rather than stock levels. In general, the effect of changing service lives has an unpredictable effect on growth rates because service lives act like weights. An upward revision to the service life of a particular asset increases the share of that asset in the total stock. An upward revision to a faster (slower) growing component of the stock will raise (lower) the growth rate of the capital stock as a whole.[2] In the Canadian study, reducing service lives generally increased capital stock growth rates during the period 1950 to 1970 but decreased them from 1971 to 1998.

The study carried out by Statistics Netherlands focused on stocks of machinery in the chemical industry and covered the period 1978 to 1995. Five different service lives were used – 10, 15, 20, and 25 years (the average service life actually used is 19 years). While the Canadian study deals only with estimates of the gross capital stock, the Netherlands study looked at the effects on both gross and net stocks and on consumption of fixed capital.

The level of the gross stock again changes in the same direction as the changes to service lives. Depreciation, however, generally changed in the opposite direction; that is, increasing the service lives reduced the amount of depreciation. This happened because, with longer service lives, each asset is written off over a longer period and this outweighs the increase due to the fact that longer service lives mean that there are more assets in the stock. In some years, however, the increase in the number of assets in the stock due to the use of longer service lives outweighed the reduction in the amounts of consumption of fixed capital charged to each asset and total consumption of fixed capital increased with longer service lives.

Net capital stock is obtained by deducting accumulated consumption of fixed capital from the gross stock. Since longer service lives will always increase the gross capital stock and will usually decrease consumption of fixed capital, the net capital stock will tend to increase when longer service lives are used. Moreover, the increase in net capital stock as service lives are lengthened will be relatively larger than in the case of the gross capital stock. A similar conclusion applies to the effects of changing service lives to the productive stock.

A final conclusion from the Netherlands study is that growth rates of gross and net stocks and of consumption of fixed capital become less volatile as service lives are lengthened. With longer service lives any lumpiness in investment flows into and out of the stock tends to be dampened by the larger size of the stock.

13.2. Retirement patterns

This section looks at the assumptions made about the distribution of retirements around the average service life. "Retirements" and "discards" are here used interchangeably to mean the removal of an asset from the capital stock, with the asset being exported, sold for scrap, dismantled, pulled down or simply abandoned. As used here retirements and discards are distinguished from "disposals" which also includes sales of assets as second-hand goods for continued use in production.

Simultaneous exit. The simultaneous exit retirement 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. The survival function therefore shows that all assets of a given type and cohort (*i.e.* year of installation) remain in the stock until time T, at which point they are all retired together. This retirement pattern is sometimes referred to as "sudden exit" but this term is ambiguous. Whatever mortality pattern is used, individual assets are always retired suddenly; the distinguishing feature of this function is that all assets of a given type and vintage are retired *simultaneously*.

It is however, not plausible to assume that all assets of a given vintage will all be withdrawn from the stock at the precise moment when they reach the average service life for that asset type. Some assets will be discarded before they reach the average service life because they are overworked, poorly maintained or fall victim to accidents, while others will continue to provide good service several years beyond their average life expectancy. Simultaneous exit must be regarded as an inappropriate retirement pattern.[3]

Linear. With a linear retirement pattern, assets are assumed to be discarded at the same rate each year from the time of installation until twice the average service life. The mortality function is a rectangle whose height – the rate of retirement – equals 1/2T where T is the average service life. The survival function shows that the surviving assets are reduced by a constant amount each year, equal to 50/T% of the original group of assets.

It is equally implausible to assume that a constant proportion of assets of a given vintage are discarded each year beginning in the first year that they are installed. Assets are by definition expected to remain in use for several years and discards in the years immediately after installation are likely to be rare for most assets. Thus, linear retirement also fails the test of plausibility.

Delayed linear. A linear retirement pattern assumes that retirements start immediately after they are installed and this is generally regarded as an unrealistic assumption. A delayed linear retirement pattern makes the more realistic assumption that discards occur over some period shorter than 2T. Retirements start later and finish sooner than in the simple linear case. Suppose for example that it is assumed that the assets are retired over the period from 80% to 120% of their average service life. The rate of retirement in the mortality function is then equal to 1/T (1.2-0.8) or 250/T% per year during the period when the retirements are assumed to occur.

Delayed linear assumes that once retirements begin, equal parts are discarded until the entire vintage has disappeared and this is probably less plausible than the assumption

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of a gradual build-up of discards in the early years and a gradual slowdown in later years, which is implied by bell shaped distributions.

Bell-shaped. With a bell-shaped mortality pattern, retirements start gradually some time after the year of installation, build up to a peak around the average service life and then taper off in a similar gradual fashion some years after the average. Various mathematical functions are available to produce bell-shaped retirement patterns and most provide considerable flexibility as regards skewness and peakedness (or *kurtosis*). They include gamma, quadratic, Weibull, Winfrey and lognormal functions. The last three are probably most widely used in PIM models and are described here.

Winfrey distribution. Winfrey curves are named after Robley Winfrey, a research engineer who worked at the Iowa Engineering Experimentation Station during the 1930s. Winfrey collected information on dates of installation and retirement of 176 groups of industrial assets and calculated 18 "type" curves that gave good approximations to their observed retirement patterns (see Box 8). The 18 Winfrey curves give a range of options for skewness and kurtosis. They are used in PIM models by several countries.

The group of symmetrical Winfrey curves is written as:

$$F_T = F_0 \left(1 - \frac{T^2}{a^2}\right)^m \tag{15}$$

In (15), F_T is the marginal probability of an asset retiring at age T, where the age has been expressed as a share of the average service life. Thus, T varies from zero to infinity and F_T is largest at the average service life. In Winfrey (1935), T is expressed in units equal to 10 percent of the average service life, and the parameters a and m provided by Winfrey are consistent with the age variable expressed in deciles. F_0 shapes the mode of the distribution, *i.e.* the maximum probability of retirement (at average service life). Two widely used Winfrey curves are the symmetrical S2 and S3 curves with parameters (F_0 = 11.911; a = 10; m = 3.70) for S2 and (F_0 = 15.610; a = 10; m = 6.902) for S3.

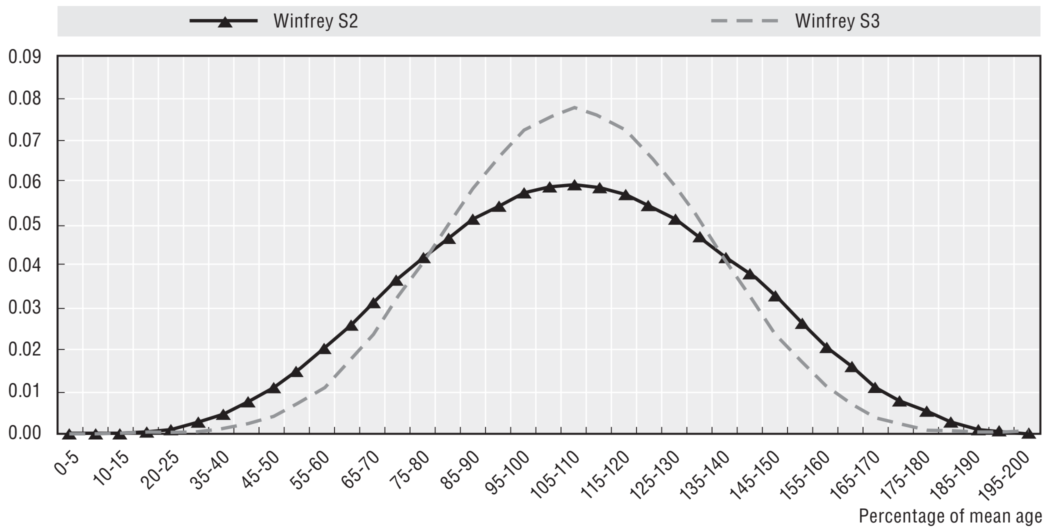
Table 13.1 shows how marginal probabilities are computed for two symmetric Winfrey retirement functions. The first column depicts intervals of 10 percentages of the average service life, followed by the probability to retire during this age bracket. For example, the probability for an asset to retire while between 20 and 30 percent of the average service life is 0.27% under the S2 Winfrey distribution, as shown in the second column and 0.01% under the S3 Winfrey distribution as shown in the third column. These values are obtained by inserting the age variable T = 20 into the Winfrey formulae with the parameters shown above. To obtain a more refined measure, say for five percent intervals, quintiles are shown in the fourth column of Table 13.1. The marginal probabilities in the fifth and sixth columns are then obtained by linearly interpolating between the probabilities derived for deciles. The result is shown graphically in Figure 13.1.

Weibull distribution. The Weibull function has been widely used in studies of mortality in natural populations. It is a flexible function that can adopt shapes similar to those designed by Winfrey. It was devised by the Swedish mathematician Walled Weibull in 1951 and it is used by several countries for PIM estimates. The Weibull frequency function is written as:

$$F_T = \alpha\lambda\,(\lambda T)^{\alpha-1}\, e^{-(\lambda T)^{\alpha}} \tag{16}$$

T is again the age of the asset, $\alpha>0$ is the shape parameter and $\lambda > 0$ is the scale parameter of the distribution. Statistics Netherlands has used data from surveys of discards to estimate

Figure 13.1. **Two symmetric Winfrey distributions**



Box 13.4. **Winfrey Mortality Functions**

During the 1920s and 1930s, Robley Winfrey assembled information on retirements of 176 different kinds of assets. Data were "accumulated from many sources, representing the following industries: gas, electric light and power, railway, telephone, telegraph, water supply, agricultural implement, motor vehicle and street pavement" (Statistical Analyses of Industrial Property Retirements, Robley Winfrey, page 59). His data sources included many of the major companies of the time – the *American Telephone and Telegraph Company*, the *Atchison, Topeka and the Santa Fe Railway* and the *Pacific Gas and Electric Company*. He also used information from the *Chicago Water Works System* and other municipal enterprises and he examined Iowa State vehicle registration records covering a wide range of "motor trucks" and "motor cars" – the latter including over 6 000 Model-T Fords and 5 000 cars of other makes.

His interest was in the ways in which a group of assets – *e.g.* creosoted cross-ties (sleepers), motor cars, waterworks boilers and asphalt pavements – that had been installed or constructed in a given year were retired over their total life-span. Winfrey plotted the 176 individual mortality functions showing when each member of each "cohort" (group of assets installed in a given year) was retired from the capital stock and concluded that they could be grouped into 18 "type" curves which he denoted by L, S and R for left-modal, symmetrical and right-modal and by the numbers 0 through 6 for the flattest to the most peaked curves. The 176 different kinds of assets were fairly evenly spread between the L, S and R curves but slightly more assets were assigned to the left-modal group – *i.e.* mode to the left of the mean. Over half of them had rather peaked mortality functions (numbers 3 to 6) indicating that most retirements happen within a short space of each other.

Weibull discard patterns for a wide range of assets. The table below shows the values of λ and α for the Netherlands. α can be interpreted as a measure of changes in the risk of an asset being discarded: $0 < \alpha < 1$ indicates that the risk of discard decreases over time; $\alpha = 1$ indicates that the risk of discard remains constant through the lifetime of the asset; $1 < \alpha < 2$ indicates that the risk of discard increases with age but at a decreasing rate; $\alpha = 2$ indicates a linearly increasing risk of discard, and $\alpha > 2$ indicates a progressively increasing risk of discard.

Table 13.1. **Computation of two Winfrey retirement functions**

Percentage of average service life	Marginal probability of retirement during decile		Percentage of average service life	Marginal probability of retirement during quntile	
Deciles	Winfrey S2	Winfrey S3	Quintiles	Winfrey S2	Winfrey S3
0-10	0.0000	0.0000	0-5	0.0000	0.0000
			5-10	0.0001	0.0000
10-20	0.0003	0.0000	10-15	0.0001	0.0000
			15-20	0.0007	0.0000
20-30	0.0027	0.0001	20-25	0.0014	0.0001
			25-30	0.0031	0.0004
30-40	0.0099	0.0015	35-40	0.0049	0.0007
			40-45	0.0082	0.0022
40-50	0.0228	0.0072	45-50	0.0114	0.0036
			50-55	0.0160	0.0072
50-60	0.0411	0.0214	55-60	0.0205	0.0107
			60-65	0.0259	0.0171
60-70	0.0625	0.0469	65-70	0.0312	0.0234
			70-75	0.0366	0.0321
70-80	0.0840	0.0814	75-80	0.0420	0.0407
			80-85	0.0466	0.0498
80-90	0.1024	0.1178	85-90	0.0512	0.0589
			90-95	0.0543	0.0659
90-100	0.1148	0.1456	95-100	0.0574	0.0728
			100-105	0.0585	0.0754
100-110	0.1191	0.1561	105-110	0.0596	0.0781
			110-115	0.0585	0.0754
110-120	0.1148	0.1456	115-120	0.0574	0.0728
			120-125	0.0543	0.0659
120-130	0.1024	0.1178	125-130	0.0512	0.0589
			130-135	0.0466	0.0498
130-140	0.0840	0.0814	135-140	0.0420	0.0407
			140-145	0.0366	0.0321
140-150	0.0625	0.0469	145-150	0.0312	0.0234
			150-155	0.0259	0.0171
150-160	0.0411	0.0214	155-160	0.0205	0.0107
			160-165	0.0160	0.0072
160-170	0.0228	0.0072	165-170	0.0114	0.0036
			170-175	0.0082	0.0022
170-180	0.0099	0.0015	175-180	0.0049	0.0007
			198-185	0.0031	0.0004
180-190	0.0027	0.0001	185-190	0.0014	0.0001
			190-195	0.0007	0.0000
190-200	0.0003	0.0000	195-200	0.0001	0.0000

Table 13.2. **Parameters of Weibull distribution for the Netherlands**

Asset	Parameter range of Weibull distribution	
	λ	α
Buildings	0.021-0.050	0.970-2.210
Passenger cars and other road transport equipment	0.134-0.251	1.130-2.120
Computers	0.066-0.286	1.140-2.840
Machinery and equipment	0.020-0.074	1.270-2.500
Other tangible fixed assets	0.028-0.108	0.980-2.630

Source: Central Bureau of Statistics, Netherlands.

Gamma distribution. The Gamma distribution is used by some statistical offices, for example the German *Statistisches Bundesamt* because this distribution has empirical support from observed patterns of car registration. It is measured as:

$$F_T = a^p \Gamma(p)^{-1} T^{p-1} e^{-aT} \quad (17)$$

The parameters a and p determine the shape of the retirement function. In Germany, for most goods, they are set to equal 9 which best approximates the empirical pattern of car retirement.

Normal and l**ognormal distribution**. The normal distribution is widely used in many branches of statistics. The normal frequency distribution is symmetrical and has the useful property that 95% of the probabilities lie within two standard deviations around the mean. The lognormal distribution is a distribution whose logarithm is normally distributed and is widely used as a mortality distribution for the PIM. The lognormal distribution is right-skewed and gives zero probability of discard in the first year of an asset's life. The right-hand tail of the distribution, however, approaches but never reaches zero and must be arbitrarily set to zero when the probabilities become small.

The lognormal frequency distribution is:

$$F_T = \frac{1}{T\sigma\sqrt{2\pi}} e^{-(\ln T - \mu)^2/2\sigma^2} \quad (18)$$

T is the age of the asset, σ is the standard deviation of the lognormal function and μ is its mean. σ itself is computed as $\sigma = \sqrt{\ln(1 + (m/s)^{-2}}$ and μ is computed as $\mu = \ln(m) - 0.5\sigma^2$ where m and s are the mean and the standard deviation of the underlying normal distribution. The lognormal frequency distribution has been used in capital stock measurement in the European Union. With *m* as the estimated average service life, the standard deviation s is set to between *m*/2 to *m*/4 to give more and less peaked distributions of retirements.

Both Weibull and lognormal mortality patterns have some empirical support. Statistics Netherlands and the French INSEE respectively, have shown that they can satisfactorily replicate observed discard patterns.

13.3. Integrating retirement patterns with age-efficiency and age-price profiles

Retirement or survival functions as discussed in the preceding section capture the idea that individual assets in a cohort retire at different ages. There are several options for combining retirement patterns with age-efficiency patterns or with age-price patterns of a single asset. We shall conduct the discussion in terms of age-efficiency cohorts. The method carries directly over to age-price patterns. Whether one starts with integrating retirement patters and age-efficiency profiles and derives age-price profiles or vice versa is not a trivial point because results are not in general identical as shown in Annex 4.

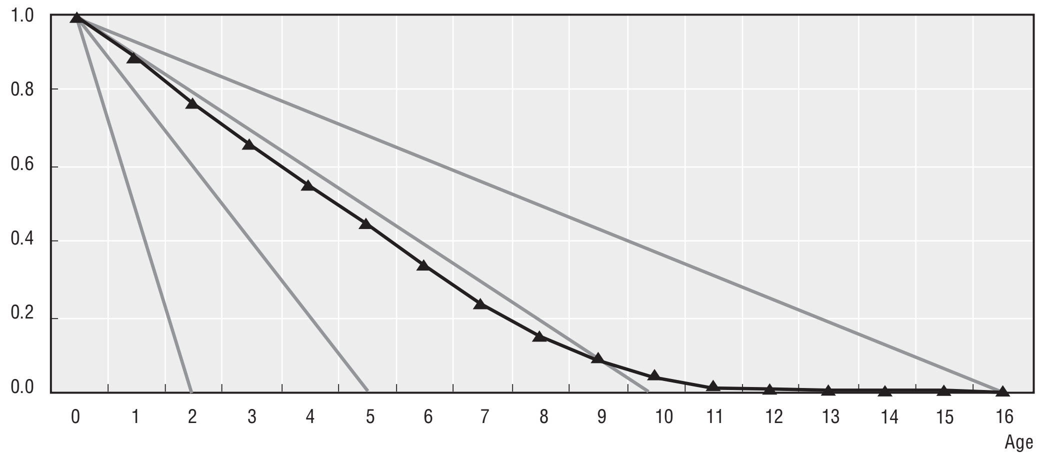
With this caveat in mind, the first possibility of integrating age-efficiency and retirement patterns consists of defining a separate age-efficiency pattern for each service life in the retirement distribution. Thus, a cohort of assets consists of a whole family of age-efficiency profiles that are distinguished by differences in their expected service lives, as suggested, for example by Hulten (1990):

"We have thus far taken the date of retirement T to be the same for all assets in a given cohort (all assets put in place in a given year). However, there is no reason for this to be true, and the theory is readily extended to allow for different retirement dates. A given cohort can be broken

into components, or subcohorts, according to date of retirement and a separate T assigned to each. Each subcohort can then be characterised by its own efficiency sequence, which depends among other things on the subcohort's useful life T_i" (Hulten 1990, p.125).

The average age-efficiency profile for the cohort (or equivalently, the combined age-efficiency/retirement profile) is then obtained as a weighted average of the efficiency of each profile for a particular age, with the survival probability as weights. This is shown graphically in Figure 13.2. The figure shows four linear age-efficiency profiles, with service lives of 2, 5, 10 and 16 years. The figure also shows the age-efficiency/retirement profile for the cohort as a whole, derived as a probability-weighted average of the age-efficiency values for each profile and each point in the service life.

Figure 13.2. **Age-efficiency/retirement profile for a cohort**



Algebraically, the procedure translates as follows: let $0 \le \{g_0, g_1, \ldots g_T\} \le 1$ be the age-efficiency function of a single asset with service life T, and let the combined age-efficiency/retirement function be $0 \le \{h_0, h_1, \ldots h_{TMAX}\} \le 1$ for the cohort as a whole:

$$h_n = \sum_{T=n}^{TMAX} g_n(T)\, F_T \; ; \; n = 0, 1, \ldots T^{max} \qquad (19)$$

In equation (19), T^{max} is the maximum service life considered in the cohort. F_T, in line with the notation in the previous section, stands for the marginal probability of retirement at age T (or at the age-interval T). By way of a numerical example, the procedure is shown in Table . The first column in the table shows the marginal probability of retirement after T years, based on a normal retirement function. The highest probability of retirement in the cohort is at the age of 9 years and the distribution has been cut off at $T^{max} = 17$. The first line of the table shows a simple linear age-efficiency profile for a single asset, defined – by way of example – for T^{max}. The second line delivers h_n, the result of the calculation. Each h_n is the sum of the column below and each element in the column is a probability-weighted age-efficiency value for age n of a family of age-efficiency functions in the cohort. For example, the fifth element in the column h_1 is obtained by multiplying two elements: *(i)* the age-efficiency of a one year old asset with expected service life of 5 years $g_1(5) = 1–1/5 = 4/5$ by *(ii)* the probability of a retirement age of 5 years = 1.65%. The multiplication yields 4*0.0165/5 = 0.013.

The procedure described above implies, for example, that after two years, an asset with a five-year service life exhibits a different efficiency than an asset with an eight-year

Table 13.3. **Integrated age-efficiency/retirement function**

	g_n →	0.938	0.875	0.813	0.750	0.688	0.625	0.563	0.500	0.438	0.375	0.313	0.250	0.188	0.125	0.063	0.000
Marginal probability	h_n →	0.889	0.778	0.667	0.557	0.448	0.342	0.243	0.158	0.091	0.046	0.020	0.007	0.002	0.000	0.000	0.000
	n-->	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	T																
0.0000	1	0.000				g_n (T) = (1 – n / T)											
0.0002	2	0.000	0.000														
0.0011	3	0.001	0.000	0.000													
0.0049	4	0.004	0.002	0.001	0.000												
0.0165	5	0.013	0.010	0.007	0.003	0.000											
0.0441	6	0.037	0.029	0.022	0.015	0.007	0.000										
0.0918	7	0.079	0.066	0.052	0.039	0.026	0.013	0.000									
0.1499	8	0.131	0.112	0.094	0.075	0.056	0.037	0.019	0.000								
0.1915	9	0.170	0.149	0.128	0.106	0.085	0.064	0.043	0.021	0.000							
0.1915	10	0.172	0.153	0.134	0.115	0.096	0.077	0.057	0.038	0.019	0.000						
0.1499	11	0.136	0.123	0.109	0.095	0.082	0.068	0.055	0.041	0.027	0.014	0.000					
0.0918	12	0.084	0.077	0.069	0.061	0.054	0.046	0.038	0.031	0.023	0.015	0.008	0.000				
0.0441	13	0.041	0.037	0.034	0.031	0.027	0.024	0.020	0.017	0.014	0.010	0.007	0.003	0.000			
0.0165	14	0.015	0.014	0.013	0.012	0.011	0.009	0.008	0.007	0.006	0.005	0.004	0.002	0.001	0.000		
0.0049	15	0.005	0.004	0.004	0.004	0.003	0.003	0.003	0.002	0.002	0.002	0.001	0.001	0.001	0.000	0.000	
0.0011	16	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.0002	17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

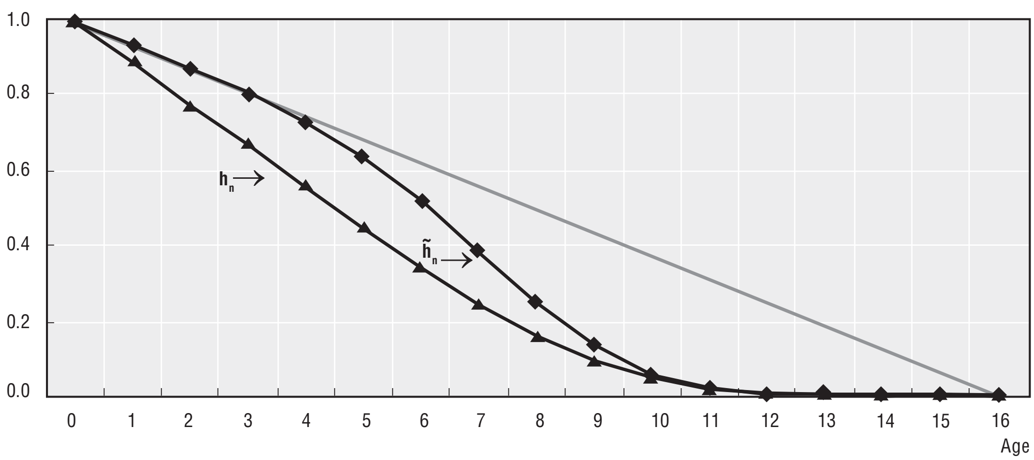
service life. This is reflected by the different shapes of the asset-specific age-efficiency functions in Figure 13.2. An alternative way of combining age-efficiency and retirement functions is to assume that until an asset retires, it exhibits the same age-efficiency. Under this assumption, the combined age-efficiency/retirement pattern would be given by the expression in equation (20). The term in brackets is the cumulative probability of survival after n periods. Thus, the age-efficiency function g_n defined over the maximum service life is written down by the probability of survival.

$$\tilde{h}_n = g_n \left(1 - \sum\nolimits_{T=0}^{n} F_n\right);\ n = 0, 1, \ldots T^{max} \quad (20)$$

This method has, for example, been used by the OECD for its capital services estimates (Schreyer *et al.* 2003). Its main advantage is simplicity of implementation. Statistical offices, for example the Australian Bureau of Statistics, have opted for the first method, as described by equation (19). Figure 13.3 compares the resulting profiles. Whatever the choice, however, it is clear that linear age-efficiency functions for a single asset do not translate into linear age-efficiency functions for the cohort as a whole. The combined age-efficiency/retirement function always exhibits a more or less convex form.

When the implementation of capital measures starts from an age-price or depreciation profile, exactly the same procedure can be applied: age-price functions for a single asset are combined with retirement functions to yield an age-price function for the cohort as a whole (which is then used to derive consistent age-efficiency profiles). By the same argument as above, the age-price function for a cohort will best be described by a convex shape, and a simple geometric depreciation pattern may be a very reasonable choice, because it tends to be supported empirically and because it facilitates implementation immensely.

Figure 13.3. **Age-efficiency/retirement profile for a cohort – alternative methods**



Notes

1. Diewert (2006c) examines a model based on Harper (2007) where rising real wage rates will induce early retirement of assets; *i.e.*, this model can provide an explanation for obsolescence. The paper studies how to aggregate over vintages and how to measure depreciation in the context of this embodiment model.

2. For a relatively homogenous class of assets which depreciate geometrically at the rate δ and where investment grows at the constant rate g, then if investment in period 0 is I^0, the end of period 0 capital stock K^0 will be $I^0\{1+[(1-\delta)/(1+g)]+ +[(1-\delta)/(1+g)]^2+\ldots\}=I^0[1+g]/[g+\delta]$. Similarly, the end of period 1 capital stock will be $I^0(1+g)^2/[g+\delta]$. Thus, the rate of growth of the capital stock going from period 0 to period 1 is $K^1/K^0=(1+g)$ which is independent of the geometric depreciation rate. Thus, for a relatively homogenous asset that has a geometric depreciation rate and where investment has followed a relatively steady growth rate, changes in the rate of depreciation should not greatly affect the rate of growth of the corresponding capital stock. The same conclusion need not hold when assets are heterogeneous because depreciation rates affect aggregation weights. This was pointed out in a comment by Erwin Diewert.
3. In section 6 of their paper, Diewert and Wykoff (2006) make a proposal how a discard/disposal survey for assests could be used to estimate depreciation rates without making explicit adjustments such as in Hulten and Wykoff (1981a, 1981b) to account for the fact that not all assets are retired at the same time. However, the Diewert/Wykoff method has not yet been tested.

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Chapter 14

Gross Fixed Capital Formation

Whatever the specific way of implementing measures of capital services and capital stocks, one of the key ingredients is investment data. Investment data should be broken down by type of asset and by economic activity. The level of disaggregation should be as detailed as the data allows and distinguish in particular those capital goods whose purchase prices follow different trends. Likewise, the industry break-down is important if it is believed that asset compositions vary greatly between industries and/or different industries face different depreciation rates, required rates of return and purchase prices of capital goods.

The time series of current-price gross fixed capital formation (GFCF) data are deflated by the appropriate investment price index. The investment price index should be a constant-quality price index. By applying it to investment series at historical prices, they are converted to a sequence of comparable volume estimates of investment, approximately expressed in efficiency units of the year to which the investment price index is referenced. Typically, these are the efficiency units of the latest vintage. This is important because it implies that the volumes of past investment (initially expressed as physical units of the respective vintage) have now been converted into units of the latest vintage. An improvement in the quality in the class of assets is therefore treated as an increase in the volume measures of investment.

GFCF is defined as the acquisition, less disposals, of fixed assets plus major improvements to, and transfer costs on, land and other non-produced assets. The assets acquired may be new or they may be used assets that are traded on second-hand markets. The assets disposed of may be sold for continued use by another economic unit, they may be simply abandoned by the owner or they may be sold as scrap and be broken down into reusable components, recoverable materials, or waste products.

An important aspect of capital formation concerns improvements to existing assets, concerning in particular dwellings and land:

> *"Gross fixed capital formation may take the form of improvements to existing fixed assets, such as buildings or computer software that increase their productive capacity, extend their service lives, or both. By definition, such gross fixed capital formation does not lead to the creation of new assets that can be separately identified and valued, but to an increase in the value of the asset that has been improved. A different treatment is applied to improvements to land in its natural state. In this case the improvements are treated as the creation of a new fixed asset and are not regarded as giving rise to an increase in the value of the natural resource. If land, once improved, is further improved, then the normal treatment of improvements to existing fixed assets applies. The distinction between which ordinary maintenance and repairs constitute intermediate consumption and which are treated as capital formation is not clear cut." (Revised SNA, chapter 10).*

Assets acquired (or improvements carried out) are valued at purchasers' prices which include all transport and installation charges as well as all costs incurred in the transfer of ownership in the form of fees paid to surveyors, engineers, architects etc. and any taxes

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payable on the transfer. Generally, the national accounts treat costs of ownership transfer of assets as GFCF. The rationale is that ownership transfer costs constitute an element of cost that purchasers of assets take into account in their investment decision. Put differently, the value of an asset to its owner has to reflect these costs.

Furthermore, in line with practice in statistical offices, flows of investment are considered to be spread evenly throughout accounting periods. In the model presented in Part III of the *Manual*, this idea is captured by the assumption that investment takes place at mid-period.

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Chapter 15

Computing Net, Gross and Productive Capital Stocks and Depreciation

At this point, the following elements should be available: an age-price and an age-efficiency profile for cohorts of particular types of assets; a depreciation profile which constitutes a direct transformation of the age-price profile and time series of gross fixed capital formation at constant prices as well as the corresponding deflators. With these elements in hand, the computation of the net stock, the value of depreciation, the productive and the gross capital stock is relatively straight forward. However, there is a practical issue that we have so far neglected – the periodicity of calculations. In most of the discussion above, allusion was made to "a period" or "a year" signalling that annual periodicity has been the implicit guide for presentation. And annual frequency is indeed the typical periodicity for capital stock measures in national statistical offices. But of course, quarterly national accounts exist and, if anything have become increasingly important in recent years. Even if balance sheets of the economy are compiled annually, flow measures such as depreciation should have their place in quarterly accounts and their calculation depends on measures of the capital stock. Moreover, a central aspect of capital services measurement is the possibility for a complete decomposition of the income side of the national accounts into price and volume measures and implementing such a price-volume split at quarterly rhythm should at least be a medium-term objective. In principle, it is possible and should suffice to present a quarterly model for computations, along with the relevant formulae for annual data derived from quarterly variables. For many countries, this may be an unrealistic way forward, however, given data availability. For this *Manual*, we shall not venture into a presentation of quarterly measures and only short reference will be made to sub-annual calculations below. Otherwise, the presumption is that a period corresponds to one year.

15.1. *Annual frequency*

In the context of annual data, it is important that formulae for the calculation of the different variables reflect certain national accounts conventions. For example, the latest vintage of investment that enters the net stock at the beginning of year t, is the investment that took place during period t-1, and which on average will be half a year old by the beginning of year t. Thus, the depreciation rate or age-price ratio for a half year-old asset applies. Also, all variables relate to cohorts, rather than to individual assets. For further details concerning the derivation of the individual formulae, the reader is referred to chapter 19 of this *Manual*. For convenience, we re-state the definition of the variables used below.

15.2. *Depreciation (consumption of fixed capital)*

- Age-price profile defined over prices of assets of different age n:

  $\psi_n = P_n^{tB}/P_0^{tB} = P_n^{tE}/P_0^{tE}$ n = 0.5; 1.5; 2.5;…

- Depreciation profile $\{\delta_n\}$ derived from age-price profile $\{\psi_n\}$:

  $\delta_n = 1 - P_{n+1}^{tB}/P_n^{tB} = 1 - \psi_{n+1}/\psi_n$ n = 0.5; 1.5; 2.5;…

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- Age-price profile derived from depreciation profile:

  $\psi_n = (1 - \delta_{n-1})(1- \delta_{n-2})\ldots(1 - \delta_0/2);$ $n = 1.5; 2.5;\ldots$

  $\psi_{0.5} = 1 - \delta_0/2.$
- Value of depreciation at current average prices of period t:

  General profile: $D^t = P_0^t\,[(1-\psi_{0.5})\,I^t + (\psi_{0.5} - \psi_{1.5})\,I^{t-1} + (\psi_{1.5} - \psi_{2.5})\,I^{t-2} + \ldots]$

  Geometric profile: $D^t\,(\text{geometric}) = P_0^t\,\delta[I^t/2 + W^{tB}(\text{geometric})\,]$
- Price index of depreciation: P0t/P0t0 where t0 is a base or reference year

15.3. *Net capital stocks*

- Net capital stock at the beginning of period t, expressed in prices of a reference year, WtB:

  General profile: $W^{tB} = \psi_{0.5}\,I^{t-1} + \psi_{1.5}\,I^{t-2} + \psi_{2.5}\,I^{t-3} + \ldots$

  Geometric profile: $W^{tB}(\text{geometric}) = (1-\delta/2)[I^{t-1} + (1-\delta)I^{t-2} + (1-\delta)^2I^{t-3} + \ldots]$
- Net capital stock at the end of period t, expressed in prices of a reference year, WtE:

  General profile: $W^{tE} = \psi_{0.5}\,I^t + \psi_{1.5}\,I^{t-1} + \psi_{2.5}\,I^{t-2} + \ldots$

  Geometric profile: $W^{tE}(\text{geometric}) = (1-\delta/2)[I^t + (1-\delta)I^{t-1} + (1-\delta)^2I^{t-2} + \ldots]$
- Stock-flow relation for geometric profile:

  $W^{tE}(\text{geometric}) = W^{tB}(\text{geometric}) + I^t - \delta[I^t/2 + W^{tB}(\text{geometric})]$
- Average net capital stock of period t expressed in prices of a reference year, W^t:

  $W^t = (W^{tB}+W^{tE})/2$

15.4. *Productive stocks*

- Productive stock at mid-period t expressed in prices of a reference year, K^t:

  General profile: $K^t = I^t/2 + h_{0.5}I^{t-1} + h_{1.5}I^{t-2} + h_{2.5}I^{t-3} + \ldots$

  Geometric profile: $K^t(\text{geometric}) = I^t/2 + W^{tB}(\text{geometric})$

15.5. *Gross capital stocks*

- Gross capital stock at the beginning of period t expressed in prices of a reference year, G^{tB}:

  General profile: $G^{tB} = I^t/2 + j_{0.5}I^{t-1} + j_{1.5}I^{t-2} + j_{2.5}I^{t-3} + \ldots$

  Geometric profile: not defined (the geometric profile combines age-efficiency and retirement functions and the retirement function which is required to compute the gross capital stock, cannot be separated out)

15.6. *Sub-annual frequency*

With the rising importance of quarterly information it would, in principle, be desirable to have a complete set of measures of stocks and flows of capital at quarterly frequency. Given quarterly measures, the annual figures could be consistently built up from the sub-annual data. This is, however, a highly unrealistic scenario. Most of the data sources required to build measures of capital stocks and flows are available at annual frequency or less and the relation between annual and sub-annual measures is not one of consistent construction of yearly data from quarterly observations. The vast majority of countries do not construct quarterly capital stock measures or balance sheets. Where quarterly flow variables are required such as for the estimation of consumption of fixed capital, they would typically be based on interpolations of annual data.

Sub-annual considerations also enter in a high-inflation context. When inflation is high, nominal values of flows from different sub-periods cannot be added because a unit of currency in one quarter is not directly comparable with one unit of currency in another quarter. Annual accounts could be established using the average value of the currency in a given quarter as the unit of the annual account. It should also be noted that in high inflation countries, problems may arise in measuring volumes measures when simple unit values are averaged over the four quarters. Similarly, seasonal products require care when annual price indices are established. A discussion of accounting in a high inflation context can be found in Hill (1996). For a discussion of quarterly accounts and the link between annual and quarterly price indices, the reader is also referred to Bloem, Dippelsman and Maehle (2001).

15.7. Estimating an initial capital stock in the absence of full time series of investment

The preceding formulae assume that a sufficiently long time series of investment data is available for each asset. For long-lived capital goods, this may not be the case as the longest living assets, usually structures, may have service lives in excess of 100 years. There are several ways to deal with this situation. The first possibility consists of estimating time series of investment, for example by establishing an econometric relationship between GDP and investment based on existing observations. This relationship can then be applied to historical GDP data (provided these are available) to generate estimates of time series of investment.

Another possibility is to construct a benchmark estimate on the basis of other sources than long investment series. Possible sources for benchmark estimates include:

- Wealth surveys
- Population censuses
- Fire insurance records
- Company accounts
- Administrative property records
- Share valuations.

Specific surveys of capital goods are a direct way of obtaining information on assets. National wealth surveys (for example in Japan) register the quantity of existing assets. Because, by definition, existing assets are assets that have survived, a direct wealth survey dispenses from making assumptions about survival or retirement patterns. **Population census** records usually provide information on the numbers of dwellings of different types. Estimated values will have to be assigned to the various types of dwellings identified in the Census records. **Fire insurance** records normally give the net values of assets at current prices and will have to be adjusted to gross valuation. They are incomplete because small companies may not insure their assets at all and very large enterprises and government bodies often prefer to bear the risks themselves and so will also be excluded from fire insurance records. **Company accounts** give asset values at depreciated historic costs and will need adjusting both to express them in prices of a single reference year and to "as new" values. An additional problem is that they are only available for the corporate sector. **Administrative property records** typically record residential and commercial buildings at values which purport to be current market prices but which are usually historic prices that are revalued to current prices at irregular intervals. The **share valuation** of a company's fixed assets can be obtained by multiplying the number of shares issued by a company by the share price and subtracting financial assets net of liabilities. The resulting values should reflect the current market values of the company's fixed capital assets but the valuation will also be affected by various unquantifiable factors such as "good-will", differences in entrepreneurial skill and the general business climate. In addition, this approach can only be used in countries with active stock markets and then will only provide valuations for corporate enterprises whose shares are quoted on stock exchanges.

It is clear that a benchmark estimate based on any of these sources will be highly approximate but the importance of errors introduced into the stock figures will diminish over time as the base period is left further behind.

A simple approximation (Kohli 1982) can be used in particular when geometric age-efficiency or age-price profiles apply. In this case, the productive (or net) stock at the beginning of the benchmark year t0 can approximately be written as the cumulative, depreciated investment of previous years:

$$W^{t0} \text{ (geometric)} \approx [I^{t0-1} + (1-\delta)I^{t0-2} + (1-\delta)^2 I^{t0-3} + \ldots] \tag{21}$$

Next, make a plausible assumption about the long-run growth of volume of investment – a simple possibility may be to set it equal to the long-run growth rate of volume GDP for which there may be empirical estimates, and call this long-run growth rate θ. Alternatively, regressing log real investment on time can yield an estimate of θ albeit based on the period after the initial stock. By assumption, one has $I^t = I^{t-1}(1+\theta)$. This relation can be inserted into the expression above for the initial capital stock:

$$\begin{aligned} [I^{t0-1} + (1-\delta)I^{t0-2} + (1-\delta)^2 I^{t0-3} + \ldots] &= I^{t0-1}[1 + (1-\delta)(1+\theta) + (1-\delta)^2(1+\theta)^2 + \ldots] \\ &= I^{t0-1}(1+\theta)/(\delta+\theta) = I^{t0}/(\delta+\theta). \qquad (22) \\ &= I^{t0}/(\delta+\theta). \end{aligned}$$

It is now possible to approximate the initial capital stock at the beginning of period t0 by the product of the level of investment expenditure in period t0 (the first period for which there is information on investment expenditure) and a combination of parameters of longer-term investment or GDP growth and depreciation.

15.8. Chain indices for gross fixed capital formation and the perpetual inventory method

A central feature of the perpetual inventory method is that flows of investment from different periods are aggregated, after adjustment for depreciation and retirement. Aggregation consists of adding up the so-adjusted measures of capital formation. Consistent addition is, however, only possible if every investment flow is valued with the same price vector of a base year. In practice, volume measures in many countries' national accounts are expressed in prices of the preceding year. Addition of volume measures requires re-referencing them with regard to a particular year, thus expressing them in "chained dollars" or "chained euros" of the reference year. Two questions have been raised by the German Federal Statistical Office (Schmalwasser 2002) in this context:

- Capital stocks in balance sheets should be valued at the prices of point in time to which the balance sheet relates. The question is whether "*…the use of a capital formation series which is linked by chaining to a reference year (re-referencing) does not meet the requirement of the valuation at the purchasers' prices of the current period,* ***because the price trend is only correctly represented by way of a direct comparison with the previous year, but not with the reference year****. In contrast, on a fixed price base, the price trend between the current year and the* *base year for prices is represented exactly, whereas, the price trend in the previous year's comparison can be ascertained only to a limited extent owing to the changing weighting"*.

- Volume measures that are expressed in "chained dollars" are not additive: chained dollar values of higher-level aggregates are not in general the sum of chained dollar values of lower-level aggregates. The question was posed "*How can consistency be checked in the light of the* ***multidimensionality of the calculations*** *of the consumption of fixed capital and the calculations of the fixed capital by asset types, industry, sector and market and non-market producers, if there is* ***no additivity*** *across the various dimensions?"*

These questions deserve further discussion. A first point is of a general nature regarding fixed and chain price or volume indices. While it is correct that chain price indices make no direct comparison of prices between non-adjacent periods, this is also the case – to a certain extent – in the practice of fixed base price indices. When fixed based indices[1] were used in the past, re-basing typically meant linking indices at 5 or 10-year intervals rather than constructing a complete new time series on the basis of one single base year. The reason for this has been one of practicality. It reflects the fact that in a world where products change continuously, it is often impossible to make direct comparisons over several years because products have ceased to exist. Thus, a first conclusion might be that even under a 'fixed base' approach, there is an element of indirect comparison by simple necessity.

A second point concerns the level of aggregation at which the perpetual inventory method is put in place. There is no doubt that in the presence of chain indices, the resulting capital measure depends on the level of aggregation from which the perpetual inventory method has been built up. The general rule is that a lower level of aggregation is preferable to a higher level of aggregation. The more detailed the asset classification that constitutes the starting point for revaluating investment series, the less important the issue although, for reasons mentioned above, there are limits to disaggregation. At the lowest level of aggregation, volume series are expressed in chained dollars of the date to which the balance sheet relates. Age-price and retirement profiles are applied and the resulting adjusted time series of investment are simply added up across vintages, industries or sectors. No issue of non-additivity arises unless the same operation is conducted at a higher level of aggregation. But there is little reason to do this given that the lowest level of aggregation available is normally to be preferred over a higher level of aggregation.

A second conclusion would thus be that the careful preparation of detailed investment series is key to the quality of the resulting capital stock measures. When the Netherlands reviewed its capital measurement programme, van den Bergen, de Haan, de Heij and Horsten, (2005) reported that:

> "A substantial amount of work in this project concerned the recovery of original source data on investments. The first year covered in the investment time series in current and constant (t-1) prices is 1953. The time series were constructed at the level of 57 industry branches, 20 asset types and 18 institutional (sub)sectors" (page 7).

A third point is that the above discussion related to *levels* of capital stocks for balance sheets. This is but one purpose of capital measurement. For other purposes, dollar levels of capital stocks are of secondary if any interest. For example, for productive stocks, their rate of change is of interest, not their level because the rate of change describes the flow of capital input into production. As explained elsewhere in this *Manual*, such a rate of change should be based on a superlative or at least chained index number formula.[2]

Notes

1. As a technical aside it may be mentioned that fixed-base Laspeyres volume indices require Paasche price indice that directly compare prices between the base period and the reporting period. In practice, price indices are computed on the basis of a Laspeyres-type formula.
2. If only flows are of interest, even the aggregation across vintages can proceed with more general index number formulae than simple addition (Diewert and Lawrence 2000) although this has rarely been put in place in practice.

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Chapter 16

Estimating Rates of Return

Part I of this *Manual* (Section 8.3) discussed the conceptual foundations for the computation of rates of return. Two main approaches (*ex-post*, endogenous rates and *ex-ante*, exogenous rates) can be found in the literature, each with its advantages and drawbacks. The Section at hand will provide more details for all three avenues towards measuring the rate of return.

16.1. Rates of return for market producers

16.1.1. Endogenous, ex-post rates of return

As explained in Section 8.3.1, the endogenous, *ex-post* approach is the most frequently used method in empirical applications of capital measurement. It consists of computing the period-by-period *ex-post* rate of return, on the basis of information about non-labour income, depreciation and real holding gains or losses for the market sector. When the necessary information is available, these computations may be carried out at the level of individual industries. Non-labour income consists of gross operating surplus as available from the national accounts and the part of mixed income that can be attributed to capital (G^t). Capital-related taxes $T_K{}^t$ are discussed further in Section 18.4.1.

Splitting mixed income of unincorporated businesses owned by households into a labour and capital element is not easy. It is sometimes difficult to put a value on the labour of a self-employed person, or alternatively, to put a value on the capital services part of mixed income. Probably the most frequently-used approach (but not necessarily the most satisfactory) is to assume that wages of self-employed persons and unpaid family members equal the average wage of employed persons. The part of mixed income that remains after the imputed compensation for the labour of the self-employed has been accounted for is the remuneration of capital. A more elaborate version of this approach is to use information on skills and experience of self-employed persons and compute a wage rate for a comparable set of skills that is observable on the labour market. Alternatively, if the stock of assets in use by unincorporated businesses is known, the value of capital services can be calculated and the labour share of mixed income falls out as a residual.[1]

The endogenous, *ex-post* rate of return for every period is computed by equating G^t plus capital related taxes on production to the total user costs of capital U^t. How U^t has been derived is shown in Part III of this *Manual*. For the purpose at hand, it suffices to remind the reader that in the expression below, r^{t^*} is the real rate of return that applies at the beginning of period t and which will be computed, i^{k,t^*} is the ex-post, real rate of asset price inflation for asset k during period t; $P_0{}^{k,tB}K^{k,t}$ is the productive capital stock of asset k during period t, valued at beginning of the period prices $P_0{}^{k,tB}$; δ^k is the rate of depreciation for a new asset k; ρ^t is the rate of change of the consumer price index at the beginning of period t. By setting G^t+$T_K{}^t$ to equal the total value of user costs and noting that all variables are known except for the rate of return, it is possible to compute r^{t^*}. For the present exposition, we have assumed a geometric depreciation profile to simplify notation.

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However, the reasoning carries directly over to the non-geometric case, and is laid out in Part III of this *Manual*.

$$G^t + T_K{}^t = \Sigma_{k=1}^{N} P_0{}^{k,tB}(1+\rho^t)\,[r^{t^*} + \delta^k(1+i^{k,t^*}) - i^{k;t^*}]K^{k,t} \qquad (23)$$

Expression (23) constitutes a variant of the most widely-used approach towards estimating the rate of return, although computations have typically been based on the (equivalent) user cost formulation with nominal rates of return and a nominal term for holding gains or losses: see for example Jorgenson (1995), or Jorgenson and Landefeld (2006).

In the case of geometric depreciation, the computation of the rate of return can be given a direct and useful interpretation: the nominal *ex-post*, endogenous rate of return r^t corresponds to the ratio between net operating surplus N^t plus capital-related taxes on production plus revaluation of assets R^t divided by the value of the productive capital stock. Net operating surplus is computed as the difference between gross operating surplus (including the capital part of mixed income) minus depreciation: $N^t = G^t - D^t$. Under geometric depreciation, these terms are defined in such a way (see Part III of the *Manual*) that (24) follows directly from (23).

$$r^t = \frac{N^t + T_K^t + R^t}{\sum_{k=1}^{N} P_0^{k,\,tB}\;K^{k,\,t}} \qquad (24)$$

This is an intuitively appealing calculation of the rate of return: net operating surplus constitutes the proceeds from business operations to which revaluation gains are added and losses deducted to obtain a 'net rate of return' before payment of capital-related taxes. Subtracting the general rate of inflation ρ^t from r^t and dividing by $(1+\rho^t)$ yields the real rate of return r^{t^*} that corresponds to r^t.

Harper, Berndt and Wood (1989) and Baldwin and Gu (2007) find that the growth in capital services is lower for the case when capital gains, derived from asset price changes, are not included in the estimation of user cost. This matches observations from other empirical work. Baldwin and Gu (2007) provide the following explanation:

"*This result is due to (1)the long-run historical shift toward equipment (with relatively high depreciation and high user cost) and away from structures (with relatively low depreciation and user cost), which increases the capital composition effect; and (2) the long-run tendency for the price of structures (with low depreciation) to increase faster than the price of equipment (with high depreciation), causing the capital gains that are subtracted in the user cost of structures formulae to be larger than those subtracted in the user cost of equipment estimates. This increases the difference in the user cost of structures and equipment, and thus leads to an increase in the growth in capital composition*." The simplified version of the *ex-post* approach builds on the concept of 'balancing real rates' (see Box 9). The main simplifying assumption is that the real revaluation of assets is set to zero.[2] The real rate $r^{t^{**}}$ in the simplified method exactly exhausts capital income as measured in the national accounts:

$$G_{(tB)} + T_K{}^t = \sum_{k=1}^{N} P_0^{k,\,tB}(1+\rho_{(tB)})\,[r_{(tB)}{}^* + \delta^k(1+i_{(tB)}{}^{k^*}]\,K^{k,\,t} \qquad (25)$$

For each asset one obtains a fairly simple expression for the price of capital services, $P_0{}^{k,tB}(1+\rho^t)\,[r^{t^{**}}+\delta^k]$ which is the basis for constant price measures and volume indices of capital services. By construction, the total value of capital services across assets equals ex-post capital income $G^t+T_K{}^t$.

Box 16.1. **"Balancing real rates" of return for Japan**

Japan constitutes an interesting showcase for the computation of user costs and rates of return: the Japanese economy experienced strong growth for several decades after the Second World War but there was also a pronounced and extended slow-down starting at beginning of the 1990s. Finally, the Japanese market for land has undergone enormous swings with all signs of a bubble market for a lengthy period of time. These factors combined make Japan not only an interest economy to study but they also pose challenges for the measurement of economic growth.

In an unpublished paper Diewert, Mizobuchi and Nomura (2005) develop a set of data for Japan and compute a balancing real rate of return for the Japanese market sector. They do so by setting real holding gains i^{it^*} in an equation similar to (23) to equal zero and then solve for r^{t^*}. They reason that if they use "…actual *ex post* inflation rates, we will almost certainly generate user costs which are negative for some years, which is not sensible in our context since we want our user costs to closely approximate market rental rates for the assets and these rates would not be negative. Even if we estimate [price changes] by smoothing the *ex post* values for these variables or using a forecasting model, with Japanese data, we will inevitably generate some negative user costs for land components, due to the very rapid land price inflation that occurred in Japan during the 1980's". With the balancing real rate, they find that:

"…the average *ex post* real rate of return over the entire sample period was 2.152% per year, which is not an unusual real rate of return by international standards when inventory and land stocks are included in the asset base. However, there are some interesting trends in the *ex post* real rates of return. The average *ex post* real rate up to the first oil shock (the years 1955-1973) was a relatively high 5.096% per year. For the years 1974-1979 (these are the years between the two oil shocks), the average real rate of return fell to 0.747% per year. For the bubble years, 1980-1990, the real rate of return remained rather low; it averaged 0.718% per year. However, for the post bubble years 1991-2003, the *ex post* real rate of return fell to a negative rate: –0.287% per year on average.

It is not plausible that producers could anticipate the quite variable balancing real interest rates, and then use these interest rates in setting their annual rental prices for fixed assets. However, they may be able to anticipate the trend in this series."

16.1.2. Exogenous, ex-ante rates of return

As explained in Section 8.3.1, an alternative to the endogenous model above is to choose an extraneous, *ex-ante* rate of return, for example as an average of different interest rates that prevail on financial markets. It is preferable to operate with a real rate for this purpose as real rates are independent from overall rates of inflation and tend to show less volatility. As an *ex-ante* measure, it will be necessary to smooth the time series of observed real rates because it is implausible that economic actors fully anticipate every movement of market interest rates. In many cases, a simple long-run average will be sufficient unless there is a marked trend in the time series of real rates. Work at the OECD where exogenous real rates have been used for capital services measurement at the total economy level showed that in the 18 countries examined, long-run averages of real interest rates oscillated around values between 3 and 5 percent per year, depending on the country.

The real rate of return expected at the beginning of period t (call it $r_{(tB)}^{*}$) is then combined with an expression for the expected rate of real holding gains or losses for asset type k, $i_{(tB)}^{k^*}$. The latter is based on the time series of *ex-post* rates of real asset price changes, i^{kt^*}. Unless there is a marked trend in the ex-post series, as may be the case for high-tech equipment, setting the *ex-ante* real asset price change to equal zero is a plausible way of dealing with the issue. This includes the case of bubble markets (such as land) that are discussed further below. Expression (23) also includes ρ^t, the rate of change of a general price index such as the consumer price index. For the *ex-ante* version, it has to be replaced by the trend rate of the CPI, $\rho_{(tB)}$.

Inserting the expected rates $r_{(tB)}^{*}$, $i_{(tB)}^{k^*}$ and $\rho_{(tB)}$ into the user cost expression, summing up across assets and factoring in capital-related taxes on production $T_K{}^t$ yields a dollar value $G_{(tB)}+T_K{}^t$, the expected remuneration of capital for the accounting period t.

$$G_{(tB)} + T_K{}^t = \sum\nolimits_{k=1}^{N} P_0^{k,\,tB}(1 + \rho_{(tB)})\,[r_{(tB)}{}^{*} + \delta^k(1+i_{(tB)}{}^{k^*}]\,K^{k,\,t} \qquad (26)$$

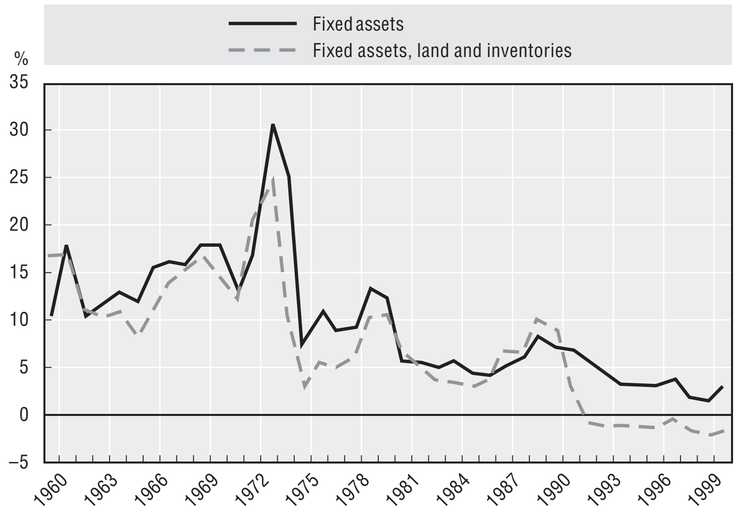
When the market sector has been broken down by economic activity, the rate of return becomes industry-specific and the remuneration $G_{(tB)}$ should be computed for every industry although it may not always be obvious to measure industry-specific rates of return on financial markets. To obtain an average real rate of return for the market sector, a weighted average of industry-specific rates of return is constructed. A natural weight for this measure is each industry's share in the total value of the net stock of the market sector.

Inherent in the *ex-ante* approach is the fact that $G_{(tB)}+T_K{}^t$ the computed remuneration of capital services is not in general equal to $G^t+T_K{}^t$, the *ex-post* remuneration as identifiable in the generation of income account of the national accounts. This issue is further discussed in the next Section because it also arises for the simplified approach towards measuring the rate of return that is presented next.

There are at least two situations when the exogenous approach towards measuring rates of return is a useful choice. First, when the stock of assets considered is incomplete in the sense that important sources of capital services are not part of the computed stock. The most probable candidate for such omissions is land for which information may not be available or at least not with reliable quality. In this case, an endogenous rate of return can be upward biased because non-labour income is put in relation to an under-valued capital stock. Second, when no empirical distinction can be made between the market sector and the government sector, computations with an endogenous approach will imply a downward bias of the rate of return because there is no net operating surplus for government assets so that the market sector's operating surplus will be brought into relation with an asset base that comprises assets in the total economy and is therefore too big.

To illustrate the point and to show the impact of a change in the scope of assets, consider Figure 16.1. It shows the exogenous, nominal rate of return computed on the basis of fixed assets and on the basis of fixed assets plus land and inventories for a 40-year period for Japan. During three decades, the differences in the resulting rates of return are relatively contained. However, during the 1990s, a gap emerges between the two series – the rate based on fixed assets remains higher than the rate based on the more complete asset base. Thus, the choice of the asset base can make a difference to results and an incomplete asset base can give rise to an overstatement of the rate of return when the endogenous method is applied.[3] Under these circumstances, an exogenous real rate of return may be the appropriate choice. For its estimation, one would typically turn to interest rates on financial markets and select an average of key rates that bear a link to the

Figure 16.1. **Rates of return for different scope of assets in Japan**



Source: Nomura (2004).

opportunity costs of investing in non-financial assets. Candidates for interest rates are government bonds, corporate bonds and interest rates on corporate debt of varying maturity.

Period-to-period interest rates tend to be volatile and user costs based on *ex-post* market interest rates are likely to generate more volatile user costs than an *ex-ante* measure. This practical consideration favours the use of an *ex-ante* or trend, exogenous rate of return rather than an *ex-post* exogenous rate.

16.1.3. Ex-post and ex-ante income of capital for the market sector

In general, the sum of user costs computed with the *ex-ante* rate of return does not equal the *ex-post* level of non-labour income $G^t + T_K{}^t$ as shown in the national accounts. The existence of such a difference is not in itself problematic because it reflects differences between an *ex-post* figure and an *ex-ante* calculation and can give rise to interesting analytical explanations (evidence of windfall profits or losses, return to unobserved private assets, economies of scale). There is thus a difference in the usage of the two results which are relevant for different analytical questions.

For statements about the *ex-post* distribution of income between labour and capital, *ex-post* figures from the national accounts are the relevant variable so that the capital share in income corresponds to the share of non-labour income to total income. For the measurement of volume indices of capital services, *ex-ante* shares of each asset in total *ex-ante* capital income would seem more appropriate. The reason is that *ex-ante* capital shares are a better approximation to the parameters[4] of the underlying production function that one wishes to capture.[5]

In the case of *ex-ante* capital income measures that deviate from the *ex-post* data, how should the discrepancy be dealt with in an accounting framework?

- For ***current-price v***alues in conjunction with the generation of income account in the SNA, the following break-down can be envisioned for market producers:

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Gross value added =	Labour	Capital
Compensation of employees	Compensation of employees	
+Other net taxes on production	Net taxes on production concerning labour	Net taxes on production concerning capital
+Gross operating surplus		+Gross operating surplus
+Gross mixed income	+Labour part of gross mixed income	+Capital part of gross mixed income
	= Labour income, ex-post	= Capital income, ex-post
		Ex-ante value of capital services
		Asset type 1
		Asset type 2
		:
		Asset type N
		Residual profits or losses

- For ***constant-price*** values, the *ex-ante* value of capital services would be shown in prices of a reference period t0, where the price (index) of capital services, $P^{0k,t0B}(1+\rho^{t0})\ [r^{t0**}+\delta^{k}]$, comes into play. Summed over assets, this yields the value of capital services in prices of a reference year. No constant price value would be shown for the residual profits, or for the *individual* items net taxes, gross operating surplus and capital part of gross mixed income. Residual profits, by their nature, do not lend themselves easily to a price-volume split.
- The above treatment gives rise to two types of ***implicit price indices for capital services:*** *(i)* an *ex-ante* price index that corresponds to the ratio between the *ex-ante* value of capital services at current prices divided by the ex-ante value of capital services at constant prices; *(ii)* an *ex-post* price index obtained by dividing the *ex-post* value of capital services at current prices by the ex-ante values of capital services at constant prices. In the latter case, a residual profit or loss would translate into a price effect – in the presence of residual profits, this implicit price index would show a larger value than the corresponding *ex-ante* price index.

16.2. Rate of return for own-account production of households

The real rate of return r^{H,t^*} for households' own-account production is best chosen so as to correspond to the explicit or implicit rate of return associated with owner-occupied housing – see Section 8.3 for a discussion of concepts – more on the practice of measuring owner-occupied dwellings is discussed in Section 18.1.2. In the absence of such information, the social rate of time preference (Section 16.3.3) constitutes a practicable alternative.

16.3. Rate of return for the government sector

Section 8.3 concluded that, for analytical purposes, it is useful to impute a positive rate for the cost of capital assets held by the government sector, with a view to capturing the opportunity costs of government investment. This is at variance with the *System of National Accounts* where the convention of a zero rate of return for government assets has been adopted. The present Manual proposes several methods how to measure the cost of capital for non-market producers but it is well understood that this is for analytical purposes only and in full recognition of the fact that no such imputation is warranted in the national accounts. An example for analytical studies that recognise a positive rate of return is Mas *et al.* (2006) who examine the role of infrastructure capital, largely held by government entities, for economic growth in Spain. If a positive rate for the cost of capital is imputed, it is recommended that the rate of return for the government sector be consistent in concept with the rate of return to the private sector. Thus, if an *ex-ante* approach has been followed for the market sector as described above, an *ex-ante* approach should be chosen for government.

The scope of assets belonging to government is often large and includes produced and non-produced assets. For example, natural resources are often government-owned and can account for an important part in the total wealth of the public sector. Note, however, that when government owns a non-produced, non-financial asset such as land or a subsoil resource and leaves its exploitation to another unit, the act of renting is not itself considered production. Thus, the capital services provided by land and subsoil assets should be registered with the users of assets and there is no need to make an imputation for government. In other words, all assets that are used in production processes undertaken by governments should be considered as sources of capital services in government production and hence as candidates for a return on capital. For most practical purposes, this would limit the scope of government assets for which a net return is estimated, to produced assets (including inventories) plus land associated with structures used by government. In concept of course, all non-financial assets that are used in production by government are within the scope of assets for which a value of capital services could be computed, at least for analytical purposes. The next two sub-sections discuss in greater detail the options for calculating a rate of return for government, depending on the detail and extent of the available empirical information.

16.3.1. Full information on rates of return for the market and the household sector available

The first data point for an estimate of the net return to government assets is the net stock of the relevant assets or more generally, the time series of investment in the various assets. In principle – though not always in practice – this information is a prerequisite to the calculation of depreciation on government assets which has been in place in the national accounts for some time.

Although it could be argued that an industry-specific real rate of return should be used for government assets, it is simpler to employ a single real rate of return r^{G,t^*}. This can be justified by an opportunity cost argument (investment by the private sector or consumption by households would not necessarily have been in the same type of asset as the government investment – see Section 8.3). Given the required information, the government rate of return is then measured as a weighted average of the rates of return of the market sector $r^{t^*}$and of the household sector r^{H,t^*}. θ is a longer-term or trend value of the market sector's share in the total value of assets between the market and the household sector.

$$r^{G,t^*}=\theta r^{t^*} + (1-\theta)r^{H,t^*} \tag{27}$$

How the real rate of return to the market sector can be derived has been described above. If the market sector is further broken down, for example into financial and non-financial corporations or if there is a cross-classification by industry, the rate of return to the market sector is a weighted average of the rates of return by sub-sector or by industry.

The household real rate of return r^{H,t^*} is best chosen so as to correspond to the explicit or implicit rate of return associated with owner-occupied housing.[6] In the absence of such information, the social rate of time preference (see below) constitutes a practicable alternative. The return to government assets is then measured as the real rate of return r^{G,t^*}

applied to the average net stock of government assets, valued at beginning of the period prices, $\Sigma_{i=1}{}^{N}P_0{}^{i,tB}W^{i,t}$. For consistency with the set-up for the market sector, we maintain the term $(1+\rho^t)$ whose precise form results from the assumption that benefits from using the assets accrue at the end of the accounting period (see Section 19.1). Finally, the total user cost of government capital is given by the sum of the return to capital minus real holding gains plus depreciation $D^{G,t}$. If real holding gains/losses are neglected, the simplified measure for the total value of capital services from government-owned assets is:

$$U^{G,t*} = (1+\rho^t)\, r^{H,t*}\sum_{k=1}^{N} P_0{}^{k,tB}W^{k,t} + D^{G,t} \qquad (28)$$

16.3.2. Financing costs

An alternative to combining market sector and household returns to obtain a rate of return for the government sector is to consider financing costs of government projects. Under an ex-ante approach, the expected return to investment would then equal the expected costs of financing and could, for example, be captured by borrowing rates for government as apparent in government bonds. To generate expected rates, it may be appropriate to use a smoothed series of government bond rates of different maturities where the latter could be chosen in accordance with the structure of government assets.

16.3.3. Social rate of time preference as the government rate of return

When the national accounts do not directly provide information on market and household rates of return, a practicable possibility is to identify the government rate of return with the household rate of return and measure the latter as the social rate of time preference (SRTP). The theoretical background for the SRTP or consumption rate of interest has been elaborated by Marglin (1963), Feldstein (1964, 1965), Kula (1984) although the broader issue of discounting has been the source of much debate in economics (Ramsey 1928). Today, it is a well-established formula to determine discount rates for government projects – see, for example OXERA (2002) or HM Treasury (2003). Despite variations to the theme, the SRTP – which has the nature of a real rate - typically comprises the following basic components:

$$SRTP = (1+g)^e(1/\Pi^w)-1 \qquad (29)$$

In this expression,

- g is the trend growth in real per capita household consumption. Without dwelling on theory too long, the idea is that the rate of substitution between the present and the future in a society can be approximated by the ratio of consumption between two periods or more generally, by the trend rate of growth of private consumption over long periods. For the United Kingdom, for example, this rate is around 2% over long periods.
- e captures the elasticity of marginal utility of consumption, *i.e.* it indicates the percentage change in utility from an additional percent of consumption. The classic source of estimates of e is Stern (1977). Estimates of e can be derived econometrically and there is a broad range of outcomes in the various studies. OXERA (2002) review the various empirical results and discuss their plausibility. The overall conclusion is that a value of 0.5 to 1.2 seems reasonable.
- Π is the survival probability of an individual – it captures the risk that an individual in society is not able to benefit from future returns on an investment. Π is measured by one minus the ratio of deaths over population. Conceptually, Π is supposed to capture a ‘rate

of pure time-discounting' – a concept whose discussion goes back to Jevons (1871). More recently, some authors, *e.g.* Evans and Sezer (2002), have suggested to weight Π by a coefficient that reflects the degree of 'selfishness' of present generations vis-à-vis future generations. For example, measured as Πw, w = 0 would imply no selfishness at all, w = 1 is no consideration for future generations and w = 0.5 an intermediate value. As will be shown below, sensitivity of the SRTP with respect to w is low and w = 0.5 constitutes a plausible value.

Table 16.1. **Social rate of time preference for OECD countries**

	Consumption per capita	Survival probability	Social rate of time preference					
			w=0.5	w=1	w=0.5	w=1	w=0.5	w=1
	g		e=1	e=1	e=0.5	e=0.5	e=1.2	e=1.2
Australia	1.99%	0.99261	2.4%	2.7%	1.4%	2.4%	1.9%	2.9%
Austria	2.21%	0.98890	2.8%	3.4%	1.7%	2.8%	2.5%	3.6%
Belgium	2.05%	0.98894	2.6%	3.2%	1.6%	2.6%	2.4%	3.4%
Canada	1.74%	0.99286	2.1%	2.5%	1.2%	2.1%	1.7%	2.6%
Denmark	1.64%	0.98901	2.2%	2.8%	1.4%	2.2%	2.2%	3.0%
Finland	2.31%	0.99050	2.8%	3.3%	1.6%	2.8%	2.3%	3.5%
France	1.93%	0.99033	2.4%	2.9%	1.5%	2.4%	2.1%	3.1%
Germany	1.99%	0.98879	2.6%	3.1%	1.6%	2.6%	2.4%	3.4%
Greece	2.61%	0.99085	3.1%	3.6%	1.8%	3.1%	2.4%	3.7%
Iceland	3.05%	0.99330	3.4%	3.7%	1.9%	3.4%	2.3%	3.9%
Ireland	2.81%	0.99069	3.3%	3.8%	1.9%	3.3%	2.5%	4.0%
Italy	2.07%	0.99029	2.6%	3.1%	1.5%	2.6%	2.2%	3.3%
Japan	2.50%	0.99322	2.8%	3.2%	1.6%	2.8%	2.1%	3.3%
Luxembourg	2.68%	0.98962	3.2%	3.8%	1.9%	3.2%	2.6%	4.0%
Netherlands	1.73%	0.99150	2.2%	2.6%	1.3%	2.2%	1.9%	2.8%
New Zealand	1.28%	0.99223	1.7%	2.1%	1.0%	1.7%	1.6%	2.2%
Norway	2.55%	0.98985	3.1%	3.6%	1.8%	3.1%	2.5%	3.8%
Portugal	2.91%	0.98978	3.4%	4.0%	2.0%	3.4%	2.7%	4.2%
Spain	2.61%	0.99156	3.0%	3.5%	1.7%	3.0%	2.3%	3.7%
Sweden	1.30%	0.98922	1.9%	2.4%	1.2%	1.9%	2.0%	2.6%
Switzerland	1.12%	0.99100	1.6%	2.0%	1.0%	1.6%	1.7%	2.2%
Turkey	1.78%	0.99127	2.2%	2.7%	1.3%	2.2%	2.0%	2.9%
United Kingdom	2.28%	0.98870	2.9%	3.4%	1.7%	2.9%	2.5%	3.7%
United States	1.96%	0.99135	2.4%	2.8%	1.4%	2.4%	2.0%	3.0%
Average	2.1%	0.99068	2.6%	3.1%	1.5%	2.6%	2.2%	3.3%

Source: OECD Annual National Accounts, OECD Population Statistics and author's calculations.

In Table , we take a look at how the SRTP turns out empirically for OECD countries. We compute the trend rate of per capita consumption for the period 1970-2005, shown as the rate g in the second column. On average, the rate is around 2%, albeit with some variation across countries. The third column shows the average survival probability for the same 35 years, computed as the ratio of the number of deaths over the population. Finally, six parameter combinations for the committal to future generations (w) and for the elasticity of utility with regard to consumption (e) are used for the computation of the SRTP. Based on the literature w = 0.5 and e = 1 is our preferred parameter combination. It generates an average SRTP of 2.6% for the countries under consideration. Given the comparatively light data requirements, SRTPs should also be measurable for countries with less developed statistical systems than the OECD countries.

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Moore, Boardman, Vining, Weimer and Greenberg (2004) review the various methods to arrive at a social rate of time preference and provide clear guidance, depending on whether a project is intra-generational (less than 50 years) or inter-generational (50 years or more), and depending on whether a project is likely to crowd out private investment or not. With some further differentiation not mentioned here, they end up with recommended central estimate of 3.5 percent where 2.0 percent is given as a lower and 5.0 percent as an upper bound.

Notes

1. This requires an exogenous rate of return for unincorporated businesses; otherwise one runs into an issue of simultaneity: in the case of an endogenous rate calculation, the capital share of mixed income is an input to the computation of the rate of return. Thus, the latter cannot be used to needed to compute the capital share first.
2. Note that there is one particular asset, land, for which it is always recommended to set real holding gains to zero or to some long-run value rather than using the ex-post movements of real land prices. The reason – further discussed in Section 18.1 – is that land markets are often subject to bubbles and bursts which, by definition, incorporate an element of irrational behaviour but also risk-taking on the side of economic actors. The standard equilibrium condition which predicates that the price of an asset reflects the discounted value of future benefits from using the asset, is unlikely to hold on such markets and expectations in a context of speculative behaviour are nearly impossible to gauge on the basis of *ex-post* observations. Thus, there are both practical and conceptual reasons to stay away from estimating asset-specific expected holding gains in the case of land.
3. The nominal rate of return with the complete asset ase is negative in the case of Japan during the 1990s. This reflects the specific situation during this period with declining land prices and deflationary expectations and as such this result has an analytical use. But it is more difficult to interpret a negative rate of return in the context of user costs, *i.e.* as a component in the price that a user-owner computes when deciding on whether or not to use the asset in production.
4. In a volume index of combined labour and capital inputs, labour and capital shares are used to approximate the output elasticities of labour and capital that characterise the production process. Output elasticities show the percentage increase in output if a particular input rises by one percent. See Balk (1998) for a rigorous presentation of input quantity indices and see OECD (2001a) for a discussion of input indices for productivity measurement.
5. An interesting theoretical reasoning comes from Oulton (2007) who proposes that the volume index of capital services should be constructed using ex ante user cost shares, *i.e.* the weight for each asset should be the ex ante user cost of that asset, as a share of the total of all ex ante user costs. Oulten arrives at this conclusion by starting from his a target measure – the true ex post value of the marginal product. In practice, true ex post shares are not observed but they can be estimated by the ex ante method. In particular, he shows that ex ante and true ex post shares are exactly equal when the production function is CES and approximately equal in more general cases as well. A helpful implication from an accounting perspective is that although each asset's user cost share is the ex-ante share, the level of capital compensation is the ex-ante unit user cost adjusted by the ratio between total ex-post and ex-ante capital compensation. So the returns to each type of asset add up to ex post capital income. Hence there would be no residual. Note, however, Oulton's method requires that there are no unobserved assets and that production is characterised by constant returns to scale.
6. See Section 8.3 for a discussion of concepts – more on the practice of measuring owner-occupied dwellings is discussed in Section 18.1.2.

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Chapter 17

Aggregation Across Assets and Industries

17.1. Aggregation across assets

To this point, most of the discussion has been conducted with reference to a single (type of) asset. Many concepts are indeed best conveyed in this manner but aggregation plays an important role in how the concepts of productive stock, capital services, net stock and capital composition translate into measurement.

The single most important point in this context is that it is the process of aggregation that essentially shapes the difference between capital services and the net or wealth capital stock. At the level of individual assets, the productive stock may differ from the net capital stock but not necessarily so. The most important case where the two measures coincide is in the presence of constant, geometric rates of depreciation which imply the same rates of efficiency decline and hence identity between productive and net stock at the asset level. However, for all types of age-efficiency and age-price profiles, when the productive stock is multiplied through by an expression for unit user costs, a difference arises between the value of the net stock and the value of capital services. This difference carries through in the aggregation across types of assets, because aggregation weights differ in the two cases.

For a measure of wealth, a natural way of valuing assets is with their market price, taking into account that older assets normally fetch a lower price than new assets. For a measure of capital services, assets should be valued with the user costs that they generate during a period. The user cost shares of an asset will be relatively higher than its share in wealth if an asset is short lived (high rates of depreciation make it more costly than a long-lived asset) and/or if its market price rises less quickly or falls more rapidly than the average price level of capital goods. High user cost shares are often found with assets that undergo quick technical change, implying a short service life and falling market prices due to obsolescence.

It should be underlined that most of the analytical value of measures of the productive stock does not lie in the level of the stock as such but in its rate of change because this rate of change constitutes the volume index of capital services that is in turn the analytical objective for measures of capital input and productivity. Aggregation itself should be in line with the formulae used in the national accounts, typically chain index number formulae – either of the Laspeyres or of the Fisher type. Generally, superlative[1] index number formulae such as the Fisher ideal index are to be preferred to other formulae but this has to be weighed against the requirement of consistency with the index number formulae used in the national accounts.

These ideas are best described by way of the numerical example in Table below. Two assets are shown, “trucks” and “computers” along with their wealth stock and productive stock at prices of a reference year. To keep simple, and as would be the case for geometric age-price and age-efficiency profiles, the productive and wealth stock for each asset has the same value. Values of each stock, expressed in prices of year 0, are shown for each product and for both years in the first line of the table. The price index of (new) trucks rises by 5%, while that of computers falls by 5%. Thus, the wealth stock for trucks in year 1, valued at prices of year 1, amounts to 105 currency units and the wealth stock for computers to 114 currency units. The fourth line in the first panel shows each asset's share in total wealth at prices of the corresponding year – between the two years, the share of trucks declines, and that of computers rises. The Laspeyres volume index of the wealth stock rises by 10%, the Paasche index rises by 9.5% and the Fisher index by 9.7%.

Table 17.1. **Aggregation across assets – numerical example**

		Trucks		Computers	
		Year 0	Year 1	Year 0	Year 1
Wealth stock at prices of year 0		100	100	100	120
Price index of new asset		1	1.05	1	0.95
Wealth stock at prices of each year		100	105	100	114
Share in total wealth		50.0%	47.9%	50.0%	52.1%
Laspeyres volume index	1.100				
Paasche volume index	1.095				
Fisher volume index	1.097				
Productive stock at prices of year 0		100	100	100	120
Real rate of return	0.04				
Rate of depreciation		0.15	0.15	0.3	0.3
Capital service price (unit user cost)		0.19	0.20	0.34	0.32
Value of capital services		19.00	19.95	34.00	38.76
User cost share		35.8%	34.0%	64.2%	66.0%
Laspeyres volume index	1.128				
Paasche volume index	1.124				
Fisher volume index	1.126				

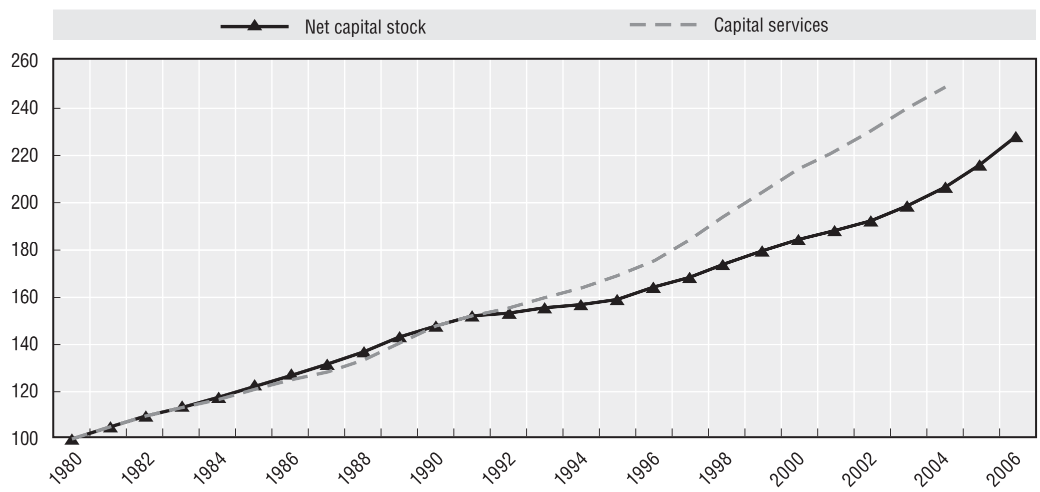
Next, turn to the productive stock. Some more information is needed to construct a user cost measure for each asset: assuming a real rate of return of 4% and depreciation rates of 15% for trucks and 30% for computers, a capital service price is calculated by multiplying the price index of new assets by the sum of the real rate of return and depreciation. As the price index for capital goods equals one in the reference year 0, the price of capital services equals 1*(0.04+0.15)=0.19 for trucks and 1*(0.04+0.30)=0.34 for computers.[2] Multiplication of this capital service price the productive stock, also measured in prices of year 0, yields the total value of capital services for each asset – 0.19*100=19.0 currency units in the case of trucks in year 0, and 0.34*100=34.0 currency units in the case of computers.

A similar calculation is carried out for year 1. For trucks, the price of capital services is now 1.05*(0.04+0.15)=0.199 and for computers one gets 0.95*(0.04+0.30)=0.323. The value of capital services for each asset is again derived by multiplying the capital services price by the volume of the capital stocks: 0.199*100=19.9 in the case of trucks and 0.323*120=38.75 in the case of computers. With prices and volumes for both assets at hand, a Laspeyres volume index of capital services can be computed as the user-cost weighted average of the volume change of each asset's productive stock. It turns out to be 12.8%, quite a bit higher than the volume change of the wealth stock. The same holds for the other index number formulae. This stylised difference, a faster growth of capital services than of the wealth stock, can frequently be observed in practice. It occurs when short-lived assets, due to falling relative prices, occupy an increasing share in the structure of capital inputs.

Although the volume of capital services is the conceptually correct way to measure the quantity of capital input into production rather than the volume change in the net stock, there is analytical value in considering both indices for analysis. Jorgenson (1995) was the first to construct an index of "capital quality" by comparing the volume change of capital services and the volume change of the net stock. This is best understood as an index of compositional change of capital input. In the above example, the index of compositional change would be measured as the ratio between the Fisher volume index of capital services and the Fisher volume index of the net stock, *i.e.* as 1.126/1.097=1.0259 or about 2.6%. A rise in this index would signal a compositional shift towards capital goods with relatively high unit user costs and hence relatively high marginal productivity per period – for example, a computer needs to generate significant marginal returns, to cover rapid depreciation and obsolescence charges.

Such a rise in the index of compositional change is, for example borne out by the series in Figure below which shows an index of capital services and an index of the net capital stock for Australia's market sector. The divergence between the two measures has been visible since the beginning of the 1990 and it reflects a compositional shift in Australian investment towards more short-lived capital goods with higher-than-average rates of depreciation.

Figure 17.1. **Net capital stock and capital services in the Australian market sector**



Source: Australian Bureau of Statistics and OECD calculations based on ABS data.

17.2. Aggregation across industries

Data permitting, the analysis of capital measures at the industry level can be of significant interest. In an ideal dataset, industry-level information will be cross-classified by major institutional sector (corporations, households, government) and aggregation can proceed in three steps:

- For every industry/sector combination, aggregate capital measures across assets as described in the preceding section;
- For every sector, aggregate capital measures across industries, by sector. This gives rise to capital measures by institutional sector – broadly speaking, market producers, households and government.
- Alternatively, aggregate capital measures across sectors, by industry. This gives rise to capital measures by industry.

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- For the economy as a whole, aggregate capital measures across sectors or across industries.

The three-step aggregation procedure is a general way of going about the construction of total economy aggregates. It is more general than a single step aggregation technique to moves directly from assets to the economy as a whole or to the market sector as a whole. The reason is that first aggregating to the industry level keeps industries as the building blocks and permits, implicitly that the same factors are remunerated differently across industries. This can be due to market imperfections, adjustment costs that vary across industries or industry-specific risk of operations calling for different expected rates of return to capital. Theory would also suggest that differences in user costs and rates of return across industries have to be taken into account. These can be brought about by many factors – tax wedges, asset composition.

A direct aggregation procedure that omits the industry dimension implicitly assumes that a particular type of asset gets the same remuneration wherever it is used in the economy. One could also say that by treating the economy or the sector as a single industry, one assumes that all markets "internal" to this big firm work smoothly and efficiently. There is, however, a theoretical justification for proceeding like this. Jorgenson, Ho and Stiroh (2005) show that the one-step aggregation procedure corresponds to specifying a "production possibility frontier". The production possibility frontier describes how capital, labour and productivity interact and grow under efficient market conditions. The authors then use the one-step procedure as a benchmark and compare results with a multiple-step aggregation procedure. They interpret differences as "reallocation" effects. For example, reallocation effects appear when the aggregate volume of capital input changes simply because capital shifts between industries and generates different marginal products, depending on where it is used. Thus, both the single-step and the multiple step procedure are analytically meaningful, in particular when both are applied and compared to each other. The single-step procedure has value as a reference or benchmark for capital and productivity growth under functioning markets, the multiple-step procedure is useful in describing the actual state of capital accumulation and productivity growth.

Jorgenson, Ho and Stiroh (2005), Oulton (2007) and Baldwin and Gu (2007) find that the reallocation of capital services across industries has a significant effect on the aggregate capital service growth. The main reason is that industries with high rates of return tend to have high growth rates of capital services and capital stock. For example, Baldwin and Gu (2007) find that the reallocation effect accounts for about 10% of capital services growth in the business sector of the Canadian economy over the 1981 to 2001 period.

In practice, a fully developed dataset may not be available. Also, the distinction between market and non-market producers is sometimes difficult to draw, specifically in industries such as education and health services where both types of producers operate. A simplified approach consists in combining all industries that are dominated by market producers into the "market sector", possibly with the exception of the real estate industry where provision of owner-occupied housing should be separately identified as production by households. The government sector would then be identified with public administration and defence (ISIC category L) and other community, social and personal services (ISIC category O).

Notes

1. "Superlative" index numbers were developed as part of the economic approach to index numbers. Under this approach, the microeconomic theory of producers or consumers serves as a rationale for choosing between index numbers. Diewert (1976) introduced the notion of "flexible aggregators". These are functional forms that provide a second-order approximation to an arbitrary, twice differentiable linear homogenous function. Flexible aggregators can be interpreted as functional forms that cover a wide range of utility, production, distance, cost or revenue functions. Furthermore, Diewert calls index numbers "exact" when they can be directly derived from a particular flexible aggregator. For example, the Törnqvist index is exact for the translog flexible functional form – a widely used specification in empirical economics. Thus, if one accepts a translog form as an approximation to a production function, and uses standard assumptions about producer behaviour, the Törnqvist quantity index provides an exact formulation for inputs and outputs. An index that is exact for a flexible functional form is called "superlative". A similar reasoning applies for the Fisher ideal index which also qualifies as a superlative index number formula. For a full discussion see Diewert in: ILO *et al.* (2004).
2. The price of capital services (or unit user cost of capital) is the current dollar value of capital services per constant (year 0) dollar of the productive stock. Its dimension is thus current dollars over dollars of a reference year.

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Chapter 18

Special Issues in Capital Measurement

18.1. Land and dwellings

The SNA, in its asset classification, distinguishes between dwellings and other buildings and structures as part of produced assets and land as a non-produced asset. Other buildings and structures are, in turn broken down into non-residential buildings, other structures and land improvement. Although land is a non-produced asset, it is well established in the economic literature as a factor of production and therefore as an asset that provides a flow of capital services into production.

> *"It is not only produced assets which are used in production. The first and oldest recognised form of non-produced capital is land. Land is special in that under good management, the value is assumed to remain constant from year to year except for the effects of inflation in land prices. That is to say, there is no depreciation of land and all the contribution to production can be regarded as income. […] It may seem slightly odd to think of a non-produced asset contributing a "service" since in national accounts services are always produced. This is simply a reflection of the words chosen by economists to describe the contribution of capital to production without connecting the word 'service' to the specific interpretation given to it in the SNA. Similarly one may hear compensation of employees described as the cost of labour services." (2008 SNA, forthcoming).*

In the discussion about capital measurement, land and dwellings deserve special attention because:

- Special measurement problems arise because it is often not possible to separate the value of land from the value of structures on it. However, such a separation is needed because structures depreciate but land does not;
- Residential and non-residential structures have long service lives and the corresponding investment series needed to implement the perpetual inventory method may not be available. Stocks of structures may then have to be estimated on the basis of physical information on the stock of dwellings, land registers etc. which involves additional statistical uncertainty, in particular when it comes to valuing the stock of land and buildings;
- Markets of land may be subject to bubbles in the price of assets. Such phenomena are at odds with the relatively simple equilibrium theory underlying the capital services model and may therefore invalidate standard methods to estimate the value and the volume of capital services for these assets;
- Owner-occupied housing is an important non-market activity of household production. Capital services and user cost measures are one way of estimating the value of this production and can significantly alter the level and growth rates of GDP;
- Price indices for residential and non-residential houses are notoriously difficult to develop and yet much of the quality of valuation of capital services from land and structures depends on the quality of available price indices;

- More generally, the measurement of capital services from land and structures affects three singularly important economic variables: GDP, capital input and the consumer price index and a consistent approach towards these measures is desirable.

For practical purposes, only land under structures and buildings and cultivated land should be considered a source of capital services.

18.1.1. Measuring and valuing the stock of land

Land is not a homogenous asset and land prices can develop at very different rates, depending on the use of land and depending on geographical location. The classification for non-produced asset distinguishes between four types of land:

- Natural land under buildings and structures and associated surface water;
- Natural land under cultivation and associated surface water;
- Natural recreational land and associated surface water;
- Other natural land and associated surface water.

For many statistical purposes it will be useful to keep these categories apart because price developments will typically differ between the categories and because not all types of land are necessarily sources of capital services. It would seem clear that land under buildings and structures and land under cultivation are sources of capital services – there is an apparent input into production as defined in the national accounts. The extent to which this applies to recreational and other natural land is not clear. For most practical purposes it would thus appear that only land under building and structures and cultivated land should be considered sources of capital services.

Land registers provide a natural starting point to measure the quantities of different land categories. A much more difficult issue is the valuation of land and construction of a price index for each type of land. For residential land, one way of approaching valuation is by using information on sales of dwellings (comprising both structures and land beneath) with information on structures only to derive land values residually (see box for an example from Australia). A similar, residual approach towards estimating a time series of the price of residential land has been adopted by Davis and Heathcote (2004) for the United States.

Information on the price and quantity of structures and buildings without land is often more readily available when data on the stock of dwellings uses the perpetual inventory method with investment series for structures and buildings from the national accounts. Investment surveys on construction permit relatively easy collection of information on the value of structures excluding land.

Valuing stocks of land is also problematic when land prices vary significantly between locations and applying an 'average' price of land seems liable to significant bias. A first step towards capturing regional differences in land prices is a minimum stratification to differentiate between areas with the largest differences in land prices, such as urban versus rural areas. Blades (2006) points out that estimates of the average ratio of the value of land to the average value of dwellings (excluding land) can sometimes be obtained from sources such as real estate agents or official records of land values. Some countries may be able to borrow ratios estimated from neighbouring countries which have similar population densities and housing structures.

Box 18.1. **Valuing land and dwellings owned by households in Australia**

A new method put in place for the valuation of land and dwellings owned by Australian households started out with a comparison of different sources for the combined value of land and dwellings. For this purpose, ABS compared three sources in terms of the overall and the mean dwelling value for 2004:

- The Survey of Income and Housing with household reports on the value of properties, comprising both structures and land (mean dwelling value $ 299 000);
- Estimates by the Reserve Bank of Australia, which are derived by applying average sales prices from private contractors to the number of dwellings as registered in the ABS Census of Population and Housing (mean dwelling value $ 335 000);
- Estimates from the national accounts with detailed information on the stock of housing from the 1991 Census of Population and Houses (mean dwelling value $ 349 000).

The comparison showed that the two independent estimates from the Reserve Bank of Australia and from the Survey of Income and Housing are broadly in line with each other. ABS then adopted the Reserve Bank estimate of the combined value of residential land and dwellings.

Estimates of the value of land held by sectors other than the household sector are estimated residually by the ABS by deducting the estimate of residential land and dwellings held by households from the aggregate estimate of the value of residential land and dwellings estimated by the Reserve Bank.

This new method has resulted in a revision of the level and sector allocation of the value of land and dwellings as shown in the table below. All numbers are in billions of Australian dollars and relate to June 2005.

	Non-financial corp.	Financial corp.	Government	Households
Dwellings				
old estimate	44.6	--	3.7	1038.9
new estimate	44.1	--	3.6	1038.5
Residential land				
old estimate	83.4	--	--	1437.7
new estimate	179.1	--	10.8	1683.0
Commercial land				
old estimate	32.4	22.3	--	138.7
new estimate	138.4	24.4	--	40.7
Rural and other land				
old estimate	16.7	--	133.2	192.2
new estimate	16.6	--	133.2	191.4

Source: Australian Bureau of Statistics (2006).

18.1.2. User costs of land

Having established that land is a source of capital services, the question arises how to go about measuring the user costs for land and the structures on it. We shall restrict the discussion to residential dwellings and the associated land because most of the points carry over to non-residential structures and the land underneath as well as to land under cultivation. Also, residential dwellings play an important role by their sheer size but also because owner-occupied dwellings have a double nature: they constitute a source of capital

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services and they are the most important occurrence of production by households. This raises an issue of consistency when measures of capital services on the input side of the economy are based on a user cost approach and when the output of dwelling services provided by households is estimated with a different approach, such as the rental equivalent approach, more of which below.

Because land is a non-produced asset, there is no depreciation element in its user costs. User costs of land are thus composed of two elements: the real return to capital and real holding gains or losses. However, land is special insofar as land markets, in particular for residential land, are not free from speculative bubbles, which raises a conceptual and a measurement challenge when it comes to assessing the price and volume of capital services from land.

Land prices are regularly subject to speculative bubbles. The simple equilibrium approach towards asset valuation cannot handle such a situation very well.

Box 18.2. **Valuing land in Canada**

In Canada, the value of land is measured for three types of land.

Agricultural land (declining proportionally over time) – This is the value of all privately-owned agricultural land, and is supplied by Agriculture Division at Statistics Canada. Annual data on the capital value of farms are based on the decennial census, the quinquennial census and intercensal projections. The latter are based on transactions data supplemented by annual farm surveys.

The value of buildings (and depreciation thereon) is calculated as a portion of total farm capital (land plus buildings excluding inventory). Therefore, farmland is calculated as a residual. However, given land's relative size in overall farm capital any measurement errors associated with this process of estimation are relatively small.

Quarterly estimates of agricultural land are linear interpolations of annual estimates. To the extent that these reflect booms and busts in agricultural products and product prices, and that agricultural production cycles are largely annual in nature, this method for deriving quarterly estimates is deemed acceptable.

Agricultural census data on whether farm businesses are incorporated or unincorporated are also used to calculate the sector estimates of agricultural land.

Land surrounding residential structures (largest component of land, increasing proportionally with a housing boom over most of the last 5 years) – This comprises land surrounding various types of residential structures owned in the sectors of the economy, including: single family dwellings and multiple dwellings, including doubles, row houses and apartments.

Estimates are derived by applying land-to-structure ratios (LSR). LSR are calculated by looking at new building activity by type (singles or multiples) across the country. This includes regional estimates further broken down into census metropolitan areas (CMAs). The new activity consists of selecting three key details of all units sold in a year, of which the first two are: Building permit values (BPV) and absorption price value (APV). APV is the sale value of the total residential real estate unit. Building permit values are adjusted for under-reporting in the national accounts and this same adjustment factor is applied to the BPM for this exercise.

LSR = (APV-BPV)/BPV.

Box 18.2. **Valuing land in Canada** *(cont.)*

The third key detail is the physical address of the unit completed and sold. This allows for identification of whether a unit is in a suburban area of a major city (the vast majority of new units) or in the urban centres (very limited amount of infill). LSR are always higher in urban core areas, and a further adjustment is made to the L/S to account for the higher depreciation of older buildings in urban core areas. Census weights are then used to aggregate the LSR over CMAs and by region, such that an economy-wide LSR for singles and multiples are derived to apply to the estimates of residential housing stock.

This methodology provides estimates of land that vary by type of structure, by urban and suburban areas and by regions of the country. This approach is labour-intensive and APV come in with a delay, such that this detailed methodology is typically 3-4 years behind the current data, such that LSR are projected using a set of current indicators of real estate activity and prices. Nevertheless, reliability has not proven to be a problematic issue. These same current indicators, supplemented by quarterly real estate transfer costs, are used to develop quarterly LSR.

Sector estimates are based on the sector composition of singles and multiples using the LSR. The bulk of residential land is allocated to households.

Household sector macro estimates of residential real estate (structures plus land) are very close to the independently-derived household asset-debt survey aggregated micro data estimates.

Land surrounding non-residential structures – This is the value of all commercial type land – that is, land other than residential or agricultural – owned in the sectors of the economy. Estimates exist for this category of land for incorporated business, unincorporated business and government (as well as non-profit institutions included in each of these sectors). This includes land surrounding both buildings and engineering structures.

Estimates are derived by applying land-to-structure ratios. These ratios were developed by looking at industry breakdowns for land and structures in the enterprise surveys at Statistics Canada. Industries where commercial structures are prevalent were used to derive LSR for commercial buildings. These are cross-referenced to commercial real estate indicators as part of establishing an annual growth rate pattern. In addition, quarterly LSR estimates are derived using these same indicators supplemented by transfer costs. Industries where engineering structures are prevalent were used to derive LSR for engineering structures. LSR are relatively lower for engineering structures, and quarterly patterns are linear interpolations.

Source: Statistics Canada (2007), direct communication to the OECD.

Consider the conceptual issues first. We start by referring back to a statement about *ex-ante* rates of return: cost-minimising producers will tend to use assets in such proportions that the expected risk-adjusted return is the same for all types of assets. To this point, this *Manual* has said very little about risk except that one justification for differences in the *ex-ante* rate of return between industries was that there may be differences in risk between industries. For most assets inside a particular industry, it is harder to argue why they should be subject to differences in risk. Land, however, would seem to constitute one exception here that justifies introducing an asset-specific risk premium. Nomura (2004) and Jorgenson and Nomura (2005) computed and imputed a risk premium for land in their user cost calculations for Japan. Such estimates can, for example be based on the Capital Asset Pricing Model or similar techniques. Inserted into the user

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cost formula, they will tend to reduce the problem of negative user costs that may arise in the presence of rapidly rising asset prices. However, estimation techniques remain relatively sophisticated and may not always be easily replicable.

There is a second conceptual issue associated with land and bubble markets. A fundamental relationship in the valuation of assets is the net present value condition – the price of an asset equals the discounted streams of the net benefit from use in production that it generates. This equilibrium relationship may not hold any more in the presence of asset bubbles: by definition, when there are speculative bubbles, asset prices and expectations about asset prices are driven by more or less rational expectations, and not by the expected flow of capital services of the asset. The implication is that user cost shares of assets which incorporate expected speculative holding gains, are unlikely to present a good approximation to the elasticity of total capital services with regard to the asset under consideration so that the measure of the overall flow of capital services may be distorted in such a case.

The empirical issue is just as difficult to deal with: what is a reasonable expectation of an asset price change in the presence of speculative bubbles? Can prices be predicted in such a situation? The answer is almost certainly 'no', in particular when it comes to finding a simple way of putting a value to expected price changes. Steep upward movements in land prices that are simply extrapolated from past observations will tend to generate negative user cost expressions unless an explicit risk premium is considered as described above.

In sum, both conceptual and practical considerations lead us to suggest that, if there is no possibility to estimate a land-specific risk premium, the expected real holding gains and losses for land should be set to equal zero when user costs for land are calculated – and this is true whether endogenous, mixed or exogenous methods are applied to estimate the rate of return.

A very important application of user cost measures is in the context of imputing values to the production of households that are owners and occupiers of dwellings. The value of owner-occupied dwellings and its development over time is important as a component of the national accounts and for many countries as a component of the consumer price index, although owner-occupied housing is often valued with other methods than the user cost method.[1] In particular, many countries use a "rental equivalent" approach whereby the stock of dwellings is divided up into different strata of dwellings of similar quality and location, and where the actual rents paid for dwelling services in each stratum are used to measure the average rent per dwelling. These average rents are then multiplied by the number of owner-occupied dwellings in the stratum to yield a figure for the production value of owner-occupiers of dwellings.

However, there are cases when the rental equivalent approach cannot be applied. For example, in many developing and transition countries, the share or rented dwellings is low and the share of owner-occupied dwellings is high and rents will often be an unreliable guide to the value of owner-occupied housing.[2] Then, the user cost approach constitutes a useful alternative and has been applied in a number of EU countries and in Iceland (Gudnason 2004).

For owner-occupied dwellings, user costs are best computed in two parts: user costs for structures and user costs for the land beneath the structures. The two components can then be combined to yield values of dwelling services (by adding up the component values), and temporal indices of the prices of dwelling services (by constructing an index of the user cost prices of the components between two periods) as well as volume indices of dwelling services (by constructing an index of the volume changes in stocks of the components between two

Box 18.3. **Measuring the user costs of dwellings in Argentina**

Coremberg (2000, 2004) uses a hedonic approach to value the dwelling stock for Argentina. He proceeds in several steps:

- Starting point is detailed information on the stock of housing from the 1991 Census of Population and Houses (*Censo nacional de poblacion y vivienda*) with data on the number of dwellings cross-classified by several characteristics, in particular type, location, size as well as some quality attributes.
- The second source of information is the 1996 National Survey of Household Expenditure on Rentals (*Encuesta nacional de gasto de los hoagares*) which provides rental prices by characteristics of dwellings.
- An adjustment is made to the rental prices to account for the survival probability of dwellings, *i.e.* for the fact that the survey only reports on rentals in dwellings that still exist whereas zero rents on assets that have disappeared do not appear in the sample.
- A hedonic function is estimated by regressing the observed rentals from the survey on the attributes of the dwellings, including their age. The regression coefficients of the dwelling characteristics represent their marginal valuation on the rental market.
- With the hedonic regression coefficients, rental values could be attached to the stock of dwellings from the 1991 Census. Summing up across rental values yields the estimate of the value of the housing services produced by owner-occupiers.
- Coremberg then goes on to estimate the user cost price of different groups of dwellings by dividing the value of rentals (estimated with the method described above) by the current value of the dwelling stock. In other words, he assumes that the value of user costs for each type of dwelling equals the value of rental equivalents. This ensures full consistency between the national accounts values for the production of dwelling services by owner occupiers and the capital services measure for purposes of productivity calculations.

Note that in applying this method, Coremberg estimates an implicit rate of return to owner-occupiers of dwellings. Having combined the results for dwellings with other capital goods, Coremberg estimates the overall endogenous ex-post rate of return to capital in Argentina and compares the results with an external rate of return on the financial market (interest rate for foreign currency loans for 90 days commercial papers) to assess the opportunity costs of investing in Argentina and to carry out a plausibility check for the endogenous rate of return. His internal rate of return for the period 1990-2000 varies between 12.2% and 15.5%, depending on the form of the depreciation pattern. The exogenous rate for comparison was at 13.4%. This is a plausible result.

periods). The user cost expression for land has a fairly simple form because there is no depreciation component and, if one follows the conclusion above, real holding gains and losses are set to zero. More explicitly, if $U^{L,t}$ is the user cost of land under a dwelling and $U^{S,t}$ is the user cost of the structure, and $U^{D,t}$ is the user cost for the dwelling and land combined, then one has the following expressions for their computation, assuming geometric depreciation rates for structures and following the notation used throughout this *Manual*:

$$U^{L,t} = (1+\rho^t)r^{t^*}P_0^{L,tB}\, W^{L,t} \qquad (30)$$

$$U^{S,t} = [(1+\rho^t)(r^{t^*} - i^{S,t^*})P_0^{S,tB} + P_0^{S,t}\,\delta^S]W^{S,t}$$

$$U^{D,t} = U^{L,t} + U^{S,t}.$$

It is well-known that the price and volume measures of dwelling services can differ depending on whether computations are based on the rental equivalent or on the user cost method. For example, Verbrugge (2006) examines the respective movements of rents and user costs from a consumer price perspective and finds very large differences in trends and in amplitude of their movements. To some extent, such differences reflect the economic reality of transaction costs (it is costly to assess tenants, to conclude and to terminate a contract), as well as market imperfections. In addition, such comparisons often do not use the simplified user cost formula for land (30) but reflect year-to-year changes in (expected) asset prices and year-to-year *ex-post* changes in rates of return. This may be one reason for the discrepancies between resulting measures. Heston and Nakamura (2007) also provide evidence that even over housing cycles, user costs do not approximate market rents well.

Diewert (2006b) comments this point as follows:

"[…] it is unlikely that landlords use econometric forecasts of housing price appreciation one year away and adjust rents for their tenants every year based on these forecasts. Tenants do not like tremendous volatility in their rents and any landlord that attempted to set such volatile rents would soon have very high vacancy rates on his or her properties. It is, however, possible that landlords may have some idea of the long run average rate of property inflation for the type of property that they manage and this long run average annual rate of price appreciation could be inserted into the user cost formula.

Looking at the opportunity costs of owning a house from the viewpoint of an owner occupier, the relevant time horizon to consider for working out an annualized average rate of expected price appreciation is the expected time that the owner expects to use the dwelling before reselling it. This time horizon is typically some number between 6 and 12 years so again, it does not seem appropriate to stick annual forecasts of expected price inflation into the user cost formula. Once we use annualized forecasts of expected price inflation over longer time horizons, the volatility in the ex ante user cost formula will vanish or at least be much diminished."

Diewert (2006b) then goes on and makes the following suggestion:

"[…] perhaps the 'correct' opportunity cost of housing for an owner occupier is not his or her internal user cost but the maximum of the internal user cost and what the property could rent for on the rental market. After all, the concept of opportunity cost is supposed to represent the maximum sacrifice that one makes in order to consume or use some object and so the above point would seem to follow. If this point of view is accepted, then at certain points in the property cycle, user costs would replace market rents as the "correct" pricing concept for owner occupied housing, which would dramatically affect Consumer Price Indexes and the conduct of monetary policy."

To date, this suggestion has not been tested and is therefore not a recommendation put forward by this *Manual*. However, the argument is conceptually valid and fits in with the broader notion of user costs as opportunity costs of owner-users of capital goods. Research should be undertaken to provide more evidence and discussion of Diewert's proposal.

18.2. Inventories

18.2.1. Inventories as sources of capital services

Inventories are produced but no fixed assets and they play a double role in the national accounts. First, inventories or rather the change in inventories are a component of demand. As one of the more volatile components of GDP, inventory change tends to be an important determinant of short-term variations in GDP growth and there are a number of conceptual and empirical issues associated with the measurement of nominal and real

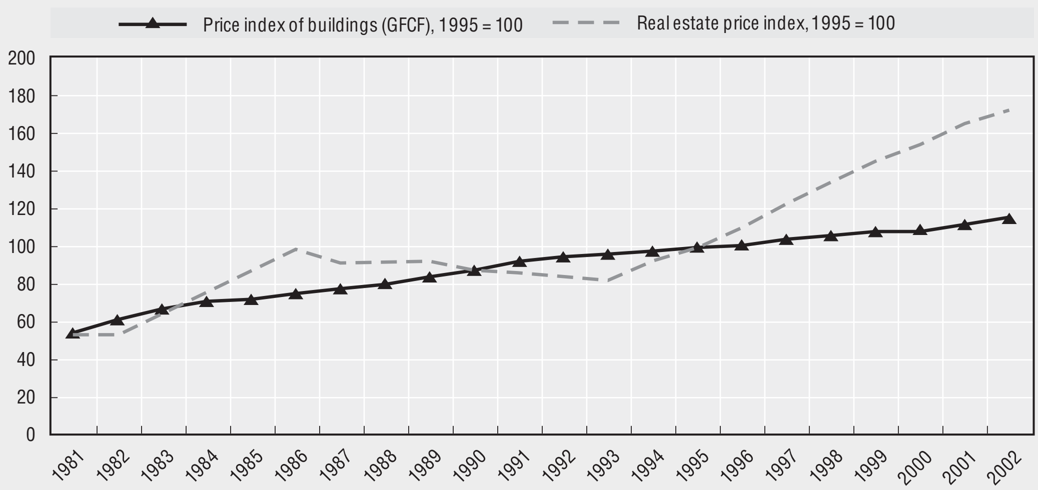
Box 18.4. **Valuation of structures in Denmark**

A key factor in PIM estimations of the net stock at current prices is price indices. Often price indices for *new assets* (GFCF) are used to determine the price development for *existing assets* in the stock. However, this could be problematic, as the following example from Denmark shows.

At Statistics Denmark, the method for estimating the value of fixed capital for buildings is to adopt the accumulated costs involved in construction of buildings (GFCF) as basis, and subsequently write down the value over time to reflect ordinary wear and tear and technical obsolescence (consumption of fixed capital). Similarly, a revaluation takes place, due to price changes. The changes in prices are measured by the changes in acquisition prices of *new assets*.

An issue arises, however, when the so-computed values of buildings are combined with information based on a different statistical source: in connection with the development of balance sheets, Statistics Denmark calculates the value of land at market prices. This is done by subtracting the value of buildings from the combined real estate value (buildings and land) on the basis of observed market prices for properties actually traded.

During the recession in the late 1980s, real estate prices declined whereas acquisition prices for new buildings increased as shown in the figure below. In the PIM estimations of the net stock of buildings, it was assumed that the prices of existing buildings (for a given age) followed the prices of new buildings which increased steadily. With decreasing prices for real estate and increasing prices for buildings, the residual – the value of land – declined. However, the decrease was so large that the value of land becomes negative for some years during the recession. A negative value for land is not an economically meaningful result.



Note: Price indices for real estate are calculated on the basis of all traded properties in a given year, while price indices of buildings comprise the entire stock of buildings. Although there may be some composition effects, it is indisputable that the price development for real properties and buildings move differently over time.

One possible reason behind the problem with negative values for land may lie in the PIM valuation of existing buildings and the use of price indices for new assets. If prices for real properties are declining for a longer period of time, it is not necessarily credible to assume that prices for existing buildings follow the path of increasing construction prices for new buildings. One explanation may lie in heterogeneity of buildings – new dwellings may have different characteristics from those real estates that have been transacted on the market. Consequently, the price index for new buildings may not be representative for price movements of the housing stock as a whole. Another reason for the apparent over-valuation of existing structures may lie in the depreciation patterns and service lives employed in the PIM.

Box 18.4. **Valuation of structures in Denmark** *(cont.)*

A way forward would be to use asset prices from the second-hand market, combined with quality characteristics of transacted real estate. This could help identifying price movements, improve the quality of depreciation rates and deal to a certain degree with the heterogeneity of properties transacted. The resulting information could then be used in the PIM. This is a very difficult task, but might be necessary if reliable and consistent estimates for the value of buildings, land and real properties should be produced. The problem with different development in prices for new and existing assets may in principle apply for all kind of fixed assets even though the problem is most likely more pronounced for assets that are rather heterogeneous, that have long service lives, and where there are well-established second-hand markets.

changes in inventories. For example, there has been a debate how to derive annual measures of inventory change from monthly or quarterly measures. And there are different ways of dealing with holding gains and losses. Second, and more recently, inventories have also been recognized as assets that provide capital services. Consequently, they should be within the scope of assets that are considered for the measurement of prices and volumes of capital services. There are again several theoretical and practical issues. The discussion in this section will mainly deal with inventories as sources of capital services. But of course these questions cannot be isolated from the issues that arise when it comes to measuring inventory change as a demand component.

According to the SNA, inventories comprise *(i) materials and supplies* that are held in stock with the intention of using them as intermediate inputs in production; *(ii) finished goods*, *i.e.* outputs awaiting sale by the producer; *(iii) goods purchased for resale* by retailers and wholesalers; *(iv) work in progress*, *i.e.* output that is not yet finished, and includes cultivated assets. Harrison and Aspden (2005) mention a fifth category, strategic reserves.

Do inventories provide capital services? While it is generally agreed that inventories constitute a form of capital, the question about whether inventories provide capital services merits closer inspection. We shall consider the different types of inventories in turn: *(i)* materials and supplies are held in stock with a view to ensuring a smooth production process – the capital service they deliver is thus the security of supply of inputs into production. Costs for these services include the opportunity costs of money invested in the goods stored as well as the direct costs of storage; *(ii)* finished goods: a stock of finished goods provides security of supply of outputs from production so that producers can deal with demand that varies over time. A similar point can be made for *(iii)* goods for resale – an adequate stock of goods purchased by retailers and wholesalers is needed to ensure that distribution services can be provided by these industries. Finally, *(iv)* work in progress: if the production process is broken down into small steps one can think of the inventory of work in progress at the beginning of each step as an input into the production process of the next step, providing a capital service.[3]

The reasoning above was based on planned or voluntary holding of inventories. There is an argument that inventories that are held involuntarily, such as finished goods piling up due to an unexpected drop in demand, do not provide capital services. This is a valid point albeit one that is not restricted to inventories as under-utilisation of fixed assets will often also be involuntarily. However, given the empirical difficulties of isolating voluntary and involuntary holdings of inventories, it would be unrealistic to recommend a different treatment. As it appears reasonable to assume that on average the major part of inventories is planned, it has been recommended for practical purposes to treat capital services for inventories as a whole, without excluding inventories that are held involuntarily.

18.2.2. Measuring inventories

The stock of inventories, as all other assets recorded in a balance sheet, should be valued at the prices prevailing on the dates to which the balance sheet relates. Transactions involving inventories are, in principle, also treated in the same way as transactions involving any other asset, *i.e.* at the prices at the times they take place. More precisely, goods entering inventory should be valued at the basic average price of the accounting period during which they are added to stocks and goods withdrawn from inventory should be valued at basic average prices of the accounting period during which they are withdrawn. Then, the value of a change in the inventory within a specific accounting period is given by the difference between additions and withdrawals from inventories, corrected for any recurrent losses. A consequence of this calculation is that the value of changes in inventories does not reflect holding gains or losses that enterprises undergo while holding the inventory.[4]

Unless records are kept of the quantities of goods entering and leaving inventories and their prices at those times, it is not possible to measure the value of changes in inventories directly. Many countries measure inventory changes using the "quantity method", based on the differencing of inventory stocks at the beginning and at the end of the accounting period. The 1993 SNA (paragraph 6.68) notes on this method:

> *"This method, which may be described as the 'quantity' measure, is widely used in practice and is sometimes mistakenly considered to be the theoretically appropriate measure under all circumstances. The quantity measure will be the same, or virtually the same, as the perpetual inventory method not only when prices are constant but also when the quantities of goods held in inventory rise or fall at a steady pace throughout the period. Conversely, the conditions under which the quantity measure may provide only a poor approximation to the PIM are when prices are rising or falling and when inventory levels fluctuate within the accounting period."*

Despite its potential shortcomings, the quantity method is widely used. The typical sequence for the calculation of inventory changes is as follows. First, information about closing and opening inventory levels is obtained from businesses. As businesses' book values do not normally reflect inventory at the time of opening or closing balance sheet, these book values have to be adjusted and then deflated to yield constant price estimates that can be differenced. Deflation is typically carried out using producer price indices for the major industries concerned (manufacturing industries, wholesale and retail services).

Given inventory levels at (constant) prices of a reference period for the beginning and for the end of the accounting period under consideration, the constant price change in inventories is obtained by differencing stocks at the beginning and at the end of the period, and by subtracting losses of goods. Differencing is done at the most detailed level possible, and in a final step, the changes in inventories expressed at current prices are obtained by valuing each component change of inventories by the average price level of the period under consideration.

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A problem that arises in this context, and which has been stressed by Diewert (2005c) is that standard index number techniques break down when applied to values that can be either positive or negative as would be the case with inventory changes. More specifically, when the volume aggregate of changes in inventory that is derived by the quantity method as specified above is divided into the corresponding value aggregate, meaningless implicit price indices can arise. Diewert proposes to separately apply index number formulae to opening and closing stocks (which by definition take non-negative values only). Only in a next step of aggregation, along with other demand components, would opening and closing stocks be brought together. While the advantage of this procedure is to have meaningful implicit price indices for each component of inventory change (opening and closing stock), the disadvantage is a somewhat unusual presentation.

Having briefly discussed some of the issues involved with the estimation of changes in inventories, we can now turn to the measurement of capital services from inventories. On a purely conceptual basis, there is at least one particularity with capital services. Although an inventory of a particular type of goods is treated as if it were a stock of one particular asset, it is in fact a perpetually renewed flow of more or less identical goods that constitute the stock of inventory. It is hard to see how, even in theory, a distinction could be made between the age-price and the age-efficiency profile of a stock of inventories. The notion of age itself is difficult to capture in the case of inventories unless one reasons in terms of average turnover of inventories or the speed at which an inventory is being renewed. In light of this difficulty, the distinction between the wealth stock and the productive stock of a particular type of inventory is not useful and will therefore be neglected for all practical purposes.

Several other empirical issues arise. It is apparent that the perpetual inventory method as used for many other types of assets is not normally used for inventories because opening and closing stocks of capital services are usually obtained directly from enterprise surveys. Further, the standard user cost formula can be applied to inventory services and turns out to be relatively simple, in particular when depreciation is ignored. If depreciation is positive, it has to correspond to the recurrent losses or leakages from inventories.

Using the standard notation for the present *Manual*, and ignoring depreciation, the value of capital services for a particular type of inventory k during period t, $U^{I,k,t}$ would be computed as:

$$\begin{aligned} U^{I,k,t} &= r_{(tB)}\, P_0^{k,tB}\, [I^{k,t}/2 + W^{k,tB}] - i^k_{(tB)} P_0^{k,tB} W^{k,t} \\ &= r_{(tB)}\, P_0^{k,tB}\, [(W^{k,tB} - W^{k,tE})/2 + W^{k,tB}] - i^k_{(tB)} P_0^{k,tB} W^{k,t} \\ &= P_0^{k,tB}\, [r_{(tB)} - i^k_{(tB)}] W^{k,t} \end{aligned} \qquad (31)$$

In the expression above, the "quantity" formula for the measurement of inventory change has been applied to measure $I^t=[W^{tB}-W^{tE}]$ as the difference between opening and closing balance. The value of user costs is then measured as the nominal rate of return minus the price change of inventory multiplied by the price of the beginning of the period P_0^{tB} and the average inventory in period t, $W^{k,t}$. Unlike for the measurement of changes in inventories where aggregation across types of inventories poses problems when some volumes are negative, this issue does not arise in the context of capital services measurement because only average stocks but not their change enter the picture.[5]

The discussion of inventories and the capital services associated with them has glossed over many difficulties that arise in implementation, in particular when it comes to quarterly measures of inventory change and their relation to annual measures. For a discussion, the reader is referred to Bloem, Dippelsman and Maehle (2001), Reinsdorf and Ribarsky (2007) and Eheman (2005).

18.3. Natural resources other than land

In addition to land, natural assets include subsoil assets such as oil reserves, non-cultivated biological resources such as natural forests and water resources such as aquifers. Depending on countries' economic structure, these assets may play more or less important roles in the composition of wealth and in the contribution to capital services. The domain of natural resources constitutes also a major link to the area of environmental accounting. How this link can be established and how natural resources should be valued and measured is dealt with at some detail in the 2003 International *Handbook on Integrated Environmental and Economic Accounting* (United Nations *et al.* 2003) to which the reader is referred. We note, however, that this 2003 Handbook is presently being revised by the London Group on Environmental Accounting to whose work the reader is referred for future developments.[6] This section will therefore only spell out a limited number of points associated with natural resources.

Terminology. Capital formation occurs only in conjunction with produced assets. The corresponding items for non-produced assets in the SNA balance sheets are "economic appearance" (*e.g.*, proven discoveries of oil fields), and 'natural growth of non-cultivated biological resources' (*e.g.*, natural growth of stock of wild fish). They constitute additions to the stock of assets. Conversely, there may be an economic disappearance, as well as 'catastrophic losses', for example if natural forest is destroyed by a storm. 'Depletion' is the item for natural resources that corresponds to 'consumption of fixed capital' or 'depreciation' for produced assets. Prices and volumes of capital services exist for all types of assets used in production. The value of capital services for natural resources has also been called 'resource rent'.

Capital services. Natural resources used in production are sources of capital services and the total gross income accruing to capital (gross operating surplus plus the capital part of gross mixed income) can be allocated across different assets, including natural resources. How this is done has been discussed earlier, in particular in Section 16.1.3. Figure 18.1 below shows diagrammatically the relationship between the treatment of produced assets and non-produced, non-financial assets, *i.e.* mainly natural resources. The Figure distinguishes capital services from produced assets from capital services from natural resources and other non-produced, non-financial assets. It shows that total capital income can be allocated between these broad types of assets in a symmetric fashion. It should be noted that the figure reflects an *ex-ante* version of capital services measures. An *ex-post*, endogenousversion exists as well in which case there would be no residual profits or losses, but in all probability a more volatile resource rent. Also, in a simplified version, the (expected) real revaluation of assets could be set to equal zero as discussed in Chapter 16.

Valuation of stocks. The principles for asset valuation in the SNA equally apply to produced and non-produced assets. If at all possible, market prices are to be used. Often, market prices do not exist for natural resources and the net present value of future benefits accruing from holding or using the asset constitutes the next best solution towards putting a balance sheet value to the asset. Note, however, that such an approach requires, among other things, information about the expected flow of resource rents, *i.e.* of the value of capital services derived from the asset. The conditions

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of an existing contract between the owner of an oil field (e.g., government) and the corporation who exploits it could constitute such a source of information on resource rents. The Handbook on Integrated Environmental and Economic Accounting spells out a number of empirical methods for the valuation of the stocks of mineral and energy resources, cultivated and non-cultivated biological resources, land and water (United Nations *et al.* 2003).

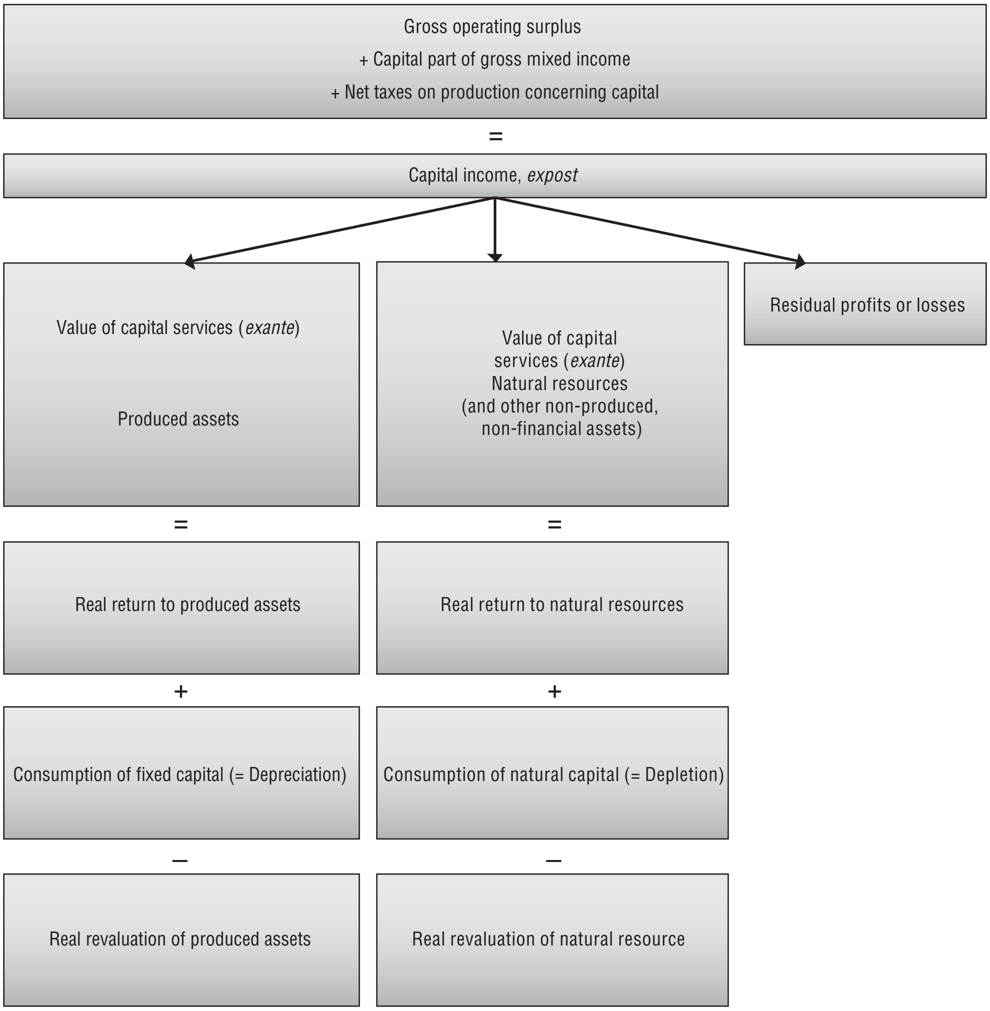
In practice, things are more complicated. One difficulty arises with the estimate and valuation of the stock of subsoil assets. Of those OECD countries that presently estimate subsoil assets (Canada, Korea, Mexico, Netherlands, Norway and the United Kingdom) five use the net present value method to derive a stock measure of subsoil assets. In the present *Manual*, the net present value relationship or asset price equilibrium condition has figured prominently as a theoretical starting point for deriving consistent expressions of user cost prices, age-price and age-efficiency patterns. However, the net present value condition has not normally been used to value assets – at least new asset prices are directly observable from investment goods markets and need not be estimated. This is different for subsoil assets. Typically, there is no market price for oil fields or coal reserves. The price for *extracted* oil or *extracted* coal is not applicable because it relates to a different good. What is required is the value of oil or coal *before* extraction. The net present value relationship constitutes one avenue towards estimating the value of the undeveloped subsoil asset. It consists of discounting an expected stream of net benefits that the asset will provide to its owner.

For example, in the Netherlands (see Veldhuizen, Graveland, van den Bergen and Schenau 2008), the net present value method is used to discount expected future incomes, which are based on a physical extraction scenario and an expected resource rent from oil and gas assets. The resource rent is calculated as the gross operating surplus less the user cost of capital other than sub-soil assets in the industry 'extraction of crude petroleum and natural gas'. Compared to the approach shown in Figure 18.1, the Dutch calculation for the value of capital services from natural resources is thus an *ex-post* approach. There is no residual profit or loss above and beyond the value of capital services for produced assets and for natural resources. A 3-year moving average is used to estimate the expected unit resource rent. The future income flow is calculated by multiplying projected yearly physical extractions with the expected income per unit of the reserves. Meaningful and fully consistent measure of the capital services from oil and gas reserves, and robust estimates of the value of oil and gas stocks are not easily guaranteed under this method as the Dutch experience shows.

To deal with the uncertainty involved in estimating values of subsoil assets, Canada employs several methods, the net present value method and the net price method. In addition, there are two alternative computations under the net price method: one with no return to capital and one with a 4.25% rate of return. The net price method values the stock of sub-soil assets by correcting the price of the resource out of the ground for the value of extraction services, typically in form of the costs of extraction, development and exploration.

To summarise, the valuation of subsoil assets, the consistent measurement of resource rents and capital services is still fraught with a number of conceptual but mainly empirical difficulties. It will be important to advance on these issues nationally and internationally.

Figure 18.1. **Capital income, produced assets and natural resources**



18.4. Taxation and user costs

Taxes and subsidies enter capital measurement in several ways. A first occurrence is in the context of determining the value of capital services; a second occurrence is in the context of determining the unit cost of capital and the after-tax rate of return. As a general principle for the treatment taxes and subsidies in conjunction with the measurement of capital services, a perspective of the owner or owner-user of the capital good should be applied. How this principle is applied to the two main instances in which taxes come into play is described in the present section.

18.4.1. Taxes and the value of capital services

Gross value added for a particular industry or for a particular sector comprises the following elements:[7]

- Compensation of employees (comprising wages and salaries and employers' social contributions);
- Other taxes on production;
- Other subsidies on production;

- Gross operating surplus (for incorporated enterprises);
- Gross mixed income (for unincorporated enterprises owned by households).

Gross operating surplus and gross mixed income are residual items, obtained after deducting compensation of employees, and net taxes on production from value-added. They measure the surplus or deficit accruing from production before taking account of interest, rent or similar charges. 'Other' taxes on production consist mainly of taxes on the ownership or use of land, buildings or other assets used in production or on the labour employed, or compensation of employees paid.[8] Other subsidies on production are payments receivable on the same items. When the components of 'other' taxes and subsidies on production are known, it is in principle possible to identify those components that relate to labour as an input into production (e.g., payroll taxes) and those components that relate to capital (e.g., property taxes). Those parts of other net taxes that cannot be allocated to either a capital asset or to labour have to be distributed according to a simple rule, for example in proportion to asset shares.

The total payments that a corporation has to hand out to labour are then the compensation of employees plus the part of net taxes on production that concerns labour. Similarly, total income to capital in a corporation is gross operating surplus plus those parts of net taxes on production that concern capital. For unincorporated enterprises owned by households, gross mixed income must also be split into a labour and a capital component. Thus, the ex-post income[9] to capital *before taxes* is the sum of gross operating surplus, the capital part of gross mixed income and the capital part of other net taxes on production. This is the required producer perspective because in hiring capital or labour, the relevant taxes on production are factored in by the producer.

User cost measures follow a producer perspective. Thus, taxes on inputs should be part of the cost of inputs. For the same reason, taxes on products which concern a firm's output are excluded from measures of output. In national accounts terms, output is valued at basic prices and inputs are valued at purchasers' prices

Another issue in conjunction with taxes on production needs mentioning here. According to the 1993 SNA, taxes on production comprise taxes on products and other taxes on production. The SNA specifies further that:

> *…in the generation of income account, taxes on imports are recorded only at the level of the total economy as they are not payable out of the values added of domestic producers. Moreover, at the level of an individual institutional unit or sector, only those taxes on products that have not been deducted from the value of output of that unit or sector need to be recorded under 'uses' in the generation of income account (paragraph 7.52) In consequence, no product taxes or subsidies on outputs that are to be recorded as payables or receivables in the producer's generation of income account when value added is measured at basic prices. It follows that the item 'taxes less subsidies on production' refers only to other taxes or subsidies on production (paragraph 7.7).*

These citations explain why, at the level of individual industries or sectors, only other net taxes on production figure as a component of value added and only the relevant capital part of those should be considered capital income. At the level of the total economy, all taxes and subsidies on production show up as a component of value added. To measure capital income at the level of the total economy, consistency should be preserved with the measures of capital income at the industry level. Thus, at the level of the total economy as well, taxes on products should not be included in capital income.

18.4.2. Taxes and the price of capital services

Tax parameters play also a part when it comes to refining the measures for the price of capital services. From an analytical perspective, it is helpful to understand the impact of different taxes on the level and on the structure of the prices of capital services. Typically, different types of taxes are not neutral with regard to the type of ownership of capital goods (when, for example, corporations are taxed differently from unincorporated businesses or households), the industry in which capital goods are used (when there are special fiscal provisions by type of economic activity) and the type of asset concerned (when, for example, there are provisions for accelerated depreciation for certain types of assets). Taxes may thus drive a wedge between relative prices of different types of capital services. Such differences affect producers and as the objective of measuring capital services prices is to emulate as closely as possible the price signals that capital owners/ users receive, the consideration of tax parameters in unit user cost measures has analytical importance. The theoretical framework and the first full implementation of tax-adjusted user costs go back to Christensen and Jorgenson (1969) who provided evidence for the United States. A recent comprehensive study of taxes and their effects on user costs and investment is Jorgenson and Yun (2001).

Before delving further into the tax adjustment of the price of capital services, a few general points should be considered:

- Full-sized implementation of tax-adjusted unit user costs requires information on tax parameters that is cross-classified by industry, asset and institutional sector. For example, income-related taxes are typically differentiated by institutional unit but not by industry. Thus, to construct consistent tax-adjusted measures of user costs by industry, there has to be information about the composition of the industry capital in terms of institutional units. In practice, cross-classified investment and capital data for industries and sectors is not easily available. Also, property income in an industry has to be split between income of the corporate sector, income of unincorporated enterprises owned by households (which implies splitting mixed income by industry) and, possibly other institutional units such as non-profit organisations.
- Tax codes are complex, and fiscal rules vary between countries, sometimes within countries, between groups of individuals, and over time. Adjustment of user costs for tax parameters are therefore more often approximations than exact representations of the tax structures. This is not necessarily a problem because the purpose of tax-adjustment of capital services prices is to bring out the quantitatively most important aspects of taxes or subsidies that may affect the cost of capital input, and after-tax rates of return. By way of example, two parameters will be discussed below: tax rates on capital and profit tax rates for corporations. We shall leave aside the interaction between taxes on household income and taxes on corporate profits because this interaction requires knowledge about financial structures and dividend policies of corporations.[10]

With the above remarks in mind, we turn to the measurement of the effective tax rate on capital for a corporation. In Section 18.4.1 it had been established that, for an industry as a whole, the *ex-post* income accruing to capital, before taxes, is measured as gross operating surplus, including the capital part of gross mixed income (G^t) plus those net taxes on production that relate to capital ($T_K{}^t$). When it comes to tax adjustment, corporate producers have to be considered separately from other institutional units, for example households. For the presentation at hand, we focus on corporate producers. Consequently,

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mixed income can be ignored and G^t stands for gross operating surplus only. In Section 16.1 a description was provided how *ex-post*, endogenous rates of return are computed without regard to taxes and for simplicity, the formula is repeated here:

$$G^t+T_K{}^t = \sum_{k=1}^N P_0{}^{k,tB}(1+\rho^t)\,[r^{t*} + \delta_0{}^k(1+i^{k,t*}) - i^{k;t*}]K^{k,t} \tag{32}$$

The real rate of return r^{t^*} is a rate of return *before* taxes. When tax parameters are explicitly recognized in the user cost calculation, the resulting rate of return will be an *after tax* rate of return. For many analytical purposes, such an after tax rate is more interesting than a rate before tax. To compute this tax adjusted real rate of return ($r_a{}^{t^*}$), the above formula is adjusted for tax parameters, and three[11] of them will be used here: the effective rate of taxes on capital inputs ($t_K{}^{k,t}$), the effective rate of taxes on corporate profits ($t_P{}^t$) and the present value of tax-related depreciation ($z^{k,t}$). The tax rate on capital inputs and the depreciation parameter can be specific to a particular asset and have therefore received a superscript 'k'. The tax rate on capital inputs is expressed as a percentage of the value of the productive stock of asset k, $K^{K,t}$ although other formulations are possible:

$$G^t + T_K{}^t = \sum_{k=1}^N [(1-z^{k,t}t_p{}^t)/(1-t_p{}^t)]\{P_0{}^{k,tB}(1+r_t)\,[r_a{}^{t^*} + d^k(1+i^{k,t^*}) \tag{33}$$

$$- i^{k;t^*}]K_{k,t}\} + S_{k=1}{}^N\, t_K{}^{k,t}P_0{}^{k,t}K^{k,t}$$

To solve this expression for the after tax rate of return $r_a{}^{t^*}$ it is necessary to know the effective tax rates $t_K{}^{k,t}$ and $t_P{}^t$ and the value of $z^{k,t}$. To compute the fist parameter, the total payment of "other taxes on production" that concerns a particular capital input k ($T_K{}^{k,t}$) is divided[12] by the value of the productive stock of this particular asset: $t_P{}^{k,t} = T_K{}^{k,t}/(P_0{}^{k,t}K^{k,t})$.

For the income tax parameter $t_P{}^t$, additional information is required on the total payments for corporate profit taxes which we shall label $T_P{}^t$. Given the total amount of corporate profit taxes, the average effective tax rate on corporate profits is total taxes on corporate profits divided by the tax base which has been defined here as gross operating surplus minus taxes on capital minus tax-relevant depreciation. Note that in general, tax-relevant depreciation is not identical with the depreciation or consumption of fixed capital as this *Manual* has defined it for the purpose of capital measurement. Tax-relevant depreciation reflects the prescriptions in the tax code that specifies the annual amount deductible from pre-tax income. For the capital services price, the time pattern of tax-relevant depreciation is captured by the parameter $z^{k,t}$ which reflects the present value of forthcoming tax-relevant depreciation that reduces the tax base. The theoretical basis for this treatment goes back to Hall and Jorgenson (1967).

Akin to the treatment of corporate capital incomes, tax parameters can be introduced into user cost expressions for unincorporated businesses. In this case, the capital part of gross mixed income plays the role of G^t and income taxes on property income payable by households play the role of corporate profit taxes $T_P{}^t$.

Another word of caution is in place with regard to introducing tax parameters into the user cost expression. When interpreting for example effective profit tax rates for corporations, it has to be kept in mind that income taxes of corporations are typically assessed on the total incomes of corporations from all sources and not simply profits generated by production. Similarly, taxes on incomes of households are levied on the total declared or presumed income from all source of the household concerned: compensation of employees, property income, pensions etc. – this affects the effective marginal and average tax rates on property income.

While of significant analytical value, there is some evidence to suggest that the effect on capital services estimates of introducing tax parameters into user cost estimation is small. Baldwin and Gu (2007) find that the effect of ignoring taxes in capital services estimates is small for both endogenous rate and exogenous rate methods, particularly for the endogenous rate method.

To summarise this section on taxation: whereas it is important and relatively straight forward to deal with other taxes on production and allocate them to labour and capital, introducing income and depreciation-related tax parameters into the user cost expressions is a more complex undertaking. While of significant analytical interest, their implementation requires institutional knowledge and statistical information on a country's tax system.

18.5. Used assets

The fact that GFCF involves transactions in used assets, which are valued at less than the prices of new assets, causes problems for capital stock estimates. Suppose, for example, that enterprise A sells a used asset to enterprise B. Enterprise A will report the sale of the asset at its current market value and not at the "as new" price which is required for valuation of the gross capital stock. This means that the GFCF reported by Enterprise A (its acquisitions less disposals of assets) will be too large for use in the PIM because its disposals are valued at (low) market prices instead of at (high) "as new" prices. At the same time, Enterprise B will report its acquisition of the used asset from A at the current market price which is lower than the "as new" price required for the gross capital stock. B's reported GFCF (its acquisitions less disposals) will be too small for use in the PIM.

The errors caused by the way that A and B report transactions in a used asset will cancel out if the records for the two enterprises are consolidated because the overstatement of A's reported GFCF is exactly matched by the understatement in B's reported GFCF. There are, however, circumstances in which there will be no compensating errors of this kind:

- Capital stock statistics need to be classified by institutional sector and by kind of activity. If transactions in used assets occur between units that are classified to different institutional sectors or kinds of activities, errors will be introduced into the sector or activity distribution of the capital stock.
- Second, used assets may move into and out of the domestic economy via imports and exports. If a used asset is imported, the acquisition will be recorded at the current market value of the asset and GFCF will be understated for PIM purposes. If a used asset is exported, the disposal will be valued at current market value and GFCF will be overstated for PIM purposes. In neither case are there any offsetting errors because the other partners to the transactions are outside the domestic economy.
- Finally, used assets may move from productive to non-productive uses. In particular, they may move between the government or corporate sectors and the household sector. Perhaps the commonest example is the sale of used vehicles by car-hire companies to households. In this case there is no offsetting entry to the overstatement of GFCF by the car-hire companies because the purchase of the used cars by households does not count as capital formation.

How important are the errors that may be introduced into the gross stock estimates because of transactions in used assets? And what can be done about them?

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As regards errors in the distribution of the stock by sector and activity, the size of the problem depends partly on the degree of detail in the sector or activity breakdowns that are used. This suggests that countries should be modest in the amount of activity detail given in their stock estimates, at least in the initial stages of developing these statistics. The importance of the problem also depends on the extent to which assets can be used in different industries. Most plant and machinery is industry-specific but buildings may often move between sectors and activities. A shop may become a bank, a factory may be used for different types of manufacturing or a railway station may become a museum. In order to make corrections for movements of assets between sectors and activities it is necessary to identify transactions in used assets separately from transactions in new assets.

Imports and exports of used assets may be quite significant for some countries but they do not cause problems additional to those mentioned above. Whether a producer sells a used asset to another domestic producer or to abroad, all that is required is to identify the sale as that of a used asset and make whatever upward adjustment is required to the disposal value. Similarly, if a producer purchases a used asset from abroad, exactly the same kind of adjustment is required as when the asset is acquired from a domestic source.

As regards movement of assets from producers to households, it seems likely that in many countries, the only significant transactions are in used vehicles sold by producers to households, although exports of used cars may be sizeable in some countries. When the latter is not the case, a reasonable assumption is that all sales of used passenger cars by producers are to households. Provided that sales of used cars can be identified in the records of producers it is possible to adjust disposal values to "as new" prices and eliminate this source of error.

18.6. Users and owners of capital assets

When assets are leased or rented, owners and users of assets may be in different units. Payments in conjunction with the use of non-produced, non-financial assets – mainly land and sub-soil assets – are labelled 'rents' in the national accounts whereas payments for the use of produced assets are called 'rentals'. The different labels correspond to different treatments in the national accounts. The act of renting out land or sub-soil assets is not in itself considered production. Rents paid are considered property income allocated to the owners of the resource after production. Thus, capital services for land and sub-soil assets should be registered in the generation of income account of the user of the asset, not of the owner. Gross operating surplus of the user will include the return on the resource which is then passed on to the asset owner.

"Rentals" is the label for payments received in conjunction with *operating leases*. Here, the renting concerns produced assets that are put at the disposal of the user for relatively short periods of time and where the owner of the asset retains responsibility for maintenance and repair. The act of providing an operating lease is considered production in which the asset owner provides a service to the asset user in return for a 'rental' payment. In the case of an operating lease, assets should in principle be classified with their owners and this is also where capital services should be registered.

Operating leases have to be distinguished from *financial leases*. A financial lease is a contract where the risks and reward of ownership are de facto transferred from the legal owner to the user of the asset. A financial lease is a form of financing, and an alternative to financial lending. In contrast to operating leasing, and akin to the renting out of land and sub-soil assets, financial leasing is not itself considered a process of production. Here the user is considered to be the economic owner of the asset and the consequence is that the asset and the ensuing capital services should be registered with the user, not with the legal owner of the asset.

In practice there are many types of leases and it is often difficult to decide whether a given leasing arrangement belongs in the operational or financial categories. It has therefore been suggested that for analytical purposes such as productivity measurement it may be useful to classify *all* assets according to the kind of activity of the *user* of the asset, without attempting to distinguish between operational leases on the one hand and financial leases and rents of land and sub-soil assets on the other hand. This is certainly a pragmatic way forward.

It should be noted, however, that when all assets are classified by user, data cannot always be related to other flows in the national accounts when these are compiled on an ownership basis. In particular, for operational leases, the distribution of value added among different kinds of activities depends on asset ownership rather than on asset use. If assets are rented on an operational lease, the income generated by the asset appears in the value added of the owner and not that of the user. This is because the rental payment is deducted as intermediate consumption from the gross output of the user and appears in the gross output of the owner. Thus, the computation of capital services on a user basis without correcting the flows of intermediate inputs for the payments to asset owners will give rise to biased cost shares of capital. As discussed earlier, an operational lease is a purchase of intermediate inputs – capital services – and should be treated as such. If assets are rented on a financial lease, both ownership and use are recorded in the using industry, and no particular problem arises.

The above argument hinges of course on the availability of reliable information on the capital services flows between lessors and lessees who are transactors in the operational lease. This cannot always be taken for granted and may therefore bring us back to an exclusive classification of assets according to the industry of the user if the bias so incurred would seem less important than the bias due to the inconsistency between value-added and capital input mentioned earlier.

Notes

1. For an overview of the methods used in the consumer price index, see ILO *et al.* (2004), Chapter 23.
2. A case in point was central European accession countries to the European Union or countries in the Western Balkans.
3. This links in with "Austrian" or "Neo-Austrian" views of production as formulated by Hicks (1973): "Like Böhm-Bawerk (or Hayek) I think of general productive process as being composed of a number (presumably a large number) of separable elementary processes. […] we shall use an elementary process that converts a sequence (or stream) of inputs into a sequence of outputs." (pp. 5). Hicks then treats capital goods as intermediate inputs into an elementary process.
4. There are exceptions: (expected) increases in the (real) value of goods that are deliberately held in storage such as crops or wine are recognised as a value of production, not holding gains (see Aspden and Harrison 2005 for a discussion).
5. See Diewert (2005a) for a comprehensive approach towards measuring capital services from inventories and changes in inventories.
6. See *http://unstats.un.org/unsd/envaccounting/londongroup/*.
7. In the national accounts, these items are shown in the generation of income account.

8. System of National Accounts 1993, paragraph 7.49.
9. In this general formulation, *ex-post* income to capital can have two components: a remuneration of capital services which corresponds to the value of capital services plus a residual component in the form of pure profits or losses that arise as the consequence of un-anticipated events. *Ex-ante*, the expected or normal income of capital would correspond to the value of capital services. See also the discussion on ex-ante and ex-post rates of return in this *Manual*.
10. This interaction was first dealt with by Hall (1981).
11. It was already mentioned that more elaborate treatments of the tax system are possible and useful but such an exposition would go beyond the scope of this *Manual* and the reader is referred to the specialized literature, in particular Jorgenson and Yun (2001).
12. This operation implies that $T_K{}^t = \Sigma t_K{}^{i,t} W^{i,t}$ and the term $T_K{}^t$ can be dropped from the left hand side of equation) and $= \Sigma t_K{}^{i,t} W^{i,t}$ from the right hand side. This does not make the computation of $t_K{}^{i,t}$ redundant because the unit user cost of any particular type of asset still contains this asset-specific tax parameter.

PART III

Capital Stocks and Capital Services – Theory

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Chapter 19

The Model

The purpose of this chapter is to present, at some detail, the formal model behind capital measures. Although theoretical, this presentation is targeted towards implementation, *i.e.* it takes account of issues such as valuation of flows at mid-period prices that are relevant for national accounts and which sometimes complicate an algebraic presentation. At the same time, these considerations are indispensable for implementation of capital services measures. This part of the *Manual* starts out with a chapter on the derivation of user costs and its elements, the return to capital, depreciation and revaluation. It continues with the price-volume split of the value of capital services and finishes with capital measures in balance sheets.

National accounts never work with individual assets but with cohorts. Individual assets inside a cohort are similar (ideally identical) in their specifications, were installed at the same time but exhaust their individual productive capacities over different service lives. In what follows, all variables relate to cohorts of assets, not to individual assets.

19.1. Deriving user costs

In the theoretical model and in line with national accounts practice, investment is assumed to take place at mid-period.

User costs of capital are the price that the owner-user of a capital good "pays to himself" for the service of using his own assets. Alternatively, user costs correspond to the marginal returns generated by the asset during one period of production. In a perfect market, and defining away any labour and intermediate costs for supplying a rental, user costs would take the same value as the rental that the owner of a capital good could achieve if he rented out the asset during one period for use in production.

The basic idea of user costs can be traced back to Walras (1874) but modern formulations of this fundamental relation in capital theory and its role in capital measurement are due to Jorgenson (1963), Christensen and Jorgenson (1973) and Diewert (1974). All formulations build on the idea that the price of an asset equals the discounted value of the net benefits that it is expected to generate in the future. There are different variants of setting up this relation. For example, it can be assumed that (internal) payments for using the asset arise at the beginning or at the end of the accounting period. There is also a question at which moment a newly purchased asset starts delivering capital services. This may be immediately at the moment of its purchase or there may be a lag. For the purpose at hand, we shall make the assumptions below which facilitate the link to national accounts information and are consistent with national accounts principles.

It should be noted that the conventions below have been stated with annual frequency in mind. As explained in Section 15.6, there is at present, no country with a fully-developed set of quarterly stock and flow measures of capital, and consequently. We thus do not explicitly show how annual measures can be derived from quarterly information but directly move to the annual frequency. We note that some of our computations at annual frequency are approximations[1], adopted for the sake of presentational and computational simplicity.

- A national accounts convention stipulates that investment should be measured as the average flow during the period and should be valued at average prices of the period. We approximate this convention by assuming that investment takes place at mid-period and is valued at mid-period prices. We shall denote the volume of investment in new capital goods of a particular type *i* as $I^{i,t}$ the assumption being that investment takes place at the mid-point of period t. This flow is valued at the average price of a base period t_0, $P_0^{i,t0} = (P_0^{i,t0B} + P_0^{i,t0E})/2 = 1$ which we have set to equal unity for simplicity. Furthermore, the letters "B" and "E" have been added to the superscripts of the prices $P_0^{i,t0B}$ and $P_0^{i,t0E}$ to indicate that these are the new asset prices at the beginning and at the end of period t_0. The subscript that comes with the price measure indicates the age of the asset so that the price of a new asset has a zero subscript. $[I^{i,t}, I^{i,t-1}, I^{i,t-2},\ldots]$ is a time series of constant price investment as normally found in the national accounts. The discard of assets, it is assumed, takes place at the end of periods. The only reason for this assumption is simplicity of exposition and calculation. In some cases such as geometric rates of depreciation and age-efficiency, this is irrelevant because the service life approaches infinity.
- Given information available at the beginning of period t, we shall define the expected rate of price change of capital good *i* between the beginning and the end of the period as $i_{(tB)}^{i,t} = P_0^{i,tE}/P_0^{i,tB}-1$. Although expectations about the asset price change depend on the moment when they are formed (indicated with the subscript tB), they are supposed to apply to all future periods. That is, the expected rate of price change two periods ahead is given by $P_0^{i,t+2B}/P_0^{i,tB}=(1+ i_{(tB)}^{i,t})^2$, the expected rate of price change three periods ahead by $(1+ i_{(tB)}^{i,t})^3$ and so on. Thus, we can drop the superscript t but we shall retain the subscript (tB) to refer to the fact that expectations about future price changes can change as the available information changes.
- Flows of payment or monetary benefits from using the asset are discounted by the nominal rate r. Like the expected rate of price change, the nominal interest rates may change over time as it depends on information available at the beginning of each period. For example, the nominal discount rate expected for the future periods at the beginning of period t, will be denoted $r_{(tB)}$. We shall assume a constant term structure of the interest rate, *i.e.* the two-period interest rate relevant under an information set of t is $(1+r_{(tB)})^2$ etc.
- Payments take place at the end of the period. This is an arbitrary assumption, and a beginning-of the period payment is equally plausible. For national accounts purposes, a mid-period payment would be the most natural approach. For implementation, all the following derivations have to be derived in parallel on the basis of beginning of the period rental payments and the resulting expressions have to be averaged with those derived from an end-of period perspective. There is no major difficulty involved, but a lengthy and tedious presentation which we leave aside at this point.

It is now possible to formulate the equilibrium condition that the value of an asset corresponds to the future discounted benefits that is generates. To avoid overloading the notation, we drop the superscript i for the moment but it should be understood that all derivations relate to a single type of asset. This should not be confused with the fact that derivations relate to a cohort, and not to individual assets. To signal this difference, we use

f_n^t to denote user costs rather than c_n^t as was the case in the introductory chapters of this *Manual*. The same holds for asset prices where capital letters are employed rather than simple letters. When needed such as in the discussion of aggregation across asset types, the index will be re-introduced.

$$P_n^{tB} = f_n^t (1+r_{(tB)})^{-1} + f_{n+1}^{t+1} (1+r_{(tB)})^{-2} + f_{n+2}^{t+2} (1+r_{(tB)})^{-3} + \ldots \quad n = 0.5; 1.5; 2.5; \qquad (34)$$

Equation (34) stipulates that the price of an n-year old new asset at the beginning of period t, P_n^{tB} equals the sum of rental payments $\{f_n^t, f_{n+1}^{t+1}, \ldots\}$, each discounted to the beginning of year t. The rental payments occur at the end of each accounting period. Note the somewhat unusual indexation of n, with values of 0.5, 1.5, etc. This reflects the national accounts assumption of mid-year investment: at the beginning of period t, the youngest asset is just half a year old, so n = 0.5. Investment goods purchased in the middle of period t-2 are 1.5 years old at the beginning of period t and so on. Thus, expression (34) relates only to those assets that are already in place at the beginning of the period. Assets that are purchased during period t are dealt with separately. To derive a user cost equation, shift expression (34) by one period without, however, changing the information set that will be kept at tB:

$$P_{n+1}^{t+1B} = f_{n+1}^{t+1} (1+r_{(tB)})^{-1} + f_{n+2}^{t+2} (1+r_{(tB)})^{-2} + f_{n+3}^{t+3} (1+r_{(tB)})^{-3} + \ldots \qquad (35)$$

Multiply (34) by $1+r_{tB}$ and subtract (35) from the resulting expression to get

$$P_n^{tB}(1+r_{(tB)}) - P_{n+1}^{t+1B} = f_n^t \; ; \; n = 0.5; 1.5; 2.5; \qquad (36)$$

where the asset price P_{n+1}^{t+1B} is an expected variable given that the above relationship has been developed under an information set available at the beginning of period t. The asset price at the beginning of period t+1 equals the asset price at the end of period t, so P_{n+1}^{t+1B} can be replaced by P_{n+1}^{tE}.

New assets that are being purchased during period t generate half a period of rentals and will be called f_{H0}^t. Note that this half-year rental cannot be directly compared to rentals $\{f_n^t\}$ which relate to payments for a full period. The exact user cost relation for new assets (based on available information at the beginning of period t) is:

$$P_0^t(1+r_{(tB)}/2) - P_{0.5}^{tE} = f_{H0}^t. \qquad (37)$$

However, to keep things more tractable and in all probability with little consequences from a practical perspective, we shall simply take the half-period user cost f_{H0}^t to correspond to half of a hypothetical user cost that an asset would fetch had it been purchased at the beginning of the period. Thus, for the remainder of the discussion, the following approximation will be made:

$$f_{H0}^t \approx f_0^t/2 = [P_0^{tB}(1+r_{(tB)}) - P_1^{tE}]/2. \qquad (38)$$

19.2. De-composing user costs

The next step consists of de-composing the user cost expression and to aggregate over vintages to derive expressions for depreciation, net return to capital and revaluation. We shall first tackle the set of existing assets and then look at new assets. To this end, we measure the *rate of depreciation d of an n-year old asset during period t,* as the percentage difference between the value of an n-year old asset and an n+1 year old asset. Strictly speaking, this is an expected rate, depending on the information available at the beginning of period t. There should thus be a subscript indicating the information set but to overload notation, this is omitted. Another simplification is the assumption, that, for every information set, there is only one set of depreciation rates. Thus, the (expected) rate of depreciation of a 2-year old asset in the current period is the same as the (expected) rate of depreciation of a 2-year old asset in future periods:

$$\delta_n \equiv (P_n^{tE} - P_{n+1}^{tE})/P_n^{tE} = 1 - P_{n+1}^{tE}/P_n^{tE} = (P_n^{tB} - P_{n+1}^{tB})/P_n^{tB}. \quad (39)$$

Turning to the user cost expression (36), the price difference between an n-year old asset at the beginning of the period and an n+1 year old asset at the end of the period, $P_n^{tB} - P_{n+1}^{tE}$ can be decomposed into a price difference that reflects depreciation and into a price change that reflects revaluation or holding gains and losses. There are different ways of breaking out the two components and we follow Balk and van den Bergen (2006) and take an average of two possibilities. More specifically, we define the *value of depreciation per asset* d_n^t that is n years old at the beginning of period t as the product of the rate of deprecation and the average price of the asset during the period. This corresponds to the required treatment of depreciation or consumption of fixed capital in the System of National Accounts. The derivation is shown in the expression below:

$$\begin{aligned} d_n^t &= 0.5[(P_n^{tB} - P_{n+1}^{tB}) + (P_n^{tE} - P_{n+1}^{tE})] \quad (40) \\ &= 0.5[P_n^{tB}(1 - P_{n+1}^{tB}/P_n^{tB}) + P_n^{tE}(1 - P_{n+1}^{tE}/P_n^{tE})] \\ &= 0.5[P_n^{tB}\delta_n + P_n^{tE}\delta_n] \\ &= \delta_n 0.5[P_n^{tB} + P_n^{tE}] \\ &= \delta_n P_n^t \\ &= P_n^{tB}\delta_n(1+i_{(tB)}/2) \qquad \text{for } n = 0.5; 1.5; 2.5 \end{aligned}$$

Half-year depreciation for a new asset d_{H0}^t will simply be treated as $d_{H0}^t = d_0^t/2 = \delta_0 P_0^t/2$. Given the value of depreciation for an n-year old asset, the *revaluation* or *holding gains and lossesper unit of an n-year old asset* which makes up the difference to the total change in asset value, $P_n^{tB} - P_{n+1}^{tE}$ is measured as:

$$\begin{aligned} z_n^t &= 0.5[(P_n^{tE} - P_n^{tB}) + (P_{n+1}^{tE} - P_{n+1}^{tB})] \quad (41) \\ &= 0.5[P_n^{tB}(P_n^{tE}/P_n^{tB} - 1) + P_{n+1}^{tB}(P_{n+1}^{tE}/P_{n+1}^{tB} - 1) \\ &= 0.5[P_n^{tB}\, i_{(tB)} + P_{n+1}^{tB}\, i_{(tB)} \\ &= i_{(tB)}\, 0.5[P_n^{tB} + P_{n+1}^{tB} \\ &= P_n^{tB}\, i_{(tB)}\, 0.5\,[1 + P_{n+1}^{tB}/P_n^{tB} \\ &= P_n^{tB}\, i_{(tB)}\, 0.5\,[2 - \delta_n \\ &= P_n^{tB}\, i_{(tB)}\,[1 - \delta_n/2] \qquad \text{for } n = 0.5; 1.5; 2.5; \end{aligned}$$

The last line of this expression contains the term $P_n^{tB}[1-\delta_n/2]$: the beginning of the year price of an asset, corrected for half a year's depreciation. This can also be taken as a (close) approximation to the value of an asset that is n+0.5 years old which corresponds to the average age of the asset during the accounting period. Thus, revaluation during period t is measured as the beginning of the year value of an asset that is on average n+0.5 years old, multiplied by the expected price change during the period. Again, for new assets, revaluation will be set at $z_{H0}^t = z_0^t/2 = P_0^{tB}\, i_{(tB)}\,[1 - \delta_0/2]/2 \approx P_{0.5}^{tB}\, i_{(tB)}/2$. Then, the user cost per unit of an asset that is n years old at the beginning of the period, and assuming that rental payments take place at the end of the period, is:

$$\begin{aligned} f_n^t &= P_n^{tB}(1+r_{(tB)}) - P_{n+1}^{tE} \quad (42) \\ &= P_n^{tB} r_{(tB)} + d_n^t - z_n^t \\ &= P_n^{tB} r_{(tB)} + P_n^{tB}\delta_n(1 + i_{(tB)}/2) - P_n^{tB}\, i_{(tB)}(1 - \delta_n/2) \qquad \text{for } n = 0.5; 1.5; 2.5; \ldots \end{aligned}$$

$f_{H0}^{t} = (P_0^{tB} r_{(tB)} + d_0^{t} - z_0^{t})/2.$

The expressions above provide the basic de-composition of the unit user cost for new and for vintage investment into:

- a return on capital, $P_n^{tB} r_{(tB)}$ obtained by applying the expected rate of return during the period to the value of the capital good at the beginning of the period;
- an (expected) depreciation charge d_n^{t};
- an (expected) revaluation term z_n^{t} which reflects the expected rise in prices of the asset, for a given asset age.

Each term is part of a flow, the marginal benefit from using the asset during t. We shall now take a closer look at each of the three components, starting out with depreciation and then turning to the return on capital and revaluation.

19.3. Depreciation

The total value of depreciation for an n-year old asset is obtained by multiplying the unit value of depreciation by the total quantity of vintage investment of age n:

$$D_n^{t} = d_n^{t} I^{t-n-0.5} = P_n^{tB} \delta_n (1 + i_{(tB)}/2) I^{t-n-0.5} \qquad \text{for } n = 0.5; 1.5; 2.5;\ldots \qquad (43)$$

$$D_{H0}^{t} = d_0^{t} I^{t}/2 = P_0^{tB} \delta_0 (1 + i_{(tB)}/2) I^{t}/2$$

The implicit assumption in this calculation is that all investment in a particular period is by way of new capital goods. In practice, this is not necessarily the case and one would need to distinguish, for every flow of investment during t, the vintage composition of this investment. However, doing so adds another dimension of complexity due to the need to trace all flows of investment by vintage. To avoid this complication, we assume that all investment is in new goods only[2]. The severity of this assumption depends on the volume of transactions in second hand assets compared to the purchase of new assets and on how much of the transactions in second-hand assets occur within the sector or the industry under consideration. With these caveats in mind, we obtain a measure of depreciation that is the product of the depreciation rate δ_n and the volume of (n+0.5)-year old investment goods, valued at average prices of period t. The total value of depreciation or consumption of fixed capital for a given asset type is measured as:

$$D^{t} = D_{H0}^{t} + D_{0.5}^{t} + D_{1.5}^{t} + \ldots \qquad (44)$$

$$= P_0^{t} \delta_0 I^{t}/2 + \delta_{0.5} P_{0.5}^{t} I^{t-1} + \delta_{1.5} P_{1.5}^{t} I^{t-2} + \ldots$$

Several remarks are in place concerning this expression. First, depreciation can now be related to the *age-price profile*. The age-price profile, as explained earlier in this *Manual,* shows how the purchase prices of different vintages of the same asset relate to each other. We shall denote the age-price profile for a given type of asset as $\psi_n \equiv P_n^{t}/P_0^{t}$ (n= 0.5; 1.5; …). There is a one-to-one link between the depreciation profile and the age-price profile as can easily be verified from the definition of the rate of depreciation: $\delta_n = 1 - \psi_{n+1}/\psi_n$ so that $\delta_n \psi_n = \psi_n - \psi_{n+1}$. By collecting P_0^{t} in the above expression, one obtains:

$$D^{t} = P_0^{t} [\delta_0 I^{t}/2 + \delta_{0.5} \psi_{0.5} I^{t-1} + \delta_{1.5} \psi_{1.5} I^{t-2} + \ldots] \qquad (45)$$

$$= P_0^{t} [(1 - \psi_{0.5}) I^{t} + (\psi_{0.5} - \psi_{1.5}) I^{t-1} + (\psi_{1.5} - \psi_{2.5}) I^{t-2} + \ldots]$$

The last line in the above expression shows how the value of depreciation can be expressed with the age-price profile only. Every vintage of an n-year old investment is multiplied by the equivalent of a depreciation profile, *i.e.* a one-year difference in the age-

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price pattern ($\psi_{n-0.5}$- $\psi_{n+0.5}$) for n=1, 2, ... For the most recent vintage of investment, we have set $\delta_0/2=1-\psi_{0.5}$.

The discussion in this Chapter has been conducted in terms of a single asset, but it should be well understood that in general the age-price profile $\{\psi_n\}$ relates to a cohort of assets and should reflect the retirement profiles around which individual assets of the same cohort are distributed. How age-price profiles for entire cohorts can be derived empirically has been described in Section 13.3 An additional and more technical discussion is provided in Annex 4.

The second remark concerning expression (45) refers to the special case of geometric age-price profiles. Under constant geometric depreciation rates, the measurement of total depreciation simplifies to applying a constant rate of depreciation to the wealth or net stock at prices of the current period. In the absence of geometric rates of depreciation, the total value of depreciation cannot be expressed as a proportion of the wealth stock and one has to keep track of the vintage-specific rates and values of depreciation for every type of asset. However, for geometric depreciation, if $\delta_n=\delta$ for n=0.5, 1.5, 2.5, ..., total depreciation becomes:

$$D^t \text{ (geometric)} = \delta P_0^t [I^t/2+ \psi_{0.5} I^{t-1} + \psi_{1.5} I^{t-2} +...] \quad (46)$$

$$= \delta P_0^t [I^t/2 + W^{tB}]$$

5. Here, the rate of depreciation applies to the stock at the beginning of the year, $W^{tB}=\psi_{0.5} I^{t-1} + \psi_{1.5} I^{t-2} + \psi_{2.5} I^{t-3} + ...$, and to half of the investment undertaken during year t. The current price expression for depreciation of an asset group (45) is also a useful starting point to examine possible price-volume splits of depreciation. A natural price index for depreciation is the mid-year price index of new assets, P_0^t. Then, the term $[\delta_0 I^t/2 + \delta_{0.5}\psi_{0.5}I^{t-1} + \delta_{1.5}\psi_{1.5} I^{t-2} +...]$ constitutes the volume part of depreciation, expressed in (constant) prices of the reference year by which the investment series have been deflated. A chain Laspeyres volume index of depreciation for a particular asset type between period t and t-1 as would typically fit into a system of national accounts[3], would then be set up in the following manner:

$$Q_L^{t/t-1}(D) = P_0^{t-1} [\delta_0 I^t/2 + \delta_{0.5}\psi_{0.5} I^{t-1} + \delta_{1.5}\psi_{1.5} I^{t-2} +...]/D^{t-1} \quad (47)$$

$$= (D^t/D^{t-1})/(P_0^t/P_0^{t-1})$$

The extension from the single asset type perspective to a measure that encompasses all assets is relatively straight forward. Use the superscript k to denote one of N asset types (k=1,2,...N). The total value of depreciation for all N asset types at current prices and the corresponding Laspeyres-type volume index are:

$$D^t = \Sigma_{i=k}^N D^{k,t} \text{ and} \quad (48)$$

$$Q_L^{t/t-1}(D) = \Sigma_{k=1}^N D^{k,t-1} Q_L^{k,t/t-1}(D)/D^{t-1} \quad (49)$$

19.4. Return to capital and revaluation or holding gains

We now turn to the two other elements of user costs, namely the return to capital and revaluation. It is not by accident that these two terms are treated together. Return to capital and revaluation are indicators that an investor would consider jointly: the return to capital corresponds to the (expected) return that an investor would require at the end of the day once allowance has been made for depreciation and revaluation. Thus, the expected return minus expected revaluation corresponds to the return that an asset has to generate from 'normal' business activity, and net of depreciation. If an asset undergoes a lasting price decline (*i.e.* there is an expectation of holding losses), the asset has to generate a large income from normal business to make up for the holding loss so that the rate of return $r_{(tB)}$ corresponds to the return that the market expects, given a certain level of risk of the business operation. There is a direct correspondence with financial assets. For example, the rate of return to a bond is composed of interest payments (the equivalent to return from 'normal' business for a fixed asset) and of price changes of the bond. The difference between interest payments and price changes is the rate of return to the bond. For a particular fixed asset type i, the return R^t is measured as:

$$\begin{aligned} R^t &= P_0^{tB} r_{(tB)} I^t/2 + P_{0.5}^{tB} r_{(tB)} I^{t-1} + P_{1.5}^{tB} r_{(tB)} I^{t-2} + P_{2.5}^{tB} r_{(tB)} I^{t-3} + \ldots \\ &= r_{(tB)}[P_0^{tB} I^t/2 + P_{0.5}^{tB} I^{t-1} + P_{1.5}^{tB} I^{t-2} + P_{2.5}^{tB} I^{t-3} + \ldots] \\ &= r_{(tB)} P_0^{tB} [I^t/2 + \psi_{0.5} I^{t-1} + \psi_{1.5} I^{t-2} + \psi_{2.5} I^{t-3} + \ldots] \\ &= r_{(tB)} P_0^{tB} [I^t/2 + W^{tB}] \end{aligned} \tag{50}$$

where $W^{tB}=\psi_{0.5} I^{t-1} + \psi_{1.5} I^{t-2} + \psi_{2.5} I^{t-3} + \ldots$ is the wealth or net capital stock of a particular asset type at the beginning of year t, measured in base-year prices. For revaluation Z^t one gets:

$$\begin{aligned} Z^t &= P_0^{tB} (1-\delta_0/2) i_{(tB)} I^t/2 + P_{0.5}^{tB} i_{(tB)} (1-\delta_{0.5}/2) I^{t-1} + P_{1.5}^{tB} i_{(tB)} (1-\delta_{1.5}/2) I^{t-2} + P_{2.5}^{tB} i_{(tB)} \\ &\quad (1-\delta_n/2) I^{t-3} + \ldots \\ &= i_{(tB)} P_0^{tB} [(1-\delta_0/2) I^t/2 + \psi_{0.5}(1-\delta_{0.5}/2) I^{t-1} + \psi_{1.5}(1-\delta_{1.5}/2) I^{t-2} + \psi_{2.5}(1-\delta_n/2) I^{t-3} + \ldots] \\ &= i_{(tB)} P_0^{tB} W^t \end{aligned} \tag{51}$$

$W^t = 0.5(W^{tB}+W^{tE})$ is the average net stock during period t, valued at prices of a reference period. That the transformation in the last line of (51) is valid can be shown formally[4] but inspection of the expression conveys also the intuition. By way of example, take the element $\psi_{0.5}(1-\delta_{0.5}/2)I^{t-1}$. It represents investment in period t-1, with a weight of $\psi_{0.5}(1-\delta_{0.5}/2)$. If we were dealing with the beginning of the year net stock, the weighting factor would be $\psi_{0.5}$, if it were the end of the year capital stock, the weighting factor would by $\psi_{1.5}$. The term$(1-\delta_{0.5}/2)$ takes off about half a period's depreciation so that the weighting factor $\psi_{0.5}(1-\delta_{0.5}/2)$ corresponds to an average weighting factor for a one-year old asset: $\psi_{0.5}(1-\delta_{0.5}/2)=(\psi_{0.5}+\psi_{1.5})/2$.

Combined return on capital and revaluation in their general version and under the geometric formula are then:

$$\begin{aligned} R^t - Z^t &= r_{(tB)} P_0^{tB} [I^t/2 + W^{tB}] - i_{(tB)} P_0^{tB} W^t \\ R^t(\text{geometric}) - Z^t(\text{geometric}) &= [r_{(tB)} - i_{(tB)} (1-\delta/2)] P_0^{tB} [I^t/2 + W^{tB}] \end{aligned} \tag{52}$$

19.5. Total user costs and the productive capital stock

As a next step, the various elements are brought together for an overall measure of the user costs of capital. For presentational ease, and because adding up the user costs of different types of assets does not pose any particular problem, our exposition is still in terms of a single type of asset. Total user costs U^t are the sum of user costs across all vintages or equivalently, the sum of the return to capital, depreciation and revaluation:

$$\begin{aligned} U^t &= f_{H0}^t I^t + f_{0.5}^t I^{t-1} + f_{1.5}^t I^{t-2} + f_{2.5}^t I^{t-3} + \ldots \\ &= R^t - Z^t + D^t \\ &= r_{(tB)} P_0^{tB} [I^t/2 + W^{tB}] - i_{(tB)} P_0^{tB} W^t + P_0^t [\delta_0 I^t/2 + \delta_{0.5} \psi_{0.5} I^{t-1} + \delta_{1.5} \psi_{1.5} I^{t-2} + \delta_{2.5} \psi_{2.5} \\ &\quad I^{t-3} + \ldots] \end{aligned} \tag{53}$$

When depreciation rates follow a geometric pattern, the same expression simplifies to a term that is proportional to the net stock of assets:

$$U^t(\text{geometric}) = R^t - Z^t + D^t(\text{geometric}) \quad (54)$$
$$= [r_{(tB)} - i_{(tB)}(1\text{-}\delta/2)]\, P_0^{tB}[I^t/2 + W^{tB}] + P_0^t\, \delta[I^t/2 + W^{tB}]$$
$$= [r_{(tB)} - i_{(tB)}(1\text{-}\delta/2) + \delta(1+i_{(tB)}/2)]\, P_0^{tB}[I^t/2 + W^{tB}]$$

From a practical perspective, the expressions (53) and (54) play an important role. They show how the total value of capital services can be built up but more importantly, how it can be decomposed into its component parts. As will be shown presently, there is an alternative way to measure U^t *as a whole* with the help of the productive capital stock and then de-compose it into a price and a volume component. But the above expressions remain the only valid way of breaking down total user costs into their current price components return to capital, revaluation and depreciation.

To explore the alternative way of measuring U^t, we make use of the first line of (53) which simply states that total user costs are the sum of the user costs of all vintages of capital:

$$U^t = f_{H0}^t I^t + f_{0.5}^t I^{t-1} + f_{1.5}^t I^{t-2} + f_{2.5}^t I^{t-3} + \ldots \quad (55)$$
$$= f_0^t\, I^t/2 + f_{0.5}^t I^{t-1} + f_{1.5}^t I^{t-2} + f_{2.5}^t I^{t-3} + \ldots$$

Before proceeding further, it is necessary to formally define an *age-efficiency function* for a particular type of asset. The age-efficiency function, as has been explained at length in other parts of this *Manual* (Chapters 0, 3.2, Chapter 11) indicates an asset's loss in productive efficiency with age. The age-efficiency function will be labelled $\{h_n;\ n = 0, 0.5, 1.5, \ldots\}$. This requires some extra explanation. First, in line with our general set up, we are interested in age-efficiency ratios of assets with half a period of age, 1.5 periods of age and so forth relative to a new asset. Note there is a time dimension to the asset efficiency measure – it can be thought of as the number of capital services per accounting period. Thus, the comparison of the efficiency measures for assets of different age has to be based on the same length of period for which the amount of capital services is compared. User costs also have time dimension, they represent the costs of using the asset for one accounting period. As explained earlier, the half-year user cost of a new asset in our model is taken to be half the full year user cost for a new asset[5].

Second, the age-efficiency sequence $\{h_n\}$ is declining with asset age, and h_0 is typically set to equal one. The use of an age-efficiency sequence implies that the marginal efficiency of capital goods of different vintages can be expressed in efficiency units of a new asset which is tantamount to assuming perfect substitutability of capital services of different age. As will presently be seen, the perfect substitution hypothesis (Jorgenson 1973) leads to a simple aggregation procedure for capital services[6].

Third, economic theory suggests (Hulten 1990) that a cost-minimising producer will use the different vintages of capital goods such that the relative unit costs of using different vintages correspond to their relative efficiency. This is intuitively plausible. If a five year old vintage produces half as many units of capital services as a new capital good, the user cost of a new asset, measured per physical unit, should be twice as high as the user cost of a five year old asset. A further simplification consists in the assumption that the age-efficiency function is time-invariant. With these remarks in mind, the following relationship holds for a cost-minimising user of capital goods:

$$h_n = f_n^t/f_0^t \text{ for } n=0.5; 1.5;\ldots \quad (56)$$

The value in (55) for user costs of an asset can now be expressed by way of the age-efficiency profile. A simple division by the unit user cost for a new asset, f_0^t yields:

$$U^t = f_0^t [I^t/2 + h_{0.5} I^{t-1} + h_{1.5} I^{t-2} + h_{2.5} I^{t-3} + \ldots] \quad (57)$$
$$= f_0^t K^t$$

Here, the variable K^t stands for the mid-period *productive capital stock*, expressed at mid-year prices of a base period and before making any allowance for the efficiency decline of new assets during the second half of year t:

$$K^t = I^t/2 + h_{0.5}I^{t-1} + h_{1.5}I^{t-2} + h_{2.5}I^{t-3} + \ldots \quad (58)$$

There are two practical consequences that follow from the above. The first consequence is that the total value of capital services can be computed in two different ways: by adding up the value of user costs for each vintage or by expressing vintage investment in terms of new-equivalent efficiency units, adding them up to the productive capital stock and valuing the latter with the user cost for a new asset. The two options yield equivalent results but they rest on the assumptions about perfect substitutability between vintages in production and time-invariance of the age-efficiency profile. For many practical applications, computation via the productive stock is a quicker way to measure the value of capital services and to split them into a price-volume component but if the two assumptions (substitutability and time-invariance) are rejected, the appropriate way of calculation is via (55) which constitutes the general expression for user cost measurement.

A second consequence is that when the current user costs are computed by way of the productive stock, a price-volume split of the value of capital services follows directly (see next Section). However, if a de-composition of the user costs into a value of depreciation, return to capital and revaluation is desired, it will always be necessary to revert to the general expressions (55) or (53). For example, consider the expression $f_0^tK^t$ which provides a user cost value via the productive stock. From earlier discussions, it is known that the unit user cost for a new asset $f_0^t=2f_{H0}^t= (P_0^{tB}r_{(tB)} + d_0^t - z_0^t)$. Thus,

$$U^t = f_0^t K^t = (P_0^{tB}r_{(tB)} + d_0^t - z_0^t)K^t \quad (59)$$

But it is *not* generally the case that the total value of depreciation, return to capital or revaluation can be derived from (59):

$$d_0^tK^t \neq D^t \quad (60)$$
$$P_0^{tB}r_{(tB)}K^t \neq R^t$$
$$z_0^tK^t \neq Z^t$$

The exception to this rule is again the case of geometric depreciation. A significant simplification arises because under geometric depreciation, and at the level of an individual (type of) asset, the net capital stock and the productive capital stock at prices of a reference year coincide. This is a direct consequence of the fact that for geometric patterns of depreciation, the age-price profile and the age-efficiency profile coincide:

$$h_n = f_n^t/f_0^t \quad (61)$$
$$= P_n^{tB}(r_{(tB)} + \delta(1+ i_{(tB)}/2) - i_{(tB)})/P_0^{tB}(r_{(tB)} + \delta(1+ i_{(tB)}/2) - i_{(tB)})$$
$$= P_n^{tB}/P_0^{tB}$$
$$= P_n^t/P_0^t$$
$$= \psi_n$$

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From this equality, it follows immediately that $W^{tB} = K^{tB}$.

The general purpose of (59) is to obtain a total measure of the cost of capital, and not a split into its constituent parts. For this purpose, we can also express it in the more familiar form of a user cost term with a rate of return, a rate of depreciation and a rate of revaluation:

$$\begin{aligned} U^t &= (P_0^{tB} r_{(tB)} + d_0^{\,t} - z_0^{\,t})K^t \qquad (62)\\ &= P_0^{tB}[r_{(tB)} + \delta_0\,(1+i_{(tB)}/2) - i_{(tB)}(1-\delta_0/2)]K^t\\ &= P_0^{tB}[r_{(tB)} + \delta_0\,(1+i_{(tB)}) - i_{(tB)}]K^t \end{aligned}$$

For many practical purposes it is easier to operate with real rates of return and with real rates of holding gains or losses. Let the consumer price index for the economy at the beginning of period t be c^{tB} and let anticipated end of period consumer price index be c^{tE}. Then the expected general consumer inflation rate for period t at the beginning of period t is $\rho_{(tB)}$, defined by the following equation:

$$1+\rho_{(tB)}=c^{tE}/c^{tB}. \qquad (63)$$

6. The anticipated general inflation rate for period t along with the nominal interest rate can be used to define the period t anticipated real interest rate $r_{(tB)}^{\;*}$ and the period t anticipated real asset inflation rate or real rate of holding gains/losses $i_{(tB)}^{\;*}$ as follows:

$$\begin{aligned} 1+r_{(tB)}^{\;*} &= (1+r_{(tB)})/(1+\rho_{(tB)}) \qquad (64)\\ 1+i_{(tB)}^{\;*} &= (1+i_{(tB)})/(1+\rho_{(tB)}) \end{aligned}$$

Now substitute (64) into the user cost expression (62) which can now be presented in terms of real asset inflation and revaluation rates, multiplied by an index of the overall expected change in the economy's price level:

$$\begin{aligned} U^t &= P_0^{tB}[r_{(tB)} + \delta_0\,(1+i_{(tB)}) - i_{(tB)}]K^t \qquad (65)\\ &= P_0^{tB}[1 + r_{(tB)} + \delta_0\,(1+i_{(tB)}) - (1+i_{(tB)})\,]K^t\\ &= P_0^{tB}(1+\rho_{(tB)})\,[r_{(tB)}^{\;*} + \delta_0\,(1+i_{(tB)}^{\;*}) - i_{(tB)}^{\;*}\,]K^t \end{aligned}$$

$$U^t(\text{geometric}) = P_0^{tB}(1+\rho_{(tB)})\,[r_{(tB)}^{\;*} + \delta(1+i_{(tB)}^{\;*}) - i_{(tB)}^{\;*}\,][I^t/2+W^{tB}]$$

These expressions for the general and for the geometric case are important for empirical implementation because they provide the natural starting point for the price-volume split of the total value of capital services as set out in the next Section.

19.6. Price-volume split of capital services

Having derived the total value of capital services at prices of the period t, it is of interest to decompose a value change between two periods into a price and volume component. Measuring the change in the volume of capital services is a key ingredient to the measurement of multi-factor productivity (see OECD 2001a). Here, the relation $U^t=f_0^{\,t}K^t$ provides a convenient way of breaking the value change in capital services U^t/U^{t-1} into a price and into a volume component[7]. It was shown above (expression (65)) that the capital services price for a new asset is $f_0^{\,t} = P_0^{tB}(1+\rho_{(tB)})\,[r_{(tB)}^{\;*} + \delta_0(1+i_{(tB)}^{\;*}) - i_{(tB)}^{\;*}\,]$ which equals $P_0^{tB}[r_{(tB)} + \delta_0(1+i_{(tB)}) - i_{(tB)}]$ when expressed in nominal variables. For a single type of asset, the volume component is simply the change in the productive stock K^t/K^{t-1}. This fits in with the idea that the flow of capital services is a constant proportion of the productive stock. By implication, for a single asset, the change in the quantity of capital services can be measured by the change in the quantity of the productive capital stock. We could also have started with the more general formulation (55) and derive, for example, a quantity Laspeyres index across vintages of investment:

$$Q_L^{t/t-1}(U) = [f_0^{t-1} I^t/2+f_{0.5}^{t-1} I^{t-1}+f_{1.5}^{t-2} I^{t-2}+f_{2.5}^{t-3} I^{t-3}+\ldots]/U^{t-1} \quad (66)$$
$$= f_0^{t-1} [I^t/2+h_{0.5} I^{t-1}+h_{1.5} I^{t-2}+h_{2.5}I^{t-3}+\ldots]/U^{t-1}$$
$$= f_0^{t-1} K^t/U^{t-1}$$
$$= f_0^{t-1} K^t/ f_0^{t-1} K^{t-1}$$
$$= K^t/K^{t-1}$$

With time-invariant age-efficiency functions and perfect substitutability between vintages of assets, the choice of the index number formula is irrelevant in the aggregation process across vintages. It is readily shown, for example that a Paasche type volume index would also produce K^t/K^{t-1} as the measure for the volume change in capital services for a particular type of asset. However, the choice of index number formulae matters when moving from a single type of asset to multiple assets. To discuss these aggregation procedures, it is necessary to re-introduce the subscript *k* to distinguish k = 1,2,…N different types of assets. The chain Laspyeres index and the chain Paasche index for the volume change of total capital services are:

$$Q_L^{t/t-1}(U) = \Sigma_{k=1}^N f_0^{k,t-1} K^{k,t}/\Sigma_{k=1}^N f_0^{k,t-1} K^{k,t-1} \quad (67)$$
$$Q_P^{t/t-1}(U) = \Sigma_{k=1}^N f_0^{k,t} K^{k,t}/\Sigma_{k=1}^N f_0^{k,t} K^{k,t-1}$$

Again, the same results could have been derived from defining Laspeyres or Paasche indices for the more general user cost formula based on vintage investment instead of productive stocks and aggregating simultaneously across vintages and across types of assets.

19.7. Capital measures in the balance sheet

To this point, measures of capital have essentially been discussed in a context of measuring flows: for example, net stocks are used to derive flows of depreciation or productive stocks are used to derive flows of capital services. However, net stocks are also of interest in their own right when it comes to measuring wealth and when balance sheets are set up. A principle for balance sheets in the national accounts is that assets recorded in the opening or closing balance are valued at the prices prevailing on the dates to which the balance sheets relate. Only net or wealth stocks enter balance sheets. With the notation adopted in this chapter, the period t opening stock of a particular asset would be given by $P_0^{tB}W^{tB}$ and the period t closing stock by $P_0^{tE}W^{tE}$. The difference between the value of opening and closing balance sheet can now be de-composed into a basic identity that links balance sheets, transactions and holding gains and losses.

The total difference between opening and closing balance can be broken down in two ways:

$$P_0^{tE}W^{tE} - P_0^{tB}W^{tB} = P_0^{tE}W^{tE} - P_0^{tE}W^{tB} +P_0^{tE}W^{tB} - P_0^{tB}W^{tB} \quad (68)$$
$$P_0^{tE}W^{tE} - P_0^{tB}W^{tB} = P_0^{tE}W^{tE} - P_0^{tB}W^{tE} +P_0^{tB}W^{tE} - P_0^{tB}W^{tB}$$

We form an arithmetic average of (68) to obtain a breakdown into a component that shows the quantity change of the stock measure, valued at average prices of the period and a revaluation component that shows the price change during the period, applied to the average stock during the period:

$$P_0^{tE}W^{tE} - P_0^{tB}W^{tB} =0.5(P_0^{tE}W^{tE} - P_0^{tE}W^{tB} + P_0^{tB}W^{tE} - P_0^{tB}W^{tB}) + \quad (69)$$
$$0.5(P_0^{tE}W^{tB} - P_0^{tB}W^{tB} + P_0^{tE}W^{tE} - P_0^{tB}W^{tE})$$

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$$= 0.5(P_0^{tE}+P_0^{tB})(W^{tE}-W^{tB}) + 0.5(W^{tB}+W^{tE})(P_0^{tE} - P_0^{tB})$$
$$= P_0^{t}(W^{tE}-W^{tB}) - P_0^{tB}i_{(tB)}W^{t}$$

We examine the first component first, and insert the definitions of the opening and closing stocks to obtain a measure of the change in the net stock during period t for a given set of prices:

$$W^{tE} - W^{tB} = (\psi_{0.5}I^{t}+ \psi_{1.5}I^{t-1}+ \psi_{2.5}I^{t-2}+\dots) - (\psi_{0.5}I^{t-1}+ \psi_{1.5}I^{t-2}+ \psi_{2.5}I^{t-3}+\dots) \quad (70)$$
$$= \psi_{0.5}I^{t}- (\psi_{0.5} - \psi_{1.5})\, I^{t-1} - (\psi_{1.5} - \psi_{2.5})I^{t-2} - (\psi_{1.5} - \psi_{2.5})I^{t-3} - \dots$$
$$= \psi_{0.5}I^{t}- \psi_{0.5}\, \delta_{0.5}I^{t-1} - \psi_{1.5}\, \delta_{1.5}I^{t-2} - \psi_{2.5}\, \delta_{2.5}I^{t-2} - \dots \quad \text{due to (45)}$$
$$= P_{0.5}^{t}\, I^{t}/P_0^{t} - \delta_{0.5}\, \psi_{0.5}\, I^{t-1} - \delta_{1.5}\, \psi_{1.5}\, I^{t-2} - \delta_{2.5}\, \psi_{2.5}\, I^{t-3} - \dots$$
$$= (1- \delta_0/2)I^{t} - \delta_{0.5}\, \psi_{0.5}\, I^{t-1} - \delta_{1.5}\, \psi_{1.5}\, I^{t-2} - \delta_{2.5}\, \psi_{2.5}\, I^{t-3} - \dots$$
$$= I^{t} - \delta_0\, I^{t}/2 - \delta_{0.5}\, \psi_{0.5}\, I^{t-1} - \delta_{1.5}\, \psi_{1.5}\, I^{t-2} - \delta_{2.5}\, \psi_{2.5}\, I^{t-3} - \dots$$
$$= I^{t} - D^{t}/P_0^{t}$$

The change in the net stock – at prices of a reference period – corresponds to gross investment minus depreciation, a well-known relationship which provides part of the overall de-composition of the change in balance sheet items at current prices. Returning to (69), one finds:

$$P_0^{tE}W^{tE} - P_0^{tB}W^{tB} = P_0^{t}(W^{tE} - W^{tB}) - P_0^{tB}i_{(tB)}W^{t} \quad (71)$$
$$= P_0^{t}(I^{t} - D^{t}/P_0^{t}) - P_0^{tB}i_{(tB)}W^{t}$$
$$= P_0^{t}I^{t} - D^{t} - Z^{t} \text{due to (51)}$$

This provides the full decomposition of the balance sheet item: the opening stock $P_0^{tB}W^{tB}$ valued at prices at the beginning of the period plus gross investment during the period, valued at mid-year prices ($P_0^{t}I^{t}$) minus depreciation D^{t} also valued at mid-year prices minus nominal holding gains and losses Z^{t}, measured as the price change during the period applied to the average net stock of the period. This follows the prescription in the 1993 System of National Accounts:

"[…] the total nominal holding gains accruing on a particular category of asset over a given period of time include those accruing on assets acquired or disposed of during the accounting period as well as on assets that figure in the opening or closing balance sheets. It follows that it is not possible to calculate total holding gains from balance sheet data on their own, except in certain special cases or on certain assumptions" (Paragraph 12.83).

There is one omission in the formula above: no account was taken of other changes in volumes. In addition to net capital formation (gross capital formation minus consumption of fixed capital), the volume of the stock of a produced asset can also vary mainly as a consequence of the economic appearance of produced assets and catastrophic losses that are not captured by the consumption of fixed capital. Other volume changes in assets are of a more statistical nature and concern, for example, the re-classification of assets. Other volume changes in assets imply a discrete shift in the level of the capital stocks and few more general statements can be made about them.

19.8. Summary of formulae for capital measurement

19.8.1. Depreciation (consumption of fixed capital)

- Age-price profile defined over prices of assets of different age n:

$$\psi_n = P_n^{tB}/P_0^{tB} = P_n^{tE}/P_0^{tE} \qquad n = 0.5; 1.5; 2.5;\dots$$

Box 19.1. Legend to variables

P_n^{tB} Price of n-period old asset at the beginning of year t ('tB')

P_n^{tE} Price of n-period old asset at the end of year t ('tE')

δ_n Rate of depreciation for an asset that is n years old at the beginning of the period

D^t Value of depreciation in period t at average prices of period t

W^{tB} Net stock at the beginning of period t at prices of a reference year

W^{tE} Net stock at the end of period t at prices of a reference year

K^{tB} Productive stock at the beginning of period t at prices of a reference year

K^t Productive stock at mid period t at prices of a reference year but before accounting for efficiency loss during period t ($K^t = K^{tB}+I^t/2$)

GR^t Average gross capital stock of period t at prices of a reference year

j_n Cumulative probability of survival until age n

f_n^t Price of capital services (unit user costs) in period t for an n-year old asset

U^t Value of capital services$i_{(tB)}$Rate of change of asset price in nominal terms, as expected at the beginning of period t

$i_{(tB)}^*$ Rate of change of asset price in real terms, as expected at the beginning of period t, where $i_{(tB)}^* = (1+i_{(tB)})/(1+\rho_{(tB)})-1$

$r_{(tB)}$ Rate of return in nominal terms, as expected at the beginning of period t

$r_{(tB)}^*$ Rate of return in real terms, as expected at the beginning of period t where

$r_{(tB)}^* = (1+r_{(tB)})/(1+\rho_{(tB)})-1$

$\rho_{(tB)}$ Rate of change of general price índex, for example consumer price index

- Depreciation profile $\{\delta_n\}$ derived from age-price profile $\{\psi_n\}$:

  $\delta_n = 1 - P_{n+1}^{tB}/P_n^{tB} = 1 - \psi_{n+1}/\psi_n$ n = 0.5; 1.5; 2.5;…
- Age-price profile derived from depreciation profile:

  $\psi_n = (1 - \delta_{n-1})(1 - \delta_{n-2})\ldots(1- \delta 0/2)$; n = 1.5; 2.5;…

  $\psi_{0.5} = 1- \delta 0/2$
- Value of depreciation at current average prices of period t:

  General profile: Dt $= P_0^t [(1-\psi_{0.5}) I^t + (\psi_{0.5}- \psi_{1.5}) I^{t-1} + (\psi_{1.5} - \psi_{2.5})$ It-2 +…]

  Geometric profile: Dt (geometric) $= P_0^t\, \delta[I^t/2 + W^{tB}]$
- Price index of depreciation: P_0^t/P_0^{t0} where t_0 is a base or reference year

19.8.2. Net capital stocks

- Net capital stock at the beginning of period t, expressed in prices of a reference year, W^{tB}:

  General profile: W^{tB} $= \psi_{0.5}\, I^{t-1} + \psi_{1.5}\, I^{t-2} + \psi_{2.5}\, I^{t-3} + \ldots$

  Geometric profile: W^{tB}(geometric)$= (1-\delta/2)[I^{t-1} + (1-\delta)I^{t-2} + (1-\delta)2I^{t-3} + \ldots]$
- Net capital stock at the end of period t, expressed in prices of a reference year, WtE:

  General profile: W_{tE} $= \psi_{0.5}\, I^t + \psi_{1.5}\, I^{t-1} + \psi_{2.5}\, I^{t-2} + \ldots$

  Geometric profile: W_{tE}(geometric)$= (1-\delta/2)[I^t + (1-\delta)I^{t-1} + (1-\delta)^2 I^{t-2} + \ldots]$

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- Stock-flow relation for geometric profile:

  $W_{tE} = W^{tB} + I^t - \delta(I^t/2+W^{tB})$
- Average net capital stock of period t expressed in prices of a reference year, W^t:

  $W^t = (W^{tB}+W^{tE})/2$

19.8.3. *Productive stocks*

- Productive stock at mid-period t expressed in prices of a reference year, K^t:
- General profile: $K^t = I^t/2 + h_{0.5}I^{t-1} + h_{1.5}I^{t-2} + h_{2.5}I^{t-3} +\ldots$
- Geometric profile: $K^t(\text{geometric}) = I^t/2+W^{tB}(\text{geometric})$

19.8.4. *Gross capital stocks*

❖ Gross capital stock at the beginning of period t expressed in prices of a reference year, G^{tB}:

- General profile: $G^{tB} = I^t/2 + j_{0.5}I^{t-1} + j_{1.5}I^{t-2} + j_{2.5}I^{t-3} +\ldots$

❖ Geometric profile:not defined (the geometric profile combines age-efficiency and retirement functions and the retirement function which is required to compute the gross capital stock, cannot be separated out).

19.8.5. *Capital services price (unit user cost)*

- *Ex-ante* user cost per unit of capital services for a particular type of asset.

  Presentation with real rates:

  General profile: $f_0{}^t = P_0{}^{tB}(1+\rho_{(tB)})\,[r_{(tB)}{}^* + \delta_0(1+i_{(tB)}{}^*) - i_{(tB)}{}^*]$

  Geometric profile: $f^t(\text{geometric}) = P_0{}^{tB}(1+\rho_{(tB)})\,[r_{(tB)}{}^* + \delta\,(1+i_{(tB)}{}^*) - i_{(tB)}{}^*]$

  Presentation with nominal rates:

  General profile: $f_0{}^t = P_0{}^{tB}\,[r_{(tB)} + \delta_0(1+i_{(tB)}) - i_{(tB)}]$

  Geometric profile: $f^t(\text{geometric}) = P_0{}^{tB}\,[r_{(tB)} + \delta\,(1+i_{(tB)}) - i_{(tB)}]$
- *Ex-post* user cost per unit of capital services for a particular type of asset.

  Presentation with real rates:

  General profile: $f_0{}^t = P_0{}^{tB}(1+\rho^t)\,[r^{t*} + \delta_0(1+i^{t*}) - i^{t*}]$

  Geometric profile: $f^t(\text{geometric}) = P_0{}^{tB}(1+\rho^t)\,[r^{t*} + \delta\,(1+i^{t*}) - i^{t*}]$

  Presentation with nominal rates:

  General profile: $f_0{}^t = P_0{}^{tB}\,[r^t + \delta_0(1+i^t) - i^t]$

  Geometric profile: $f^t(\text{geometric}) = P_0{}^{tB}\,[r^t + \delta\,(1+i^t) - i^t]$

19.8.6. *Total value of capital services, current prices*

- User cost per unit of capital services times productive stock, aggregated across assets.

  General profile: $U^t = \Sigma_{k=1}{}^N f_0{}^{k,t}K^{k,t}$

  Geometric profile: $U^t(\text{geometric}) = \Sigma_{k=1}{}^N f^{k,t}(\text{geometric})K^{k,t}(\text{geometric})$

  $= \Sigma_{k=1}{}^N f^{k,t}(\text{geometric})[I^{k,t}/2+W^{k,tB}(\text{geometric})]$

19.8.7. *Ex-post, endogenous rates of return*

- Ex-post, endogenous real rate of return.

  $r^{t*} = \{(G^t+T_K{}^t)(1+\rho^t) - \Sigma_{k=1}{}^N P_0{}^{k,tB} [\delta_0{}^k(1+i^{k,t*}) - i^{k;t*}]K^{k,t}\}/\{\Sigma_{k=1}{}^N P_0{}^{k,tB}K^{k,t}\}$

- Ex-post, simplified ('balanced') real rate of return.

  $r^{t**} = \{(G^t+T_K{}^t)(1+\rho^t) - \Sigma_{k=1}{}^N P_0{}^{k,tB} [\delta_0{}^k]K^{k,t}\}/\{\Sigma_{k=1}{}^N P_0{}^{k,tB}K^{k,t}\}$

19.8.8. *Total value of capital services, constant prices*

- User cost per unit of capital services of a reference year t_0 times productive stock, aggregated across assets.

  General profile: $V^t = \Sigma_{k=1}{}^N f_0{}^{k,t0}K^{k,t}$

  Geometric profile: $V^t(\text{geometric}) = \Sigma_{k=1}{}^N f^{k,t0}(\text{geometric})K^{k,t}(\text{geometric})$

  $= \Sigma_{k=1}{}^N f^{k,t0}(\text{geometric})[I^{k,t}/2+W^{k,tB}(\text{geometric})]$

Notes

1. Erwin Diewert, in a comment on this *Manual*, pointed out that some of the annual formulae were not consistent with an alternative formulation built up consistently from sub-annual data. His point is well taken, but the inaccuracy due to the approximations in our formulae has to be weighed against the advantage of relative simplicity. An annual model that is fully consistent with a theoretical quarterly model would for example require specification of quarterly age-efficiency and age-price profiles and complicate presentation and implementation. From a practical viewpoint, quarterly considerations are important with regard to two aspects: computation of some basic flow measures required in quarterly accounts such as consumption of fixed capital and treatment of prices and volumes in a high-inflation environment.
2. See Balk and van den Bergen (2006) for a system of vintage accounts as used by Statistics Netherlands that takes transactions in used assets into account.
3. Where volume indices in national accounts are based on the Fisher ideal index number formula, this can easily be accommodated by constructing a Paasche volume index and by forming the geometric average between the Laspeyres and the Paasche index.
4. The difference between the net stock at the end and at the beginning of the period is investment minus depreciation (all in prices of the same reference period): $W^{tE}=W^{tB}+I^t-D^t/P_0{}^t$. Then, the average stock during period t, W^t equals:

   $W^t = 0.5(W^{tB}+W^{tE})$

   $= 0.5(W^{tB}+W^{tB}+I^t-D^t/P_0{}^t)$

   $= W^{tB}+I^t/2-(\delta_0 I^t/2+\delta_{0.5}\psi_{0.5}I^{t-1}+\delta_{1.5}\psi_{1.5}I^{t-2}+\ldots)/2$

   $= (\psi_{0.5}I^{t-1}+\psi_{1.5}I^{t-2}+\ldots)+I^t/2-(\delta_0 I^t/2+\delta_{0.5}\psi_{0.5}I^{t-1}+\delta_{1.5}\psi_{1.5}I^{t-2}+\ldots)/2$

   $= (1-\delta_0/2)\, I^t/2+ \psi_{0.5}(1-\delta_{0.5}/2)\, I^{t-1}+\psi_{1.5}(1- \delta_{1.5}/2)\, I^{t-2}+\psi_{2.5}(1- \delta_{2.5}/2)\, I^{t-3}+\ldots$
5. Because of the present set-up where investment takes place at mid-period, $f_0{}^t$ is a hypothetical price – it is the user cost that would be charged if new investment took place at the beginning of the period.
6. Diewert and Wykoff (2006) make this point and use the Jorgensonian assumption of perfect substitution between vintages in their discussion of deterioration and obsolescence.
7. For a more general formulation of aggregation across vintages and assets see Diewert and Lawrence (2000) and Diewert and Schreyer (2008).

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ANNEX A

Asset service lives

Netherlands: the methodology underlying the estimated service lives in the table below has been described in Section 13.1.1.

Table A.1. **Average service lives by asset and industry in the Netherlands**

Asset name Nace	Industry	Dwellings	Buildings	Other structures	Passenger cars and other road transport equipment	Trains and trams	Ships	Airplanes	Computers
1 and 2	Agriculture and forrestry	75	38	55	9	28	25	16	5
5	Fishing	75	38	55	9	28	35 - 25[a]	16	5
10 and 14	Other mining and quarrying	75	41	35	6	28	25	16	6
11	Extraction of oil and gas	75	41	35	6	28	25	16	6
15 and 16	Manufacture of food products, beverages, tabacco	75	42	55	6	28	25	16	12
17, 18 and 19	Manufacture of textile and leather products	75	42	55	5	28	25	16	14
20	Manufacture of wood and products of wood	75	42	55	5	28	25	16	8
21	Manufacture of paper and paper products	75	42	55	5	28	25	16	6
22	Publishing and printing	75	42	55	5	28	25	16	8
23	Manufacture of petroleum products	75	36	55	5	28	25	16	8
24	Manufacture of chemicals, chemical products	75	41	55	7	28	25	16	12
25	Manufacture of rubber and plastic products	75	41	55	5	28	25	16	12
26	Manufacture of other non-metallic mineral producte	75	42	55	5	28	25	16	8
27	Manufatcure of basis metals	75	31	55	7	28	25	16	8
28	Manufacture of fabricated metal products	75	31	55	5	28	25	16	8
29	Manufacture of machinery and equipment n.e.c.	75	44	55	5	28	25	16	12
30	Manufacture of office machinery and computers	75	30	55	5	28	25	16	6
31	Manufacture of electrical machinery and apparatus n.e.c.	75	30	55	5	28	25	16	6
32	Manufacture of radio, television and communication apparatus	75	30	55	5	28	25	16	6
33	Manufacture of medical, precision and optical instruments	75	30	55	6	28	25	16	6
34	Manufacture of motor vehicles, trailers and semi-trailers	75	36	55	5	28	25	16	5
35	Manufacture of other transport equipment	75	36	55	5	28	25	16	5
36	Manufacture of furniture; manufatcure n.e.c.	75	42	55	7	28	25	16	10
37	Recycling	75	42	55	7	28	25	16	10
40	Electricity, gas, steam and hot water supply	75	40	35	8	28	25	16	10
41	Collection, purification and distribution of water	75	40	35	8	28	25	16	10
45	Construction	75	42	55	7	28	25	16	10
50	Trade and repair of motor vehicles/cycles	75	40	55	7	28	25	16	5
51	Wholesale trade	75	40	55	7	28	25	16	5
52	Retail trade and repair	75	40	55	7	28	25	16	5
55	Hotels and restaurants	75	32	55	7	28	25	16	5

Table A.1. **Average service lives by asset and industry in the Netherlands** *(cont.)*

Asset name Nace	Industry	Dwellings	Buildings	Other structures	Passenger cars and other road transport equipment	Trains and trams	Ships	Airplanes	Computers
60	Other land transport	75	50	55	9	28	25	16	5
611	Seagoing water transport	75	50	55	9	28	35 - 25 [a]	16	5
612	Inland water tranport	75	50	55	9	28	50 - 40 -30 [b]	16	5
62	Air transport	75	50	55	9	28	25	16	5
63 excl 6301	Supporting transport activities	75	50	55	9	28	25	16	5
6301	Railroads	75	40	40	9	28	25	16	5
64	Post and telecommunications	75	40	25	6	28	25	16	5
66	Banking	75	36	55	6	28	25	16	5
67	Insurance and pension funding	75	36	55	6	28	25	16	5
65	Activities auxuliary to financial intermediation	75	36	55	6	28	25	16	5
70	Real estate services	75	36	55	6	28	25	16	5
71	Renting of movables	75	36	55	6	28	25	16	5
72	Computer and related activities	75	36	55	6	28	25	16	5
73	Research and development	75	36	55	6	28	25	16	5
74	Other business services	75	36	55	6	28	25	16	5
75 excl 7522	Public administration and social security	75	36	55	6	28	25	16	5
7522	Defence activities	75	48	55	6	28	25	16	5
80 excl 804	Subsidized education	75	48	55	6	28	25	16	5
804	Other service activities n.e.c.	75	48	55	6	28	25	16	5
85	Health and social work activities	75	48	55	6	28	25	16	5
90	Sewage and refuse disposal services	75	36	55	6	28	25	16	5
91	Other service activities n.e.c.	75	36	55	6	28	25	16	5
92	Recreational, cultural and sporting activities	75	36	55	6	28	25	16	5
93	Other service activities n.e.c.	75	36	55	6	28	25	16	5

a) 35 years until 1989; 25 years from 1990.
b) 50 years until 1955; 40 years from 1956 until 1989; 30 years from 1990.
NG = not estimated. A direct method is used to calculate the capital stock.

Asset name Nace	Industry	Machinery and equipment	Livestock	Other cultivated assets	Other tangible assets	Transfer of ownership cost on land	Mineral exploration	Software	Originals	Transfer of ownership cost on non-produced non-financial assets
1 and 2	Agriculture and forrestry	14	NG	15	10	1	40	3	5	3
5	Fishing	14	NG	15	10	1	40	3	5	3
10 and 14	Other mining and quarrying	30	NG	15	12	1	40	3	5	3
11	Extraction of oil and gas	30	NG	15	12	1	40	3	5	3
15 and 16	Manufacture of food products, beverages, tabacco	27	NG	15	12	1	40	3	5	3
17, 18 and 19	Manufacture of textile and leather products	35	NG	15	12	1	40	3	5	3
20	Manufacture of wood and products of wood	30	NG	15	12	1	40	3	5	3
21	Manufacture of paper and paper products	27	NG	15	12	1	40	3	5	3
22	Publishing and printing	35	NG	15	12	1	40	3	5	3
23	Manufacture of petroleum products	22	NG	15	12	1	40	3	5	3
24	Manufacture of chemicals, chemical products	30	NG	15	12	1	40	3	5	3
25	Manufacture of rubber and plastic products	30	NG	15	12	1	40	3	5	3
26	Manufacture of other non-metallic mineral producte	30	NG	15	12	1	40	3	5	3
27	Manufatcure of basis metals	33	NG	15	12	1	40	3	5	3
28	Manufacture of fabricated metal products	33	NG	15	12	1	40	3	5	3
29	Manufacture of machinery and equipment n.e.c.	33	NG	15	12	1	40	3	5	3
30	Manufacture of office machinery and computers	21	NG	15	8	1	40	3	5	3
31	Manufacture of electrical machinery and apparatus n.e.c.	18	NG	15	8	1	40	3	5	3
32	Manufacture of radio, television and communication apparatus	18	NG	15	8	1	40	3	5	3
33	Manufacture of medical, precision and optical instruments	15	NG	15	12	1	40	3	5	3
34	Manufacture of motor vehicles, trailers and semi-trailers	30	NG	15	11	1	40	3	5	3
35	Manufacture of other transport equipment	30	NG	15	11	1	40	3	5	3
36	Manufacture of furniture; manufatcure n.e.c.	30	NG	15	12	1	40	3	5	3
37	Recycling	30	NG	15	12	1	40	3	5	3
40	Electricity, gas, steam and hot water supply	32	NG	15	12	1	40	3	5	3
41	Collection, purification and distribution of water	32	NG	15	12	1	40	3	5	3
45	Construction	15	NG	15	12	1	40	3	5	3
50	Trade and repair of motor vehicles/cycles	11	NG	15	10	1	40	3	5	3
51	Wholesale trade	10	NG	15	10	1	40	3	5	3
52	Retail trade and repair	10	NG	15	10	1	40	3	5	3
55	Hotels and restaurants	10	NG	15	12	1	40	3	5	3

Asset name Nace	Industry	Machinery and equipment	Livestock	Other cultivated assets	Other tangible assets	Transfer of ownership cost on land	Mineral exploration	Software	Originals	Transfer of ownership cost on non-produced non-financial assets
60	Other land transport	11	NG	15	10	1	40	3	5	3
611	Seagoing water transport	11	NG	15	10	1	40	3	5	3
612	Inland water tranport	11	NG	15	10	1	40	3	5	3
62	Air transport	11	NG	15	10	1	40	3	5	3
63 excl 6301	Supporting transport activities	11	NG	15	10	1	40	3	5	3
6301	Railroads	11	NG	15	10	1	40	3	5	3
64	Post and telecommunications	15	NG	15	8	1	40	3	5	3
66	Banking	11	NG	15	8	1	40	3	10	3
67	Insurance and pension funding	11	NG	15	8	1	40	3	5	3
65	Activities auxuliary to financial intermediation	11	NG	15	8	1	40	3	5	3
70	Real estate services	11	NG	15	8	1	40	3	5	3
71	Renting of movables	11	NG	15	8	1	40	3	5	3
72	Computer and related activities	11	NG	15	8	1	40	3	5	3
73	Research and development	11	NG	15	8	1	40	3	5	3
74	Other business services	11	NG	15	8	1	40	3	5	3
75 excl 7522	Public administration and social security	11	NG	15	8	1	40	3	5	3
7522	Defence activities	12	NG	15	8	1	40	3	5	3
80 excl 804	Subsidized education	11	NG	15	8	1	40	3	5	3
804	Other service activities n.e.c.	11	NG	15	8	1	40	3	5	3
85	Health and social work activities	11	NG	15	8	1	40	3	5	3
90	Sewage and refuse disposal services	11	NG	15	8	1	40	3	5	3
91	Other service activities n.e.c.	11	NG	15	8	1	40	3	5	3
92	Recreational, cultural and sporting activities	11	NG	15	8	1	40	3	5	3
93	Other service activities n.e.c.	11	NG	15	8	1	40	3	5	3

a) 35 years until 1989; 25 years from 1990.
b) 50 years until 1955; 40 years from 1956 until 1989; 30 years from 1990.
NG = not estimated. A direct method is used to calculate the capital stock.

United States: a full methodological description can be found in Bureau of Economic Analysis (2003), available under *http://bea.gov/national/pdf/Fixed_Assets_1925_97.pdf.*

Table A.2. **Depreciation rates and declining balance rates for the United States**
BEA Rates of Depreciation, Service Lives, Declining-Balance Rates, and Hulten-Wykoff Categories

Type of Asset	Rate of depreciation	Service life (years)	Declining balance rates
Private nonresidential equipment			
Software:	0.5500		
Prepackaged	0.3300	3	1.65
Custom	0.3300	5	1.65
Own-account		5	1.65
Office, computing, and accounting machinery:	0.2729		
Years before 1978	0.3119	8	2.1832
1978 and later years		7	2.1832
Communications equipment:	0.1500		
Business services	0.1100	11	1.65
Other industries	0.1350	15	1.65
Instruments	0.1800	12	1.6203
Photocopy and related equipment	....	9	1.6203
Nuclear fuel	0.0917	4	....
Other fabricated metal products	0.0516	18	1.65
Steam engines and turbines	0.2063	32	1.65
Internal combustion engines	0.1225	8	1.65
Metalworking machines	0.1031	16	1.96
Special industrial machinery, n.e.c	0.1072	16	1.65
General industrial, including materials handling equipment	0.0500	16	1.715
Electrical transmission, distribution, and industrial apparatus		33	1.65
Trucks, buses, and truck trailers:	0.1232		
Local and interurban passenger transit	0.1725	14	1.7252
Trucking and warehousing; and auto repair, services, and parking	0.1917	10	1.7252
Other industries	....	9	1.7252
Autos		....	....
Aircraft:			
Transportation by air, depository institutions, and business services:			
Years before 1960	0.1031	16	1.65
1960 and later years	0.0825	20	1.65
Other industries:			
Years before 1960	0.1375	12	1.65
1960 and later years	0.1100	15	1.65
Ships and boats	0.0611	27	1.65
Railroad equipment	0.0589	28	1.65
Household furniture and fixtures	0.1375	12	1.65
Other furniture	0.1179	14	1.65
Farm tractors	0.1452	9	1.3064
Construction tractors	0.1633	8	1.3064
Agricultural machinery, except tractors	0.1179	14	1.65
Construction machinery, except tractors	0.1550	10	1.5498
Mining and oil field machinery	0.1500	11	1.65
Service industry machinery:			
Wholesale and retail trade	0.1650	10	1.65
Other industries	0.1500	11	1.65
Household appliances	0.1650	10	1.65
Other electrical equipment	0.1834	9	1.65
Other	0.1473	11	1.623

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Table A.2. Depreciation rates and declining balance rates for the United States *(cont.)*

BEA Rates of Depreciation, Service Lives, Declining-Balance Rates, and Hulten-Wykoff Categories

Type of Asset	Rate of depreciation	Service life (years)	Declining balance rates
Private nonresidential structures		31	0.9747
Industrial buildings	0.0314	16	0.8892
Mobile offices	0.0556	36	0.8892
Office buildings	0.0247	40	0.8892
Commercial warehouses	0.0222	34	0.8892
Other commercial buildings	0.0262	48	0.9024
Religious buildings	0.0188	48	0.9024
Educational buildings	0.0188	48	0.9024
Hospital and institutional buildings	0.0188	32	0.899
Hotels and motels	0.0281	30	0.899
Amusement and recreational buildings	0.0300	38	0.899
All other nonfarm buildings	0.0237	38	0.948
Railroad replacement track	0.0249	54	0.948
Other railroad structures	0.0176	40	0.948
Telecommunications	0.0237		
Electric light and power:		40	0.948
Years before 1946	0.0237	45	0.948
1946 and later years	0.0211	40	0.948
Gas	0.0237	40	0.948
Petroleum pipelines	0.0237	38	0.91
Farm	0.0239		
Mining exploration, shafts, and wells:			
Petroleum and natural gas:		16	0.9008
Years before 1973	0.0563	12	0.9008
1973 and later years	0.0751	20	0.9008
Other	0.0450	38	0.899
Local transit	0.0237		
Other	0.0225	40	0.899
Residential capital (private and government)			
1-to-4-unit structures–new	0.0114	80	0.91
1-to-4-unit structures–additions and alterations	0.0227	40	0.91
1-to-4-unit structures–major replacements	0.0364	25	0.91
5-or-more-unit structures–new	0.0140	65	0.91
5-or-more-unit structures–additions and alterations	0.0284	32	0.91
5-or-more-unit structures–major replacements	0.0455	20	0.91
Manufactured homes	0.0455	20	0.91
Other structures	0.0227	40	0.91
Equipment	0.1500	11	1.65
Durable goods owned by consumers			
Furniture, including mattresses and bedsprings		14	1.65
Kitchen and other household appliances	0.1179	11	1.65
China, glassware, tableware, and utensils	0.1500	10	1.65
Other durable house furnishings	0.1650	10	1.65
Video and audio products, computers and peripheral equipment, and musical instruments	0.1650	9	1.65
Jewelry and watches	0.1833	11	1.65
Ophthalmic products and orthopedic appliances	0.1500	6	1.65
Books and maps	0.2750	10	1.65
Wheel goods, sports and photographic equipment, boats, and pleasure aircraft	0.1650	10	1.65
Autos			
Other motor vehicles	....	....	....
Tires, tubes, accessories, and other parts	0.2316	8	1.853
	0.6177	3	1.853

Table A.2. **Depreciation rates and declining balance rates for the United States** *(cont.)*

BEA Rates of Depreciation, Service Lives, Declining-Balance Rates, and Hulten-Wykoff Categories

Type of Asset	Rate of depreciation	Service life (years)	Declining balance rates
Government nonresidential equipment			
Federal:			
National defense:			
Aircraft:			
Airframes:			
Bombers	0.0660	25	1.65
F–14 type	0.0868	19	1.65
Attack, F–15 and F–16 types	0.0825	20	1.65
F–18 type	0.1100	15	1.65
Electronic warfare	0.0717	23	1.65
Cargo and trainers	0.0660	25	1.65
Helicopters	0.0825	20	1.65
Engines	0.2750	6	1.65
Other:			
Years before 1982	0.1179	14	1.65
1982 and later years	0.1650	10	1.65
Missiles:			
Strategic	....	20	....
Tactical	....	15	....
Torpedoes	....	15	....
Fire control equipment	....	10	....
Space programs	....	20	....
Ships:			
Surface ships	0.0550	30	1.65
Submarines	0.0660	25	1.65
Government furnished equipment:			
Electrical	0.1834	9	1.65
Propulsion	0.0825	20	1.65
Hull, mechanical	0.0660	25	1.65
Ordnance	0.1650	10	1.65
Other	0.1650	10	1.65
Vehicles:			
Tanks, armored personnel carriers, and other combat vehicles	0.0825	20	1.65
Noncombat vehicles:			
Trucks	0.2875	6	1.7252
Autos	....	....	....
Other	0.2465	7	1.7252
Electronic equipment:			
Computers and peripheral equipment	....	....	....
Electronic countermeasures	0.2357	7	1.65
Other	0.1650	10	1.65
Other equipment:			
Medical	0.1834	9	1.65
Construction	0.1550	10	1.5498
Industrial	0.0917	18	1.65
Ammunition plant	0.0868	19	1.65
Atomic energy	0.1375	12	1.65
Weapons and fire control	0.1375	12	1.65
General	0.1650	10	1.65

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Table A.3. **Depreciation rates and declining balance rates for selected countries**

Selected Service Life Assumptions by Activity

		Italy		Belgium		Finland		Germany	Italy	Belgium	Germany	Finland	
Activities	NACE rev 1	Machinery	Transport	Machinery	Transport	Machinery	Transport	Machinery and Equipment	Buildings and Structures	Buildings and Structures	Buildings and Structures	Non Residential Buildings	Structures
Agriculture, Hunting, Forestry	01-02	18	10	15	12	5-12	9	0	51	37		35-40	30-50
Fishing; operation of fish hatcheries and fish farms; etc	05	18	10	15	25	15	10	0	35	39			
Mining and Quarrying	10-14					18	7	21			23	30	25
Mining and Quarrying of Energy Producing Materials	10-12	18	10						35		23		
Other Mining and Quarrying	13-14	18	10	20	10			8	35	33	14		
Food Products, Beverages and Tobacco	15-16	18	10	20	10	17-19	7	14	35	34	33	40	25
Textiles and Textile Products	17-18	18	10	19	10	14	7	14	35	38	40	35	40
Leather; manufacture of luggage,etc.	19	18	10	18	10	14	7	14	35	38	41	35	40
Wood and of products of wood and cork, etc.	20	18	10	18	10	16	10	11	35	45	35	35	25
Pulp, paper and paper products, publishing, printing	21-22	18	10	19	10	15-18	6-10	12	35	45	35	40	35
Coke, refined petroleum products and nuclear fuel	23	18	10	18	10	23	10	18	35	38	27	35	40
Chemicals and chemical products	24	18	10	18	10	18	10	15	35	34	27	40	35
Rubber and plastic products	25	18	10	17	10	18	7	13	35	34	34	45	40
Other non-metallic mineral products	26	18	10	19	10	19	10	14	35	30	30	40	40
Basic metals, fabricated metal products	27-28	18	10	21	10	16-23	8-12	14	35	35	29	40	30-40
Machinery and equipment n.e.c.	29	18	10	19	10	13	8	13	35	35	30	40	30
Electrical and optical equipment	30-33	18	10	19	10	11	7	12	35	35	31	40	30
Transport equipment	34-35	18	10	18	10	15	9	11	35	35	30	45	40
Manufacturing n.e.c. recycling	36-37	18	10	18	10	14	8	12	35	35	38	35	35
Energy and water supply	40-41	18	10	25	10	24-27	8-10	19	40	42	45	45-50	35-40
Construction	45			20	10	10	10	9		42	41	40	30
Wholesale and retail trade; repairs	50-52	18	10	15	8	15	10	10	65	40	50	40	30
Hotels and restaurants	55	18	10	15	8	15	10	12	65	40	59	40	

Table A.3. **Depreciation rates and declining balance rates for selected countries** *(cont.)*

Selected Service Life Assumptions by Activity

		Italy		Belgium		Finland		Germany	Italy	Belgium	Germany	Finland	
Activities	NACE rev 1	Machinery	Transport	Machinery	Transport	Machinery	Transport	Machinery and Equipment	Buildings and Structures	Buildings and Structures	Buildings and Structures	Non Residential Buildings	Structures
Transport, storage and communication	60-64	18	10	15	15	5-25	7-25	13	80	40	33	20-50	20-70
Financial intermediation	65-67	18	10	15	8	10		10	65	40-60	66	40	
Real estate, renting and business activities	70-74	18	10	15	8	15	10	10	80	40-60	66	50	70
Public administration and defence; social security	75	28	15	15	8	15	10	11	80	60-70	51	50	70
Education	80	18	10	15	8	10-15	10	8	57	(60)	59	50	70
Health and social work	85	18	10	15	8	10-15	8-10	11	35	40	58	40-50	70
Other community, social and personal services	90-93			15	8	10-15	8-10	8		40	48	50	40-70

Table A.4. **Depreciation rates and declining balance rates for Canada**

Major group	Asset group	Asset	Definition	Estimated depreciation rate	Surveyed lives 1985 to 2001
	Commercial and	1004	Laboratories, research and development	0.066	32.4
	institutional buildings	1012	centers	0.087	24.5
		1013	Automotive dealerships	0.060	33.3
		1014	Office buildings	0.059	36.0
		1015	Hotels, motels and convention centers	0.087	23.0
		1016	Restaurants, fast food outlets, bars and	0.070	30.7
		1018	nightclubs	0.067	31.8
		1019	Shopping centers, plazas and stores	0.069	31.2
		1201	Theatre, performing arts and cultural	0.062	34.7
		1202	centers	0.055	39.1
		1203	Indoor recreational buildings	0.047	45.6
		1204	Educational buildings	0.061	35.1
		1205	Student residences	0.060	35.6
		1206	Religious buildings	0.076	27.9
		1207	Hospitals and other health centres	0.059	35.9
		1208	Nursing homes	0.094	23.3
		1209	Day care centers	0.060	35.4
		1210	Libraries	0.046	46.2
		1211	Historical sites	0.081	26.4
		1212	Penitentiaries, detention centers and	0.118	18.2
		1214	courthouses	0.096	22.3
			Museums, science centers and public		
		1299	archives	0.075	28.6
		1999	Fire stations	0.071	30.0
		2201	Post offices	0.065	32.9
Buildings		3001	Armouries, barracks, drill halls and other military type structures	0.086	30.6
			Other institutional/government buildings		
			Other building constructions		
			Passenger terminals (such as air, boat, bus and rail)		
			Broadcasting and communication buildings		
	Industrial buildings	1001	Manufacturing plants	0.089	26.6
		1006	Warehouses, refrigerated storage and freight terminals	0.068	32.2
		1007	Grain elevator and terminals	0.071	30.0
		1008	Maintenance garages, workshops and equipment storage facilities	0.084	28.0
		1009	Railway shops and engine houses	0.080	32.1
		1010	Aircraft hangars	0.096	26.7
		1011	Service stations	0.123	17.4
		1021	Farm buildings	0.095	27.0
		1022	Bunkhouses, dormitories, camp cookeries and camps	0.161	13.3
		1099	Other industrial and commercial buildings	0.085	23.9
		3401	Mine buildings	0.180	12.2
		3402	Mine buildings for beneficiation treatment of minerals (excluding smelters and refineries)	0.168	13.1
		5999	Other construction (1999/other buildings)	0.150	21.0

Table A.4. **Depreciation rates and declining balance rates for Canada** *(cont.)*

Major group	Asset group	Asset	Definition	Estimated depreciation rate	Surveyed lives 1985 to 2001
Machinery and equipment	Computers	6002	Computers and associated hardware	0.467	4.7
	Computerized Equipment	6401	Computerized material handling equipment	0.191	13.4
		6402	Computerized production equipment for manufacturing	0.174	12.7
		6403	Computerized communication equipment	0.225	9.5
		6410	Computerized production process – crushers and grinders	0.204	12.6
		6413	Computerized production process – other	0.176	14.6
		6499	Other computerized machinery and equipment	0.314	8.2
	Furniture equipment	6001	Office furniture and furnishing	0.235	8.3
		6003	Non-office furniture, furnishings and fixtures	0.214	9.4
	Heavy machinery	6009	Motors, generators, transformers, turbines, compressors and pumps	0.130	15.3
		6010	Heavy construction equipment*	0.172	13.9
		6011	Tractors of all types and other field equipment* Drilling and blasting equipment	0.171	14.5
		6013	Underground load, haulage and dump equipment	0.192	11.1
		6028	(such as slusher and muck cars)	0.208	10.2
	Equipment attached to building	6005	Heating, electrical, plumbing, air conditioning and refrigeration equipment	0.167	12.5
		6006	Pollution abatement and control equipment	0.151	16.7
		6007	Safety and security equipment	0.200	10.8
		6008	Sanitation equipment	0.218	10.7
	Non-computerized equipment	6601	Non-computerized material handling equipment	0.182	10.6
		6602	Non-computerized production equipment for manufacturing	0.154	14.0
		6603	Non-computerized communication equipment	0.214	11.1
		6610	Non-computerized production process - crushers and grinders	0.171	15.0
		6613	Non-computerized production process - other	0.201	12.8
	Other transport equipment	6205	Locomotives, rolling stock, street/subway cars, other rapid transit and major parts*	0.103	25.3
		6206	Ships and boats*	0.104	26.5
		6207	Aircraft, helicopter and aircraft engines*	0.082	27.9
		6299	Other transportation equipment*	0.201	12.6
	Road transport equipment	6201	Automobiles and major replacement parts*	0.280	8.1
		6202	Buses and major replacement parts*	0.149	17.4
		6203	Trucks, vans, truck tractors, truck trailers and major replacement parts*	0.227	10.6
		6204	All - terrain vehicles and major replacement parts*	0.190	11.6
	Scientific equipment	6004	Scientific, professional and medical devices	0.229	8.9
	Tooling equipment	6012	Capitalized tooling and other tools*	0.233	8.0
	Software	6021	Software, own-account	0.330	5.0
		6022	Software, pre-package	0.550	3.0
		6023	Software, custom-design	0.330	5.0
	Other machinery and equipment	6014	Salvage equipment	0.151	15.4
		6015	Industrial containers (transportable types)*	0.160	12.9
		6016	Navigational aids and weather measurement equipment	0.225	11.1
		8999	Other machinery and equipment (not specified elsewhere)	0.166	10.9

Table A.4. **Depreciation rates and declining balance rates for Canada** *(cont.)*

Major group	Asset group	Asset	Definition	Estimated depreciation rate	Surveyed lives 1985 to 2001
Machinery and equipment	Machinery and equipment related to electricity production	9001	Gas generators and turbines	0.130	22.9
		9002	Steam and vapour turbines	0.130	26.4
		9010	Electric motors and generators	0.130	23.9
		9011	Electric transformers, static converters and inductors Electric switchgear and switching apparatus	0.130	30.3
		9012	Electric control and protective equipment	0.130	28.0
		9013	Measuring, checking or automatically controlling	0.229	15.0
		9015	instruments and apparatus Electricity meters	0.233	23.0
		9091	Electric water heaters	0.233	23.9
		9092	Nuclear reactor parts, fuel elements and heavy water	0.167	13.4
		9093	Hydraulic turbines Boilers	0.130	20.1
		9094	Other machinery and equipment	0.130	37.3
		9095		0.166	26.2
		9099		0.166	16.9
	Machinery and equipment specific to mining and oil and gas production	6027	Raise borers and raise climbers	0.286	9.0
		6029	Mine hoists, cages, ropes and skips	0.286	9.0
		6411	Computerized production process – flotation and cyanidation	0.286	9.0
		6412	Computerized production process – gravitational concentration devices	0.286	9.0
		6611	Non-computerized production process – flotation and cyanidation	0.286	9.0
		6612	Non-computerized production process – gravitational concentration devices	0.286	9.0
Engineering	Engineering	1002	Oil refineries	0.118	22.6
		1003	Natural gas processing plants	0.106	25.1
		1005	Pollution, abatement and controls	0.095	23.1
		1017	Parking lots and parking garages	0.085	25.9
		1020	Outdoor recreational (such as parks, open stadiums, golf courses and ski resorts)	0.099	22.2
		1213	Waste disposal facilities	0.087	25.4
		2001	Docks, wharves, piers and terminals	0.078	28.1
		2002	Dredging and pile driving	0.104	21.2
		2003	Breakwaters Canals and waterways	0.211	10.4
		2004	Irrigation and land reclamation projects	0.046	47.7
		2005	Other marine construction	0.049	44.9
		2099	Highways, roads and streets (including logging roads)	0.071	31.0
		2202	Runways (including lighting)	0.089	24.8
		2203	Rail track and roadbeds	0.073	30.0
		2204	Bridges, trestles and overpasses	0.060	36.9
		2205	Tunnels Other transportation engineering	0.062	35.6
		2206	Reservoirs (including dams)	0.039	56.6
		2299	Trunk and distribution mains for waterworks	0.073	30.0
		2401	Water pumping stations and filtrations plants	0.056	39.0
		2402	Water storage tanks	0.077	28.4
		2412	Other waterworks construction	0.062	35.6
		2413	Sewage treatment and disposal plants (including	0.207	10.6
		2499	pumping stations)	0.092	23.9
		2601	Sanitary and storm sewers, trunk and collection lines	0.099	22.2
		2602	and open storm ditches	0.076	28.8

Table A.4. **Depreciation rates and declining balance rates for Canada** *(cont.)*

Major group	Asset group	Asset	Definition	Estimated depreciation rate	Surveyed lives 1985 to 2001
Engineering	Engineering	2603	Lagoons	0.081	27.0
		2699	Other sewage system construction	0.100	22.0
		2801	Electric power construction	0.096	23.0
		2811	Production plant - steam	0.055	40.0
		2812	Production plant - nuclear	0.051	43.0
		2813	Production plant - hydraulic	0.048	46.0
	Electrical lines	2814	Electrical transmission lines - overhead	0.051	43.0
		2815	Electrical transmission lines - underground	0.049	45.0
		2816	Electrical distribution lines - overhead	0.067	33.0
		2817	Electrical distribution lines - underground	0.063	35.0
	Engineering	2899	Other construction (not specified elsewhere)	0.063	35.0
	Communication engineering	3002	Telephone and cablevision lines	0.122	20.0
		3003	Communication towers and antennas	0.107	13.0
	Engineering	3099	Other communication engineering	0.146	16.0
		3201	Gas mains and services	0.070	38.0
		3202	Pumping stations, oil	0.296	9.0
		3203	Pumping stations gas	0.083	32.0
		3204	Bulk storage	0.113	23.0
		3205	Oil pipelines	0.116	23.0
		3206	Gas pipelines	0.081	33.0
		3216	Exploration drilling	0.167	16.0
		3217	Development drilling	0.167	16.0
		3218	Production facilities in oil and gas engineering	0.167	16.0
		3219	Enhanced recovery projects	0.167	16.0
		3220	Drilling expenditures, pre-mining, research and other	0.167	
			Geological and geophysical expenditures		16.0
		3221	Other oil and gas facilities	0.167	
		3299	Mining engineering - below surface (shafts, drifts,	0.074	16.0
		3403	daises)	0.147	36.0
			Tailing disposal systems and settling ponds		15.0
		3404	Mine site exploration	0.157	
		3411	Mine site development	0.137	14.0
		3412	Exploration and deposit appraisal - off mine sites	0.137	16.0
		3413	Other engineering construction	0.137	16.0
		4999		0.122	16.0
					18.0

Note: Asterisk* and bold format for asset labels indicate that we detected a problem in the anticipated *ex ante* life and replaced its estimate with *ex post* mean service life.

Source: Statistics Canada.

ANNEX B

Implementation of capital estimates using an artificial dataset

This Annex uses the formulae worked out in chapter 19 and presents them in a typical sequence of implementation. An artificial but not unrealistic dataset is used to demonstrate implementation. The purpose of this annex is to document the sequence of implementation, to demonstrate how to aggregate across sectors and industries and to examine the effects of using an *ex-ante* versus an *ex-post* approach when measuring user costs. The documented dataset with all the calculations is available in spreadsheet form on [URL here]. The data set has the following features:

- The dataset distinguishes between institutional sectors and industries. The institutional units are 'corporations' or market producers and 'government' or 'non-market producers', the industries are 'manufacturing', 'services' and 'public administration'.
- Manufacturing industry is exclusively composed of corporations. For services, a distinction has been made between market producers and non-market producers. Public administration is exclusively made up of non-market producers.
- Three types of assets are considered, 'machinery', 'software' and 'land'. They were chosen to represent three typical types of assets. 'Machinery' is the prototypical equipment with a long-run price change that is somewhat less than overall inflation, and medium-range service life; 'software' stands for short-lived high-tech equipment with a short service life, and rapid declines in relative prices; 'land' represents a non-produced asset whose quantity is fixed in our example but whose prices undergo large cyclical movements as has been observed in reality.
- Geometric age-price and age-efficiency profiles are used throughout.
- All producers face the same purchase price for assets.
- Two main methods will be compared in the computation of user costs: *ex-post* and *ex-ante* measures of costs of capital. For the *ex-post* case, a distinction is made between the standard and the simplified case, as shown in the table below.

The main steps in the calculation procedure were:

1. Apply price indices of GFCF to machinery and software investment to obtain GFCF series in chained dollars of the reference year 2000.
2. Estimate an initial stock for each asset. In our simple example, the initial stock was calculated for the year 1979 as initial stock = GFCF in 1979/(long-run growth of constant-price GFCF + rate of depreciation). Obviously, for actual implementation, the initial

Industry	Type of producer	Method		
		Ex-post rate of return		*Ex-ante* rate of return
		Standard method with *ex-post* asset price changes	Simplified method with real asset price changes set to equal zero	*Ex-ante* (average or smoothed) real asset price changes
Manufacturing	Market producers	Endogenous rate of return		4% exogenous real rate of return
Services	Market producers			
	Non-market producers	With ex-post rate as average of ex-post rate from market producers		2% exogenous real rate of return
Public administration	Non-market producers			

stock should be computed for a period that lies further in the past so that errors in the estimates of the initial stock have only a small effect on more recent levels of capital stocks. Computation of an initial stock marks a major difference to models with non-geometric patterns where no initial stock is needed but GFCF time series of the entire service life of an asset. The stock of land is expressed in physical units here, and information about it has to come from registers or land surveys. The stock of land has been taken as fixed in the present example, implying that there is only one type of land.

3. Given the net stock at the beginning of the first period, W1979B, end-period net stocks for all consecutive periods are set up by applying the stock-flow relationship $WtE = WtB + It - \delta(It/2+WtB)$. All stocks are valued at average prices (chained dollars) of the year 2000.
4. On the basis of net stock and rates of depreciation, the value of depreciation at average prices of the year 2000 is computed by applying the rate of depreciation to the net stock at the beginning of the period plus half the current period's investment: $Dt/P0t = \delta[It/2 + WtB]$. Subsequently, depreciation is re-valued to current prices by multiplying through by the price index for capital goods, P0t.
5. Only a small transformation is needed to compute the year-average net stock for every period as well as the productive stock Kt which, in the set-up in this Manual, equals the wealth stock plus investment in the latest period: $Kt=It/2+WtB$.
6. Given time series of gross operating surplus Gt along with depreciation re-valued to current prices, Dt, net operating surplus Nt is measured as Gt-Dt. For non-market producers, the net operating surplus is zero in the first instance. However, if costs of capital are imputed in the way shown in the example, the net operating surplus will be non-zero.
7. Indices of real asset prices are established by deflating nominal asset price indices by the consumer price index.
8. For every type of asset, industry and sector, the value of capital services is computed in three variants as outlined above. Results are marked up with different colours in the accompanying spreadsheet.
9. A chain Laspeyres volume index of capital services is computed as a weighted average of each asset's volume change of the productive stock with user cost shares as weights. Similar, a Paasche-type index is computed and the geometric average of both indices yields a Fisher index of capital services for each industry-sector combination.
10. Aggregation towards a measure of capital services for market producers and for non-market producers proceeds in a similar way. The volume index for capital services for the market sector is a weighted average of the volume index for market producers in the

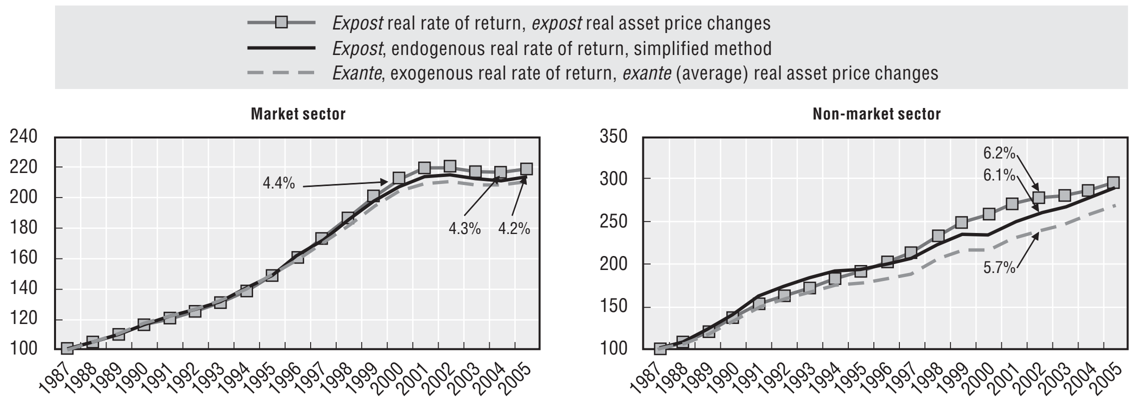
manufacturing and in the service industries. The user cost shares of each producer serve as weights in the aggregation. The same procedure is applied to non-market producers.

11. The ultimate aggregation is across market and non-market producers to yield a measure for the total economy.

The following conclusions can be drawn from examination of the results. The first and general impression is that, in terms of the volume series of capital services, one of the main outputs of the calculations, results are quite robust. The differences between the three methods of computing user costs are fairly small for the market sector. For the non-market sector, differences are larger but still less than one percentage point in average annual growth rates over the entire period (see Figure).

Figure B.1. **Comparison of three methods for the calculation of user costs**

Volume index of capital services, 1987 = 100



7. A second conclusion is that the artificial dataset confirmed an observation made in many empirical studies, namely that the *ex-post*, endogenous method for the computation of user costs produces a larger number of negative prices of capital services than the other methods. This is inconvenient from a practical perspective.

8. A third conclusion is that the comparison between the gross operating surplus for market producers as 'taken' from the national accounts and the gross operating surplus as implied by the ex-ante method yields a picture as would be expected: differences change sign and oscillate around a long-run value close to zero. This is in line with the idea that the difference between *ex-ante* and *ex-post* values is a 'surprise' term.

ANNEX C

Simplified perpetual inventory method

A full-fledged implementation of an integrated set of capital measures may be beyond the capacity of some statistical offices when, as a consequence of resourcing the statistical system, only the most basic information is available. This Annex presents a 'minimum' version of capital measures. Its objective is to sketch out a simplified method for capital measurement when the information basis is limited.

Investment series. Full implementation of the perpetual inventory method requires relatively long time series of gross fixed capital formation, broken down by type of asset and institutional sector or industrial activity. Such a data set may not be available. At a minimum, the following two-way classification for investment should be sought: sectoral dimension: GFCF carried out by government and by private sector and asset dimension: GFCF in machinery and equipment and in residential and non-residential structures.

Depending on the economic structure of the country under consideration, certain types of assets may be important to be singled out in addition. For example, in some developing countries, cultivated assets such as livestock for breeding may be an important type of capital good. In economies that are resource-rich, subsoil assets such as coal, oil or mineral reserves or non-cultivated biological resources such as natural forests may play an important role.

Calculation of net capital stocks. As has been explained elsewhere in this *Manual*, the simplest computational approach towards the measurement of depreciation and net stocks is by using a constant, age-independent rate of consumption of fixed capital (geometric rate). It dispenses from the need to specify extra parameters for a retirement profile and it permits to formulate a straight forward link between capital stocks, investment and consumption of fixed capital:

$$W^{tE} = W^{tB} + I^t - \delta(I^t/2+W^{tB}) + X^t. \quad (72)$$

For ease of presentation, we recall the variables involved here: W^{tE} and W^{tB} are the end-year and beginning-of-the year net capital stocks, I^t is gross fixed capital formation, $\delta(I^t/2+W^{tB})$ is consumption of fixed capital, and X^t is other changes in volumes of the group of assets. All variables are valued at average prices of a reference period which could be year t.

Depreciation rates. The first step towards computing the net stock above is to select a rate of consumption of fixed capital, δ. Absent good information about the rates of depreciation, δ can be set by reference to other countries' depreciation rates of similar types of assets or other countries' service lives of similar types of assets. As discussed earlier (see chapitre 13), a common way of estimating δ is the declining balance method with $\delta = R/T^A$ where T^A is the average service life of an asset, and R is a parameter around 2. Because service lives tend to be influenced by institutional and climatic conditions, it is preferable to use parameters from similar countries rather than from very different countries. The table below provides some rough-and-ready points of reference for average depreciation rates for relatively broad classes of assets.

Table C.1. **Examples of benchmarks for rates of consumption of fixed capital, by broad type of asset**

Machinery and equipment		
	Declining balance parameter R	
Average service life T^A	1.5	2
10	15.0%	20.0%
15	10.0%	13.3%
20	7.5%	10.0%
25	6.0%	8.0%

Non-residential and residential structures		
	Declining balance parameter R	
Average service life T^A	1	1.5
40	3.8%	5.0%
50	3.0%	4.0%
60	2.5%	3.3%
70	2.1%	2.9%
80	1.9%	2.5%

Initial stocks. Once a selection for δ has been made, a starting stock for some period t_0 has to be computed. For the computation of the initial stock, several avenues which have already been described in Section 15.7 – using capital survey information and/or making a plausible estimate for the long-run growth rate of volume investment. In addition, a simple approximation (Kohli 1982) can be used when geometric age-efficiency or age-price profiles apply. In this case, the productive (or net) stock at the beginning of the benchmark year t0 can approximately be written as the cumulative, depreciated investment of previous years:

$$W^{t0}\text{ (geometric)} \approx [I^{t0-1} + (1-\delta)I^{t0-2} + (1-\delta)^2 I^{t0-3} + \ldots] \quad (73)$$

Next, make a plausible assumption about the long-run growth of volume of investment – the simplest possibility may be to set it equal to the long-run growth rate of volume GDP for which there may be empirical estimates, and call this long-run growth rate θ. By assumption, one has $I^t = I^{t-1}(1+\theta)$. This relation can be inserted into the expression above for the initial capital stock:

$$[I^{t0-1} + (1-\delta)I^{t0-2} + (1-\delta)^2 I^{t0-3} + \ldots] = I^{t0-1}[1 + (1-\delta)(1+\theta) + (1-\delta)^2(1+\theta)^2 + \ldots] \quad (74)$$
$$= I^{t0-1}(1+\theta)/(\delta+\theta)$$
$$= I^{t0}/(\delta+\theta).$$

It is now possible to approximate the initial capital stock at the beginning of period t0 by the product of the level of investment expenditure in period t0 (the first period for which there is information on investment expenditure) and a combination of parameters of longer-term investment or GDP growth and depreciation.

The first period in time for which information on GFCF is available will determine the date for which this initial stock W^{t0B} can be calculated. Even if time series of volume GFCF are not available directly, it is worth attempting to estimate a series of investment data for at least some years into the past so as to place the necessarily inaccurate estimate for the initial stock as far as possible into the past. Measurement errors of the initial stock will then matter much less for the most recent estimates.

For example, a functional relationship between the volume growth of GFCF and GDP could be established on the basis of those periods for which information exists. Under the assumption that this relationship is stable over time, and given GDP series that date further back in history, a set of volume GFCF series can be estimated and then be used, together with an estimate for the initial stock, to build up stock measures W^{tE} for recent years.

Sometimes, company books or administrative records provide information about 'book values' *i.e.* about the value of assets at historical prices. Such information cannot in itself be used for capital estimates. However, in conjunction with other information, it can provide an additional reference point for initial stocks. To see how such an approach could work, consider that a book value at historical prices is simply the sum of past investment, written down by some depreciation pattern. The most typical case is a linear pattern where investment values are written off over a period of T years.

Another method to obtain an estimate of the initial stock goes back to Dadkhah and Zahedi (1986) and was recently used by Pyo (2008). They consider an aggregate Cobb-Douglas production function jointly with the stock-flow identity that links capital stocks and investment. The combination of these two relations leads to a relation where current output depends on its lagged values, on investment and on labour input. Then, an econometric search technique is applied to simultaneously determine the parameter of the aggregate production function and the rate of depreciation. This requires empirical information on output, labour input and investment but not on capital. Under the assumption that the estimated parameters are constant, they can be used to obtain an initial estimate of the capital stock. Dadkhah and Zahedi (1986) also present another approach that does not require data on labour input because it makes the assumption that capital is the constraining factor of production – an assumption that may be more easily justifiable for developing countries than for developed countries. Pyo (2008) implements estimates of initial stocks according to the Dadkhah and Zahedi (1986) and according to the Kohli (1982) method for 11 countries. For about half of them, the two methods yield similar results but for the other countries, there are large variations in estimates. It is thus recommended to use several methods for comparison and robustness tests of initial estimates.

Estimating the stock of structures under limited information. An important basic element in the national accounts is owner-occupied housing. Whether rental markets do permit using a rental equivalent method or whether a user cost method has to be applied, an estimate for the stock of owner-occupied dwellings is needed. Standard application of the PIM requires that long time series of investment in dwellings are available. When this is not the case, the question arises how approximations can be made. This section describes such an approximation method, based on Blades (2006), Eurostat (2001) and Katz (2007) but with a few additions to their method.

A minimum of information has to be available. In particular, one requires:

- The number of owner-occupied dwelling units at mid-year of the period under consideration ($W^{D,t}$). This information will typically be available from the most recent census, updated to the middle of the current period with the help of an estimated or observed growth rate of dwellings. If at all possible, this information should be stratified in a way that reflects different categories of dwellings, where categories should reflect the most pertinent price determining characteristics, such as size and/or location.
- An estimate, for example from comparison between different censuses, of the long-term growth rate of the number of dwellings (of a particular category) is also needed. This rate will be labelled b and could be calculated as $b = (W^{D,t}/W^{D,t-\tau})^{1/\tau} - 1$, if there are two pieces of census information available, τ years apart.

- The average price level of period t of a newly constructed dwelling (of a particular category), excluding land. We shall call this price $P_0^{D,t}$ where the subscript 0 indicates the age of the asset which in the present case is new.
- The ratio of the market value of land ($P^{L,t}$) to the market value of dwellings (of a particular category of dwellings) in the current year: $P^{L,t}/P_0^{D,t}$. In the absence of further information, it may be necessary to consider this ratio time-invariant.
- An estimate of the expenditure on major improvements on dwellings and land during the present year. This information is useful but not vital for the calculation at hand. Expenditure on improvements will be designated $P_0^{D,t} M^t$ where it has been assumed that the price index for major improvements is identical to the price index of new dwellings.

With these elements in hand, the method can be described more precisely. Note that despite the importance of stratifying the information if at all possible, the presentation proceeds with a single type of dwelling so as not to overburden notation. Aggregation across different strata, if available, is straight forward.

We start with re-stating the formula for the net stock of dwellings at mid period t, and valued at mid-period prices of t. In line with national accounts practice, investment is assumed to take place in the middle of periods. The maximum service life of the dwelling is T, and $P^{D,t}$ is the average price level for the net stock of dwellings. $W^{D,t}$ is measured in physical units, *i.e.* as the number of dwellings (of a particular category).

$$P^{D,t}W^{D,t} = P_0^{D,t}I^{D,t} + P_1^{D,t}I^{D,t-1} + P_2^{D,t}I^{D,t-2} + \ldots + P_T^{D,t}I^{D,t-T}. \quad (75)$$

Divide the expression by the price of a new dwelling to obtain the age-price profile $\{\psi_n\}$ which, as has been explained elsewhere in the *Manual* (Chapters 3.2, chapitre 5, and Section 19.3) reflects the ratio between the price of an n-year old asset and the price of a new asset. Then, use the information about the long-run growth rate of dwelling investment (b) to express investment in past periods as a proportion of present investment in dwellings. For example, $I^{D,t-3} = I^{D,t}(1+b)^{-3}$ constitutes the estimate for dwelling investment three periods ago. As is shown below, the stock value can then be expressed in proportion to the value of investment in new dwellings, with the factor of proportionality (B), the ratio between the value of current investment and the net stock.

$$\begin{aligned} P^{D,t}W^{D,t} &= P_0^{D,t}I^{D,t} + P_1^{D,t}I^{D,t-1} + P_2^{D,t}I^{D,t-2} + \ldots + P_T^{D,t}I^{D,t-T} \quad (76)\\ &= P_0^{D,t}\,[I^{D,t} + \psi_1 I^{D,t-1} + \psi_2 I^{D,t-2} + \ldots + \psi_T I^{D,t-T}]\\ &= P_0^{D,t}\,I^{D,t}[1 + \psi_1(1+b)^{-1} + \psi_2(1+b)^{-2} + \ldots + \psi_T(1+b)^{-T}]\\ &= P_0^{D,t}\,I^{D,t}\,B. \end{aligned}$$

The age-price or depreciation profile $\{\psi_n\}$ shows how the price of an n-year old asset relates to the price of a new asset. When entire cohorts of assets are considered, the age-price profile should take the retirement distribution into account. How age-price profiles for a single asset can be combined with retirement distributions is shown in Section 13.3. Necessary information for this calculation comprises an assumption about the form of the age-price function, a value for the maximum service life of an asset group and parameters for the retirement distribution. Blades (2006) assumes a linear age-price function. This has the merit of simplicity but makes no adjustment for a retirement distribution. The implicit assumption is that all dwellings that were constructed in a particular year end their service lives at the same moment. A simple way of approximating a linear age-price function in combination with a retirement distribution is to use a geometric rate. Katz (2007) and Eurostat (2001) suggest:

"[…] geometric depreciation can be used with a declining balance rate of 1.6. […] A declining balance rate of 1.6 is recommended because simulations have shown that with this rate, total user costs for a stock of assets are most similar to total user costs obtained using the straight-line method and an approximately normal distribution of service lives around the mean life. The geometric method is much simpler to implement than the straight-line method because it does not require depreciation to be estimated separately for each vintage of assets." (Eurostat 2001, p 19.)

Under the declining balance method (see Section 12.1), a rate of depreciation δ is computed as $\delta = R/T^A$ where R is the declining balance rate and T^A is the average service life. Following the recommendation to use R = 1.6, a 50-year service life[1] would yield a rate of depreciation of $\delta = 1.6/50 = 3.2\%$. Under a geometric rate of depreciation δ, the age-price profile is given by $\psi_n = (1-\delta)^n$ (n = 0,1,2,…) noting that the series now extends to infinity. By a manipulation similar to expression (22) one obtains:

$$\begin{aligned} B &= [1+ \psi_1(1+b)^{-1}+ \psi_2(1+b)^{-2}+\ldots+ \psi_T(1+b)^{-T}] \qquad (77)\\ &= [1+(1-\delta)/(1+b)+(1-\delta)^2/(1+b)^2+(1-\delta)^3/(1+b)^3\ldots]\\ &= [1-(1-\delta)/(1+b)]^{-1}\\ &= (1+b)/(b+\delta). \end{aligned}$$

When there is no growth in dwellings (b = 0), B equals $1/\delta$, or $[1+(1-\delta)+(1-\delta)^2+(1-\delta)^3\ldots]$. This is exactly the number of dwellings that would be observed if at every period in the past one dwelling had been built. $I^{D,t}B$ would then constitute the stock of dwellings if during the past, the same investment as in the present period, $I^{D,t}$, had taken place. When b is positive, the interpretation is similar except that there is a situation where the number of dwellings has gradually risen over time. As before, $I^{D,t}B$ is the size of the dwelling stock and $P_0^{D,t} I^{D,t} B$ its value at mid-year prices of period t.

$P_0^{D,t}I^{D,t}B$ could serve as a first estimate for the value of the dwelling stock. However, this calculation ignores an important element, namely major improvements to dwellings. These are capitalised under national accounts rules and so counted as additions to the net stock when the perpetual inventory method is applied. It should be expected that major improvements rise with rising age of capital goods. If M^t are the real expenditures on maintenance during period t, a possible relation to past investment is $M^t = \alpha_1 I^{D,t-1}+ \alpha_2 I^{D,t-2} + \alpha_3 I^{D,t-3} +\ldots$ with $0<\alpha_n$ and rising with n. To keep things simple, we shall assume that α is constant so that:

$$\begin{aligned} M^t &= \alpha\, I^{D,t}[(1+b)^{-1}+(1+b)^{-2}+(1+b)^{-3}+\ldots] \qquad (78)\\ &= \alpha\, I^{D,t}[1+(1+b)^{-1}+(1+b)^{-2}+(1+b)^{-3}+\ldots] - \alpha\, I^{D,t}\\ &= \alpha\, I^{D,t}\,(1+b)/b - \alpha\, I^{D,t}\\ &= \alpha\, I^{D,t}/b. \end{aligned}$$

Expression (78) can now be combined with (76) to form an improved estimate of the dwelling stock with major improvements added to new investment:

$$\begin{aligned} P^{D,t}W^{D,t} &= P_0^{D,t}\,(I^{D,t}+M^t)B \qquad (79)\\ &= P_0^{D,t}\,(I^{D,t}+ \alpha\, I^{D,t}/b)(1+b)/(b+\delta)\\ &= P_0^{D,t}\, I^{D,t}(1+\alpha/b)(1+b)/(b+\delta)\\ &= P_0^{D,t}\, I^{D,t}C \qquad \text{where } C\equiv(1+\alpha/b)(1+b)/(b+\delta). \end{aligned}$$

The factor C equals the ratio of new investments to the net stock of dwellings and it can be estimated relatively easily, given parameter values α, b and δ. The table below provides an example for such a calculation. Assuming that the value of investment in new dwellings during the present period ($P_0^{D,t}I^D$) equals 1000 and given an average service life of 60 years as well as a declining balance rate of 1.6, the implied rate of depreciation is 2.7%. Suppose that the long-run growth in the number of dwellings is around 2% per year and that major improvements account for about 20% of investment (for comparison, this ratio was around 25% for owner-occupied dwellings in the United States over the past two decades). Then, the estimated ratio of new investments to the net stock (C) turns out to be about 26. Multiplying this by 1000 yields an estimate of the net stock of dwellings (excluding land) for period t. Again by way of comparison, the same ratio has been 22 on average for the United States over the past two decades, so 26 does not appear as an implausible number.

Table C.2. **Example for the estimation of a dwelling stock under limited information**

Value of new investment	year t	1000
Average service life T		60
Declining balance rate		1,6
Rate of depreciation = 1.6/T		0,027
Long-run growth rate of number of dwellings (b)		0,02
Major improvements as a share of investment = α/b		0,20
C = (1+α/b)(1+b)/(b+δ).		26,2
Net stock of dwellings at current prices		26229

ANNEX D

Links between age-efficiency and age-price profiles

This annex spells out, at some detail, the links between the age-efficiency profile and the age-price profile in the non-geometric case. A distinction is made between age-efficiency and age-price profiles for individual assets and for cohorts of assets.

We first recall the optimum condition (56) which says that a cost-minimising producer will use capital goods of different age such that their relative productive efficiency equals the relative rentals for these assets. This is supposed to hold for the cohort as a whole as well as for individual assets. Let h_n and f_n^t be the cohort's age-efficiency function and user cost, respectively so that $h_n = f_n^t/f_0^t$ holds and let $g_n(T)$ and $c_n^t(T)$ stand for an individual asset's age-efficiency function and user cost so that $g_n(T) = c_n^t(T)\,/c_0^t(T)$ holds. The variables for individual assets have been indexed with T to signal their dependence on a service life T that will in general vary between individual assets.

The first task is to verify the form of a cohort age-price function, given a cohort's age-efficiency function. We do so by combining the asset market equilibrium condition (asset prices equal discounted values of expected incomes generated by the asset) with the definition of the cohort's age-price function ψ_n. As earlier in the text, P_n^{tB} stands for the price of an n-period old asset at the beginning of period t.

$$\Psi_n = P_n^{tB}/P_0^{tB}$$

$$= \frac{f_n^t(1 + r_{(tB)})^{-1} + f_{n+1}^{t+1}(1 + r_{(tB)})^{-2} + f_{n+2}^{t+1}(1 + r_{(tB)})^{-3} + \ldots}{f_n(1 + r_{(tB)})^{-1} + f_{n+1}^{t+1}(1 + r_{(tB)})^{-2} + f_{n+2}^{t+1}(1 + r_{(tB)})^{-3} + \ldots}$$

$$= \frac{f_n^t(1 + r_{(tB)})^{-1} + f_{n+1}^{t}(1 + i_{tB})(1 + r_{(tB)})^{-2} + f_{n+2}^{t}(1 + i_{tB})^2(1 + r_{(tB)})^{-3} + \ldots}{f_0^t(1 + r_{(tB)})^{-1} + f_1^t + (1 + i_{tB})(1 + r_{(tB)})^{-2} + f_2^{t+2}(1 + i_{tB})^2(1 + r_{(tB)})^{-3} + \ldots} \quad (80)$$

$$= \frac{f_n^t(1 + i^*_{(tB)})(1 + r_{(tB)})^{-1} + f_{n+1}^{t}(1 + i^*_{tB})^2(1 + r^*_{(tB)})^{-2} + f_{n+2}^{t}(1 + i^*_{tB})^3(1 + r^*_{(tB)})^{-3} + \ldots}{f_0^t(1 + i^*_{(tB)})(1 + r^*_{(tB)})^{-1} + f_1^t + (1 + i^*_{tB})^2(1 + r^*_{(tB)})^{-2} + f_2^{t+2}(1 + i^*_{tB})^3(1 + r^*_{(tB)})^{-3} + \ldots}$$

9. In this expression, the rates of return and the rates of rental price changes have been expressed in real terms. The next step consists of invoking the optimum condition $h_n=f_n^t/f_0^t$:

$$\psi_n = \frac{f_n^t(1 + i^*_{(tB)})(1 + r^*_{(tB)})^{-1} + f_{n+1}^{t}(1 + i^*_{(tB)})^2(1 + r^*_{(tB)})^{-2} + f_{n+2}^{t}(1 + i^*_{(tB)})^3(1 + r^*_{(tB)})^{-3} + \ldots}{f_0^t(1 + i^*_{(tB)})(1 + r^*_{(tB)})^{-1} + f_1^t + (1 + i^*_{(tB)})^2(1 + r^*_{(tB)})^{-2} + f_2^{t+2}(1 + i^*_{(tB)})^3(1 + r^*_{(tB)})^{-3} + \ldots} \quad (81)$$

$$= \frac{h_n(1+i^*_{(tB)})(1+r^*_{(tB)})^{-1} + h_{n+1}(1+i^*_{(tB)})^2(1+r^*_{(tB)})^{-2} + h_{n+2}(1+i^*_{(tB)})^3(1+r^*_{(tB)})^{-3} + \ldots}{(1+i^*_{(tB)})(1+r^*_{(tB)})^{-1} + h_1(1+i^*_{(tB)})^2(1+r^*_{(tB)})^{-2} + h_2(1+i^*_{(tB)})^3(1+r^*_{(tB)})^{-3} + \ldots}$$

It is now apparent that, given a cohort age-efficiency profile h_n, and a real rate of return r^* as well as a term for the real holding gains/losses i^*, a consistent age-price function ψ_n can be derived for the cohort. To simplify matters, the expected real holding gains or losses can be set to equal zero so that the above expression reduces to:

$$\psi_n = \frac{(h_n(1+r^*_{(tB)})^{-1} + h_{n+1}(1+r^*_{(tB)})^{-2} + h_{n+2}(1+r^*_{(tB)})^{-3} + \ldots)}{(1+r^*_{(tB)})^{-1} + h_1(1+r^*_{(tB)})^{-2} + h_2(1+r^*_{(tB)})^{-3} + \ldots}$$

$$= \frac{\sum_{s=0}^{T\max-n} h_{n+s}(1+r^*_{(tB)})^{-(s+1)}}{\sum_{s=0}^{T\max-n} h_s(1+r^*_{(tB)})^{-(s+1)}} \quad (82)$$

Thus, the price for n-period old assets in a cohort relative to the price of new asset corresponds to the ratio of the discounted efficiency units left in an n-year old asset relative to those left in a new asset. The efficiency profile h_n represents the age-efficiency profile of the cohort as a whole. It takes account of the fact that over the maximum service life of the asset group, T^{max}, individual assets will have different individual service lives and be retired earlier than T^{max}. In Section13.3, the cohort's age-efficiency profile was computed from age-efficiency profiles $g_n(T)$ of individual assets and a probability density function F_T for retirement as:

$$h_n = \sum_{T=n}^{T\max} g_n(T)F_T \quad (83)$$

The second avenue to be explored is the derivation of the cohort's age-efficiency profile from its age-price profile, This time, the starting point is the cohort's age-price function, ψ_n that we take as an average of the age-price functions of individual assets, $\theta_n(T)$. Akin to individual age-efficiency functions introduced above, these individual age-price functions depend on each asset's service life T. Combined with the retirement probability F_T, one gets:

$$\psi_n = \sum_{T=n}^{T\max} \theta_n(T)\, F_T \quad (84)$$

Again, the asset-market equilibrium and optimality condition invoked earlier come into play. The age-efficiency pattern for a cohort of assets is computed as follows:

$$h_n = \frac{f_n^t}{f_0^t} = \frac{P_n^{tB} r_{(tB)} + d_n^t - z_n^t}{P_0^{tB} r_{(tB)} + d_0^t - z_0^t}$$

$$= \frac{P_n^{tB} r_{(tB)} + P_n^{tB}\delta_n(1 + i_{(tB)}/2) - P_n^{tB} i_{(tB)}(1-\delta_n/2)}{P_0^{tB} r_{(tB)} + P_0^{tB}\delta_0(1 + i_{(tB)}/2) - P_0^{tB} i_{(tB)}(1-\delta_n/2)}$$

$$= \frac{P_n^{tB}(r_{(tB)} + \delta_n - i_{(tB)} + \delta_n\, i_{(tB)})}{P_0^{tB}(r_{(tB)} + \delta_0 - i_{(tB)} + \delta_0\, i_{(tB)})} \quad (85)$$

$$= \frac{P_n^{tB}(r_{(tB)} - i_{(tB)} + \delta_n(1 + i_{(tB)}))}{P_0^{tB}(r_{(tB)} - i_{(tB)} + \delta_0(1 + i_{(tB)}))}$$

$$= \frac{P_n^{tB}(r_{(tB)} - i_{(tB)} + \delta_n\,(1 + i_{(tB)})}{P_0^{tB}(r_{(tB)} - i_{(tB)} + \delta_0\,(1 + i_{(tB)})}$$

$$= \frac{P_n^{tB}(r^*_{(tB)} - i^*_{(tB)} + \delta_n\,(1 + i^*_{(tB)})}{P_0^{tB}(r^*_{(tB)} - i^*_{(tB)} + \delta_0\,(1 + i^*_{(tB)})}$$

Here, the age-efficiency profile has been expressed as a function of the real rate of return, the real rate of holding gains or losses and the rate of depreciation. A simplified version – sufficient for most practical applications is the calculation ignoring real holding gains or losses. Then, the age-efficiency profile corresponding to a depreciation profile is:

$$h_n = \frac{(P_n^{tB} r^*_{(tB)} + \delta_n)}{(P_0^{tB} r^*_{(tB)} + \delta_0)} \qquad \Psi_n = \frac{(r^*_{(tB)} + \delta_n)}{(r^*_{(tB)} + \delta_0)} \tag{86}$$

This, however, is not the end of the story. The cohort depreciation rates δ_n and δ_0 are themselves functions of the cohort age-price profile and this needs to be taken into account when a full expression for the cohort age-efficiency profile should be derived. From the definition of depreciation rates one has $\delta_n \equiv 1\text{-}\psi_{n+1}/\ \psi_n$, or when the cohort price profile is fully written out:

$$\begin{aligned}
\delta_n &\equiv 1 - \psi_{n+1} / \psi_n \\
&= 1 - \frac{\sum_{T=n+1}^{T\,max} \theta_{n+1}(T)\,F_T}{\sum_{T=n}^{T\,max} \theta_n(T)\,F_T} \\
&= \frac{\sum_{T=n}^{T\,max} \theta_n(T)\,F_T - \sum_{T=n}^{T\,max} \theta_{n+1}(T)\,F_T}{\sum_{T=n}^{T\,max} \theta_n(T)\,F_T} \\
&= \frac{\sum_{T=n}^{T\,max} \theta_n(T)\,F_T - \sum_{T=n}^{T\,max} \theta_{n+1}(T)\,F_T}{\sum_{T=n}^{T\,max} \theta_n(T)\,F_T} \\
&= \frac{\sum_{T=n}^{T\,max} (\theta_n(T)\,F_T - \theta_{n+1}(T)\,F_T)}{\sum_{T=n}^{T\,max} \theta_n(T)\,F_T}
\end{aligned} \tag{87}$$

The last two lines followed from the fact that the price of an (n+1)-year old asset with a service life of n years has to be zero, so that $\theta_{n+1}(n) = 0$. In the next step, this expression is inserted into the simplified formula for the cohort's age-efficiency profile above:

$$\begin{aligned}
h_n &= \psi_n \frac{(r^*_{(tB)} + \delta_n)}{(r^*_{(tB)} + \delta_0)} \\
&= \sum_{T=n}^{T\,max} \theta_n\,(T)\,F_T \frac{(r^*_{(tB)} + \delta_n)}{(r^*_{(tB)} + \delta_0)} \\
&= \frac{(r^*_{(tB)} \sum_{T=n}^{T\,max} \theta_n\,(T)\ \ F_T \sum_{T=n}^{T\,max}\ (\theta_n(T)\ \ F_T - \theta_{n+1}(T)\,F_T)}{(r^*_{(tB)} + \delta_0)}
\end{aligned} \tag{88}$$

$$= \frac{(\sum_{T=n}^{T\,max} r^*_{(tB)}\theta_n(T)\;F_T + (\theta_n(T)\;F_T - \theta_{n+1}(T)\;F_T)}{(r^*_{(tB)} + \theta_n F_0)}$$

$$= \frac{(\sum_{T=n}^{T\,max} r^*_{(tB)}\,P_n^{tB}(T)\;F_T + (P_n^{tB}(T)\;F_T - P_{n+1}^{tB}(T)\;F_T)}{P_0^{tB}\,(r^*_{(tB)} + \theta_0 F_0)}$$

$$= \sum_{T=n}^{T\,max} \frac{c_n(T)\,F_T}{c_0} = \sum_{T=n}^{T\,max} \frac{c_n(T)\,/\,c_0(T)\,F_T\,c_0(T)}{c_0} = \sum_{T=n}^{T\,max} = \frac{g_n(T)F_T\,c_0(T)}{c_0}$$

These lengthy derivations produce an interesting result It turns out that the cohort's age-efficiency function is a *user-cost*-weighted average of the age-efficiency functions of individual assets' age-efficiency functions[2]. This is needed for consistency with an age-price function for the cohort of the form $\psi_n = \sum_{T=n}^{T\,max} \theta_n(T)\,F_T$. If this version is chosen, it will be no more possible to follow the avenue that starts out with information on age-efficiency patterns and consecutively derive age-price functions for a cohort. This is because construction of the cohort age-efficiency function requires knowledge of user costs c_0 as shown above. To obtain c_0, a measure of depreciation is needed, and therefore an age-price profile. If one wants to use the cohort age-efficiency function as the starting point, one is thus obliged to use the approach shown in the first part of this Annex. This leads to a different cohort age-price function[3]. It is not evident which version is to be preferred.

Note another consistency issue that arises when non-geometric age-efficiency and age-price profiles are used in conjunction with endogenously computed rates of return: given an age-price profile, a rate of return is required to derive a consistent age-price profile. However, the rate of return cannot be derived endogenously unless there is information on depreciation, which in turn requires knowledge of the age-price profile. Inversely, when the age-profile is the starting point, the productive stock is required to compute the endogenous rate of return. But the productive stock hinges on the age-efficiency profile whose derivation requires information on the rates of return. In principle, the issue can be resolved through a system of simultaneous equations, provided a solution exists, or through iterative algorithms. In practice, these are tedious ways of implementing capital measures and it appears that the choice boils down to the use of geometric profiles and/or the use of exogenous rates of returns.

Notes

1. Katz (2007) points out that "…some countries in Western Europe have used a life of 50 years, which would yield a depreciation rate of 3.2 %. In contrast, because the United States now uses a 0.91 declining balance rate for residential structures, this corresponds to a geometric depreciation rate of 1.14% for 1-4 unit dwellings and a rate of 1.4 % for 5-or more unit dwellings. In comparison, the United States uses rates that are more than double these geometric depreciation rates for major replacements and for additions and alterations to dwellings."
2. The author is obliged to Brian Sliker (U.S. Bureau of Economic Analysis) who demonstrated this in a comment to an earlier version of the document.
3. In principle, thus, there should be a different notation for the cohort's age price and age-efficiency functions, depending on the direction of derivation. We abstained from adding this notational complication.

Glossary

Term	Définition
Age-efficiency profile	Describes an asset's productive capacity over its service life. The index is set to equal one for a new asset and becomes zero when the asset has reached the end of its service life. The decline in productive capacity is a result of wear and tear of the asset.
Age-price profile	Index of the price of a capital good with regard to its age. The age-price profile compares identical capital goods of different age at the same point in time. Typically, the age-price profile declines with increasing age.
Balance sheet	Statement, drawn up at a particular point in time, of the values of assets owned by an institutional unit or sector and of the financial claims (*i.e.* liabilities) incurred by this unit or sector
Capital gains	→ Holding gains
Capital input	The physical contribution of capital in the production of output. Capital input is measured as the flow of capital services into production
Capital services	→ Volume of capital services
Capital services price	→ Unit user cost
Consumption of fixed capital	"The decline, in the course of the accounting period, in the current stock of fixed assets as a result of physical deterioration, normal obsolescence or normal accidental damage" (SNA definition). "Depreciation" and "CFC" are used as synonyms in this *Manual*.
Compensation of employees	The total remuneration, in cash or in kind, payable by enterprises to employees in return for work done by the latter during the accounting period
Cost of capital	→ Value of capital services
Cohort of assets	Set of assets of the same kind and of the same age
Depreciation	The expected decline in value of a fixed asset as it ages → Consumption of fixed capital
Depreciation profile	Value loss of an asset due to aging, expressed as percentage of the value of a new asset
Depreciation rate	The rate of depreciation of an s-year old asset is the difference in the price of an s-year old asset and an s+1 year old asset, expressed as a proportion of the s-year old asset
Economic rent	Income generate by an asset when used in production. → Value of capital services
Ex-ante rate of return	Rate of return expected by investor
Ex-post rate of return	Realised rate of return – observed net operating surplus divided by the net stock of assets
Financial lease	A contract where the risks and reward of ownership are de facto transferred from the legal owner to the user of the asset
Gross capital stock	The stock of assets surviving from past investment and re-valued at the purchasers prices of new capital goods of the current period
Gross fixed capital formation	Total value of a producer's acquisitions, less disposals, of fixed assets during the accounting period plus certain additions to the value of non-produced assets such as land improvements
Historic prices	Capital stocks valued at historic prices are valued at the prices at which the assets were originally acquired.
Holding gains and losses	Holding gains and losses may accrue during the accounting period to the owners of financial and non-financial assets and liabilities as result of a change in their prices. Holding gains and losses are sometimes referred to as capital gains or as revaluation items
Mixed income	The surplus or deficit accruing from production by unincorporated enterprises owned by households; it implicitly contains an element of remuneration for work done by the owner, or other members of the household, that cannot be separately identified from the return to the owner as entrepreneur but it excludes the operating surplus coming from owner-occupied dwellings
Net capital stock	→ Wealth capital stock
Net present value	Value of discounted expected flows of benefits from using an asset in production; equals stock value of an asset in equilibrium

Term	Définition
Obsolescence	Loss in value of existing capital because it is no longer technologically suited to economic conditions or because technically superior alternatives become available. Obsolescence is typically described as a value phenomenon, not one that affects the physical services provided by a capital good. However, obsolescence can affect an asset's economic service life and hence the total volume of capital services it delivers.
Operational lease	A contract where produced assets are put at the disposal of an asset user for relatively short periods of time in return of a rental and where the owner of the asset retains responsibility for maintenance and repair
Opportunity cost	Evaluation placed on the most highly valued of the rejected alternatives or opportunities
Perpetual inventory method (PIM)	Approach towards estimating capital stocks by cumulating flows of investment, corrected for retirement and depreciation (in the case of net stocks) or efficiency losses (in the case of productive stocks)
Productive capital stock	The stock of a particular type of asset surviving from past periods and corrected for its loss in productive efficiency. Productive stocks constitute an intermediate step towards computing flows of capital services. The assumption is made that capital services flows are in fixed proportion to productive stocks.
Quantity of capital services	The flow of productive services provided by an asset that is employed in production. The volume of capital services reflects a physical (quantity) concept, not to be confused with the wealth concept of capital. The volume of capital services is the appropriate measure for capital input in production analysis.
Real values/prices	Values/prices that have been deflated with a general price index, typically the consumer price index
Rate of return (nominal)	Risk-adjusted return on investment per dollar of investment
Rate of return (real)	(1+nominal rate of return)/(1+general rate of inflation)–1
Rents on land	Rents on land are a form of property income; they consist of the payments made to a landowner by a tenant for the use of the land over a specified period
Rents on subsoil assets	Rents on subsoil assets are a form of property income; they consist of the payments made to the owner of a subsoil asset by the institutional unit for the permission to extract the subsoil deposit over a specified period
Rental (on fixed assets)	Rental on fixed assets is the amount payable by the user of a fixed asset to its owner, under an operating lease or similar contract, for the right to use that asset in production for a specified period of time
Rental price	Price for using one unit of productive stock during a particular period of time. The rental price is the price for capital services from an asset that is rented on the market → rental.
Rental value of a particular type of asset	Rental price of a particular (type) of asset multiplied by the rented productive stock of a particular (type) of asset. Equals the value of capital services purchased by the lessee.
Resource rent	The economic rent of a natural resource
Retirement	Act of putting an asset out of service because it has reached the end of its service life
Revaluation	→ Holding gains and losses
Service life	Economically useful life of an asset
Total rental value	Sum of the rental values of all productive assets
Unit user cost	User cost per constant dollar of the productive stock of an asset. Unit user costs are the price for capital services from an asset that is used by its owner. Unit user costs and capital services price are used synonymously.
Value of capital services from a particular type of asset	The income generated by assets when used in production. Calculated as unit user costs of a particular (type) of asset multiplied by the productive stock of a particular (type) of asset. "Economic rent" is a synonym for value of capital services.
Wear and tear	The loss in an asset's physical capacity to contribute to production. Wear and tear is normally modelled as a function of the asset's age. Wear and tear is the main element that shapes the age-efficiency function.
Total value of capital services	Sum of the value of capital services from all productive assets
Volume index of capital services	When there are several types of assets that deliver flows of capital services, a volume index of capital services is constructed as a weighted average of the proportionate changes in the quantity of capital services of each asset. Each asset's share in the total value of capital services constitutes the appropriate weight for the volume index.
Wealth capital stock	→ Net capital stock

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Capital – in particular of the physical sort – plays several roles in economic life: it constitutes wealth and it provides services in production processes. Capital is invested, disinvested and it depreciates and becomes obsolescent and there is a question how to measure all these dimensions of capital in industry and national accounts. The present revised *Capital Manual* is the first comprehensive guide to the approaches toward capital measurement. It is directed at statisticians, researchers and analysts and aims at giving practical advice while providing theoretical background and an overview of the relevant literature. The manual comes in three parts – a first part with a non-technical description with the main concepts and steps involved in measuring capital; a second part directed at implementation and a third part outlining theory and a more complete mathematical formulation of the measurement process.

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