Statistics Netherlands

Department of National Accounts

P.O.Box 4000
2270 JM Voorburg
The Netherlands

Perpetual Inventory Method

Service lives
Discard patterns
and
Depreciation methods

Gerhard Meinen
Piet Verbiest
Peter-Paul de Wolf

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0. Summary

The application of the Perpetual Inventory Method (PIM) requires estimates and assumptions on three parameters:

- service life
- discard pattern
- depreciation method

In this paper these parameters are discussed and choices are made in order to present an applicable approach.

Service lives are an important parameter in the Perpetual Inventory Method (PIM). However estimates of service lives, based on statistical information, are scarce. Mostly fiscal data and/or bookkeeping practices are the main sources of information. In this paper estimates of service lives based on directly observed data on capital stock and discards are presented. In addition fiscal sources, annual business reports and international data are explored. Analysis and combination of all sources resulted in a table containing "best-practice" service lives by type of asset and by industry.

It is often said that in PIM service lives are the only relevant parameter and that the influence of *discard patterns* is negligible. As a consequence a simple step function is most widely used in the PIM. However this paper shows that discard patterns seriously influence the results of PIM-calculations. Different discard patterns result in significant differences in the levels of capital stock. From this point it is hard to say which discard pattern is the "best" choice. A different way of evaluation is considering a subdivision of the capital stock in vintage classes. It turns out that the traditional PIM does not reproduce the older vintage classes sufficiently enough, compared with actual measurement of capital stock. Survival functions with a longer tail, like the Weibull and the delayed linear perform much better in this respect.
Based on these experiences, the application of the Delayed linear distribution in the PIM is recommended. The Delayed Linear survival function provides an approximation to any of the other survival functions used in this report and performs quite well when considering the subdivision of the capital stock into vintage-classes. Another advantage of the delayed linear method is that calculations are less troublesome.

The paper by Blades on *depreciation methods* shows that in most cases a straight-line depreciation provides the best approximation of the "actual depreciation".

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1. Introduction

The national accounts generally provide a comprehensive, yet detailed record of transactions and other flows that occur in the national economy in a particular period. Balance sheets complete the sequence of accounts, showing the ultimate result of the entries in the production, distribution and use of income, and accumulation accounts. Balance sheets and accumulation accounts form a group of accounts that are concerned with the value of assets owned by institutional units or sectors, and their liabilities at particular points in time and with the evolution of those values over time. Balance sheets measure the values of stocks and are compiled at the beginning and end of the accounting period. On the other hand, the accumulation accounts record the changes in the values of assets and liabilities during the accounting period. They are flow accounts, whose entries depend on the amounts of economic or other activities that take place within a given period of time.
In the balance sheets three categories of assets are distinguished:

a) non-financial produced assets
b) non-financial non-produced assets
c) financial assets

Focus in this paper will be on stocks and flows concerning non-financial produced fixed assets. In addition to gross fixed capital formation, the most important items to be estimated are net capital stock being an entry in the balance sheets and consumption of fixed capital being part of the accumulation accounts. The ESA’95 states that consumption of fixed capital must be distinguished from fiscal and commercial depreciation and should be estimated based on a gross capital stock and average service lives of different types of capital goods. The Perpetual Inventory Method (PIM) is advised to estimate gross fixed capital stock.
This paper discusses estimates for service lives based on different sources of information. Also the sensitivity of the results to different assumptions on discard patterns will be analysed, using Dutch time series data on gross fixed capital formation. In chapter 2 attention will be paid to the relation between stocks and flows and to the classifications used in the ESA. In chapter 3 the PIM will be discussed, including data requirements. Chapter 4 will focus on the estimation of service lives, while in chapter 5 possible discard patterns to be used in the PIM will be discussed. Chapter 6 discusses depreciation methods. Chapter 7 comes up with conclusions and recommendations.

2. Stocks and flows

Stocks and flows are closely related because stocks are the ultimate result of the accumulation of the relevant flows. Accumulation accounts record the changes in the values of assets during the accounting period. Balance sheets measure the values of stocks and are compiled at the beginning and end of the accounting period. The basic accounting identity links the opening balance sheet and the closing balance sheet:

the value of the net stock of a specific type of asset in the opening balance sheet

plus *the total value of the assets acquired, less the total value of those disposed of*

minus *consumption of fixed capital*

plus *other volume changes (a/o discovery of subsoil assets (+), natural disasters(-))*

plus *revaluations*

is identical with the value of the net stock of the asset in the closing balance sheet.

Within the scope of this paper, the first item required in the compilation of successive balance sheets is gross fixed capital formation (ESA code: P51), defined as:
the acquisitions, less disposals of fixed assets of resident producers during a given period plus certain additions to the value of non-produced assets realised by the productive activity of producers or institutional units. Fixed assets are tangible or intangible assets produced as output from processes of production that are themselves used repeatedly, or continuously, in processes of production for more than one year.

Gross fixed capital formation can be derived from the goods and services account or the capital account. Data on gross fixed capital formation by type of asset and industry of destination will usually be derived from the supply and use tables or input output tables.

The second item, consumption of fixed capital (ESA code: K1), is defined as:
the amount of fixed assets used up, during the period under consideration, as a result of normal wear and tear and foreseeable obsolescence, including a provision for losses of fixed assets as a result of accidental damage which can be assured against.

Consumption of fixed capital must be calculated for all fixed assets (except animals), including both tangible and intangible assets and costs of ownership transfers and major improvements associated with non-produced assets.
Consumption of fixed capital should be distinguished from depreciation allowed for tax purposes or shown in business accounts. Following the ESA95, the former should be estimated on the basis of the stock of fixed assets and the probable average economic life of the different categories of those goods (ESA95, par. 6.04).

Other volume changes mentioned as the third item above are:

- economic appearance of produced assets (ESA code: K4) that are not already recorded in the balance sheets
- catastrophic losses (ESA code: K7) which are the result of large-scale discrete and recognisable events that destroy items within any of the categories of economic assets
- other volume changes like:
    - unforeseen obsolescence (a/o resulting from the introduction of improved technology)
    - differences between allowances included in consumption of fixed capital for normal damage and actual losses
    - degradation of fixed assets not accounted for in consumption of fixed capital
    - abandonment of production facilities before completion of economic use
- changes in classifications and structure (ESA code: K12)

The last item in the link between opening and closing balance sheets is the revaluation. The value equals the holding gains or losses (ESA code: K11) on assets defined as:

the change in value for the owner of the asset as a result of a change in its price.

For the compilation of gross capital stock, the perpetual inventory method (PIM) will be applied using a time series of gross fixed capital formation as annual additions and average service lives of the assets. To arrive at current prices, revaluation is taken care of by making price adjustments to gross fixed capital formation of previous years. The “Other changes in assets” are not explicitly discussed in this paper. However in actual compilation they should be incorporated, because they affect the calculation of future consumption of fixed capital. For example: consumption of fixed capital on assets which are lost in a flood may no longer appear.

Estimation should be detailed to the types of assets distinguished in the ESA95.

In the ESA95 the following types are distinguished:

I. Tangible produced fixed assets
these include:
- *a. Dwellings*
- *b. Non-residential buildings*
- *c. Other structures*
- *d. Transport equipment*
- *e. Computers*
- *f. Other machinery and equipment*
- *g. Cultivated assets, divided in:*
  - *live stock*
  - *planting and cultivating of trees yielding repeat products*
- *h. Other tangible produced fixed assets*

II. Intangible produced fixed assets
these include:
- *a. Mineral exploration*
- *b. Computer software*
- *c. Entertainment, literary or artistic originals*
- *d. Other intangible produced fixed assets*

Brief definitions of the given types of assets are presented in annex 1.
Possible contents of the type “other intangible produced fixed assets” are not yet operationally defined and are therefore disregarded below.

3. The Perpetual Inventory Method

The ESA95 recommends the Perpetual Inventory Method (PIM) for the calculation of the stock of fixed assets whenever direct information is missing (par. 6.04). The calculation of consumption of fixed capital can be based on these stocks of assets. Besides net capital stock which appears in the balance sheets can be derived within a PIM approach. In this paragraph the basic principles of the PIM will be discussed.
Using the PIM, gross capital stock is calculated as the sum of gross fixed capital formation in previous years, of which the service live is not yet expired. In the most simple case it is assumed that the total investment of a particular asset does not deteriorate during the expected service life of that asset and is discarded as a whole after that period of time. That is, denoting the expected service life of an asset by d, an asset lasts exactly d years (See figure 3.1.)

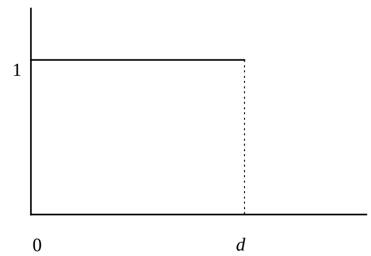

Figure 3.1: PIM-Survival function

In formula:

(3.1) $$GCS_{t,t} = \sum_{i=0}^{d-1} I_{t-i} * P_{t-i,t}$$

of which: $GCS_{t,t}$ = stock of fixed assets (gross) in year *t* in prices of year *t*
I_t = gross fixed capital formation in year *t* in current prices
$P_{t-i,t}$ = price index of year *t* with base year *t-i*
d = expected service life

Calculations using the PIM result in a gross capital stock by the end of an accounting period. Assuming straight-line depreciation, consumption of fixed capital can be calculated using formula (3.2).

(3.2) $$CFC_{t,t} = 1/d * GCS_{t,t}$$

However this calculation gives raise to a bias, because consumption of fixed capital is also imputed to the investments of December. Assuming an even distribution of the acquisitions of fixed assets over the year, the average of the stock of the current year *t* and the previous year *t-1* (of course both in prices of year *t*) seems to be a better base for the estimation. Subsequently, assuming again a straight-line depreciation of the fixed assets, consumption of fixed capital (CFC) is compiled as follows:

(3.3) $$CFC_{t,t} = 1/d * \left\{ (GCS_{t,t} + GCS_{t-1,t}) / 2 \right\}$$

Net capital stock, which appears in the balance sheets, can be compiled as gross capital stock minus accumulated consumption of fixed capital.
For each vintage of capital goods, the net value equals:

(3.4) $$NV_{t-i,t} = I_{t-i} * P_{t-i,t} - \sum_{j=0}^{i} CFC_{t-j}^{It-i}$$

of which:

$NV_{t-i,t}$ = net value of vintage *t-i* in year *t*

CFC_{t-j}^{It-i} = consumption of fixed capital I_{t-i} of vintage *t-i* in year *t-j*

The net capital stock equals the sum of the net values of still lasting vintages of gross fixed capital formation.

In formula:

$$(3.5) \qquad NCS_{t,\,t} \;=\; \sum_{i=0}^{d-1} \Big\{ I_{t-i} * P_{t-i,\,t} - \sum_{j=0}^{i} CFC^{I}_{t-j} \Big\}$$

of which: $NCS_{t,\,t}$ = net capital stock in year t in current prices

Assuming a straight line depreciation, the consumption of fixed capital per vintage equals:

$\{1/2d\} * I_t$ in year t
$\{2/2d\} * I_t$ in year $t+1$ to $t+d-1$
$\{1/2d\} * I_t$ in year $t+d$

Accumulated consumption of fixed capital per vintage can hence be written as:

$$(3.6) \qquad \sum_{j=0}^{i} CFC^{I}_{t-j} \;=\; I_t * \{1+2i\}/2d$$

Combining formulae (3.4) to (3.6) results in formula (3.7) which can be used to calculate the net capital stock

$$(3.7) \qquad NCS_{t,\,t} \;=\; \sum_{i=0}^{d-1} (I_{t-i} * P_{t-i,\,t}) * (1 - (2i + 1)/2d)$$

In annex 2 a simple example of the calculations is presented.

The main assumption in the model presented above, is that the total investment of a particular asset does not deteriorate during the expected service life of that asset and is discarded as a whole after that period of time. In chapter 5 of this paper this assumption will be relaxed and alternative approaches will be presented, using more elaborate survival functions, allowing for both earlier and later retirement of the assets.

From the formulae above the requirements for the application of the PIM can be derived. First of all long time series of data on gross fixed capital formation must be available. Depending on the assumptions made on discard patterns (see chapter 5) the necessary length of the time series surpasses the expected service life to some degree. Because service lives will vary by type of asset and by industry, detailed data on gross fixed capital formation should be available.
To arrive at current prices, price index numbers for the revaluation of gross fixed capital formation of previous years should be available.
Probably the most difficult element in the requirements is obtaining estimates of service lives detailed by type of asset and industry.
In addition to the statistical data, assumptions must be made on the discard patterns and depreciation pattern to be applied in the PIM.

4. Service lives

In most countries fairly reliable statistics on investment are available. On the contrary statistics on retirements are rare. Sources used by OECD countries to obtain information on asset service lives are tax authorities, company accounts, surveys, expert advice, and other countries' estimates (see OECD, 1993). Using this information, and assumptions on mortality functions, PIM estimates can be made. In general, estimates of average service lives and of mortality functions are less well-based than most types of economic statistics published by statistical offices. Therefore hypotheses about service lives of tangible assets and their distribution are the most difficult aspects to tackle. There is firm reason to believe that service lives differ for the various types of capital goods and even differ for the same goods as they are used in different economic activities. Besides one can imagine that service lives change over time, perhaps in conformity with technical progress and business cycles. Most PIM studies do not incorporate hypotheses that include these specifications and correlations. Attempting to arrive at accurate service lives is usually seen as the most difficult part of the PIM method. Determining this by an evaluation of their actual disposal gives serious difficulties (see: Ward 1976). One of the reasons is mentioned in West (1998): "[...] businesses saw no need to retain detailed information on disposed assets, neither for their own purposes nor to comply with accounting regulations, nor for their tax returns". The main conclusion in West's paper on the UK's experience in obtaining data on asset lives by direct observation is that direct collection of data is difficult, if not impossible.

In this chapter services lives will be estimated using three sources of information:

- directly observed data on capital stock and discards
- fiscal data
- business data

In addition the estimates will be compared with practices in other countries, based on the OECD study on methods used by OECD countries to measure stocks of fixed capital (see: OECD 1993).

4.1. Directly observed data

Estimates of service lives, based on statistical information, are scarce. Mostly fiscal data and/or bookkeeping practices are the main sources of information. In this paragraph estimates of service lives based on directly observed data on capital stock and discards are presented.

At the Canberra Conference on Capital Stock Measurement (1997) improving estimates for asset lives was discussed. Most statistical offices see as main obstacles in determining asset lives the high costs and respondent burden associated with obtaining and maintaining good measures. However, one should try to avoid the increasing reliance on estimates which largely depend on 'second-hand' estimation methods. This inevitably affects the accuracy of the estimates of capital stock.

The difficulties with PIM triggered the use of measurement of capital stock by Direct Observation of Capital Stocks (DOC) at Statistics Netherlands, in the early eighties. Presently Statistics Netherlands observes DOC benchmarks of capital stocks in each division of manufacturing industry every five years. In addition to these statistics, Statistics Netherlands introduced in 1991 a discard survey (see Smeets and Van den Hove 1993). In combination with the investment data, the discard survey reveals whether replacement of old tangible assets or additions to the capital stock levels take place. Also the DOC-benchmarks, together with the investments and discard enquiries allow Statistics Netherlands to calculate accurate in-between benchmark capital stock estimates.

Contrary to using lives of tangible assets as an input for capital stock valuation, Statistics Netherlands regard accurate service life calculations as one of the principal products of DOC estimates of capital stocks. These lives are necessary for calculating consumption of fixed capital and net capital stock for National Accounts purposes. Also Economic Planning Agencies have expressed a great need for accurate asset lives to describe and forecast economic developments.

4.1.1. The data

For manufacturing industry Statistics Netherlands is in the luxury position to have three data sources available to estimate capital stock: capital stock benchmarks, discard surveys and statistics on gross fixed capital formation. These data can also be used for the estimation of service lives of fixed assets.

All three sources use the same classification of assets and industries.

Statistics on capital stock

Usually two or three benchmarks are available for any one division of manufacturing industry, that is a two-digit standard industrial classification. The capital stock survey records all fixed assets that are used by enterprises in their production process, whether the assets are owned, rented or obtained by a leasing contract. The capital stock enquiry used by Statistics Netherlands contains information on eight types of goods:

1. land and sites (only purchase and sale of sites)
2. industrial buildings (examples are factory-buildings, offices, shops, garages and sheds),
3. civil engineering works (including site improvements), (examples are roads, pipelines for oil transport)
4. external transport equipment (for example excavators, dredging machines),
5. internal means of transport (cranes, pulleys, assembly lines),
6. computers (data processing machines that are freely programmable including peripheral devices; this excludes machinery with embedded software), (examples are personal computer, printers),
7. other machinery and other equipment (hydraulic and pneumatic installations, communication equipment, measurement equipment, control equipment),
8. other tangible fixed assets (furniture, freight containers, silos).

Capital stock benchmark surveys are performed on a rotational base, in such a way that each division of manufacturing industry will be surveyed every five years. Estimates for the years in-between are a result of the initial benchmark capital stock plus gross fixed capital formation, minus the retirements for the in-between years.

Statistics on discards

The second source available for service-life calculations is the statistics on discards (disinvestments) as a counterpart of the statistics on investments. Discards in a particular year comprise of all fixed assets which are no longer used in the production. These assets have either been scrapped or sold on the second-hand market. The discard survey started in 1991.

Statistics on investments

The third source available for service-life calculations is the investment survey for fixed tangible assets. These data are available from 1950 hitherto. The investment survey provides information on all annual additions to the in-service stock comprising of “off-the-shelf” capital goods directly entering the in-service stock, and transfers of completed facilities from the work-in-progress inventory.

The definitions used in the surveys on capital stock and investment are fairly compatible. But having two compatible definitions does not necessarily mean consistent results. The quality of the individual enterprise response is one of the main determinants of the quality of these results. Unfortunately the results are not always consistent. For some vintages initial gross fixed capital formation is smaller than the values obtained from the observed capital stock.

These differences may partly originate from enterprise transfers between industries, entry of new enterprises or bankruptcies. Further analysis indicates that some of these inconsistencies also stem from work in progress that is not properly taken into account. Theoretically, expenditure on work in progress should not be taken into account in the annual investment survey. A large and complex installation or any other tangible asset should only be included in the annual investments when it is ready and available to be used in the production process. This concept is consistent with the capital stock survey in which tangible assets are attributed to the vintage-year in which they initially became available to the production process.

Inconsistencies can partly be traced back to work in progress that was wrongly included in the investment series. Enterprises might have reported expenditures on work in progress at a point of time when payment for the tangible asset occurred, and not when it was ready for use in the production process. The guidelines for the investment survey used by Statistics Netherlands in the years before 1988, in fact even stated that work in progress should be included in gross fixed capital formation figures.

Applying the data

When reviewing the three statistical sources available for estimating service lives, one would prefer a model which uses all these sources simultaneously. Furthermore three frameworks for service life calculations can be distinguished. Firstly service lives can be examined from the point of view of a going concern (micro point of view), in which case a fixed asset is discarded as it is withdrawn from the production process of a specific enterprise, either being sold on the second-hand market or otherwise.

Secondly a fixed asset can be considered a discard when it is withdrawn from the production process of a particular industrial activity class (meso point of view) . Fixed assets withdrawn from the production process by a particular enterprise, and sold on the second-hand market to another enterprise within the same activity class are no discards within this framework.

And thirdly a fixed asset can be considered a discard when a certain vintage of capital stock is finally scrapped. None of the changes of ownership between its first year in service and its year of retirement, are then of any influence on the assets life (macro point of view).

4.1.2. The model

Having these sources at our disposal, a number of different methods of service life estimation have been reviewed (see: Van den Hove, 1994-1995). These methods have in common that for every type of capital good a survival function is postulated as a discard pattern, using a probability distribution.

Probability distribution

Assuming the discard pattern can be described using a probability distribution function, the capital stock, discards and investments can be related within a theoretical probability framework. The following equalities hold for every vintage *j* and reference date *t* (31 December year *t*):

(4.1) $$GCS_{t-1,j} = S(t-j)\cdot I_j$$

(4.2) $$R_{t,j} \equiv GCS_{t-1,j} - GCS_{t,j} \approx f(t-j)\cdot I_j$$

of which:

$GCS_{t,j}$ − gross capital stock of vintage *j* in use at 31 December year *t*.

I_j − gross fixed capital formation during year *j*.

$R_{t,j}$ − value of retirements of vintage *j* during year *t*.

$f(x)$ − probability density function: the probability a capital good is discarded at age *x*.

$S(x)$ − survival function: the probability a capital good reaches the age of *x* year, that is, the probability a capital good is not discarded before reaching the age of *x* year:

$$S(x) = 1 - \int_{y<x} f(y)dy$$

This means capital goods put into use at the beginning of a year are not distinguished from capital goods put into use at the end of the year. The vintage is determining the age. This boils down to the assumption that a capital good of vintage *j* is put into use at January 1 of that year. At December 31, its age increases with one year.

Illustration: vintage 1995

$$GCS_{95,95} = S(1)\cdot I_{95}$$

$$GCS_{96,95} = GCS_{95,95} - R_{96,95} = S(1)\cdot I_{95} - f(1)\cdot I_{95} = \big(1 - f(0) - f(1)\big)\cdot I_{95} = S(2)\cdot I_{95}$$

$$GCS_{97,95} = GCS_{96,95} - R_{97,95} = S(2)\cdot I_{95} - f(2)\cdot I_{95} = S(3)\cdot I_{95}$$

$$\ldots\ldots$$

Combing (4.1) and (4.2) results in:

(4.3) $$\frac{R_{t,j}}{GCS_{t-1,j}} = \frac{GCS_{t-1,j} - GCS_{t,j}}{GCS_{t-1,j}} \approx \frac{f(t-j)}{S(t-j)} = h(t-j)$$

of which:

$h(x)$ − Hazard rate function: the probability that a capital good, having reached age *x*-1, it is discarded at age *x* ($h(x) = f(x)/S(x)$)

Now it can be estimated which parameter values of the probability distribution give the best approximation of the survey results. However, not only the probability distribution has to be chosen, also the methodology, that is the choice of using equation (4.1), (4.2) or (4.3) in the estimation procedure, affects the final outcome.

Model assumptions

The capital stock survey provides information on the fraction of a vintage of fixed assets which survives after a certain age and thus coincides with equation (4.1). It provides information on service lives by industry (meso point of view). The discard survey provides information on the fraction of capital stock which is withdrawn at a certain age. Based on these data information on the value of retirements can be derived, which coincides with equation (4.2). Statistics on discards provide information on service lives within the framework of a going concern (micro point of view).

Theoretically equation (4.3) combines (4.1) and (4.2) and thus the results of the discard and capital stock surveys can be combined. However these two sources provide different types of information on service lives. Because of the extra information, a combination of the two sources is preferred.

Benchmark capital stock estimates are obtained every five years when a capital stock survey takes place in a particular industry. In-between benchmark estimates are the result of a combination of benchmark estimates, gross fixed capital formation and discards. Using these in-between benchmark estimates therefore means implicitly using the discard surveys, without directly relating them to the initial investments.

4.1.3. Estimation of service lives

For the specific theoretical details of the equations we use for our estimations, the reader is referred to annex 3. Assuming a Weibull distribution function the survey data can be used to estimate the best parameters for the *integrated* hazard rate by the following linear relationship.

(4.4)
$$\ln\left(\sum_{i=t-x_k}^{t} \frac{R_{t,i}}{GCS_{t,i} + R_{t,i}}\right) = \beta + \alpha \cdot \ln(x_k) + \Delta_{H,k}$$

of which:

x_k = the actual service life of the k[th] observed retirement

The error term $\Delta_{H,k}$ measures the difference between the assumed Weibull model and the measured hazard rates. Apart from measurement errors there is one more reason for this error. Contrary to the theoretical assumption, in a reference year zero discard values have been reported for certain vintages. This implies a zero hazard rate value for these vintages. The Weibull hazard rate is always greater than zero for positive age. However, the integrated hazard rate uses cumulated values, hereby circumventing the capricious behaviour of the observed hazard rate.

In the denominator of (4.4) gross capital stock of 31 December of year *t*–1 is replaced by the gross capital stock December 31 of year *t* using equation (4.2). This way the most recent survey results can be incorporated.

For every year *t* the following data are available

$i_1, i_2, \ldots, i_N$	:	Vintages with non-zero discard values.
$R_{i_1}, R_{i_2}, \ldots, R_{i_N}$	:	Observed discards of vintage i_l $(l = 1, \ldots, N)$ in the year preceding *t*.
$GCS_{i_1}, GCS_{i_2}, \ldots, GCS_{i_N}$	:	Gross capital stock of these vintages remaining on the reference date.
$x_{i_1}, x_{i_2}, \ldots, x_{i_N}$	:	Corresponding observed service lives: $x_{i_l} = t + 1 - i_l$ $(l = 1, \ldots, N)$.

Using linear regression for equation (4.4), best estimates for α and β are obtained, denoted as *a* en *b*. Using the estimates *a* and *b*, parameter estimates for α and λ of the Weibull distribution can be derived by

(4.5)
$$\hat{\alpha} = a$$
$$\hat{\lambda} = e^{b/a}$$

The estimated average service life of the capital good under consideration can then be estimated by

(4.6)
$$E(\hat{X}) = \frac{1}{\hat{\lambda}} \cdot \Gamma(1 + 1/\hat{\alpha})$$

See annex 3 for a worked example

Results

Based on discard surveys for six years (1991 - 1996), results of estimated average service lives are presented. Figures on discards, and on updated capital stock are used directly in the linear regression on (4.4) . The Weibull distribution best fitting the survey results is estimated. Table 4.1 gives the results obtained using the described methodology. It shows average service lives per type of good for every reference year. The last column gives an average service live using data of all six reference periods together.

The alpha in table 4.1. reflects three distinctive service life characteristics of the hazard rate (see: annex 3).

1. A decreasing hazard rate corresponds to $0 < \alpha < 1$;
2. A constant hazard rate corresponds to $\alpha = 1$.
3. An increasing hazard rate corresponds to $1 < \alpha < \infty$

This case can be subdivided into:
   a) a degressively increasing hazard rate: $1 < \alpha < 2$
   b) a linearly increasing hazard rate: $\alpha = 2$
   c) a progressively increasing hazard rate: $\alpha > 2$

Table 4.1 Expected service lives in manufacturing industry

	1991		1992		1993		1994		1995		1996		91-96	
Type	**e.s.l.**	alpha	**e.s.l.**	alpha	**e.s.l.**	alpha	**e.s.l.**	alpha	**e.s.l.**	alpha	**e.s.l.**	alpha	**e.s.l.**	alpha
2	**45**	1,78	**43**	1,72	**46**	1,37	**47**	1,63	**39**	1,71	**55**	1,50	**47**	1,53
3	**58**	1,89	**101**	1,65	**96**	1,57	**48**	1,53	**158**	1,28	**131**	1,82	**85**	1,60
4	**10**	1,44	**9**	1,33	**9**	1,40	**8**	1,22	**9**	1,22	**10**	1,20	**10**	1,37
5	**35**	1,44	**30**	1,62	**37**	1,54	**32**	1,53	**52**	1,17	**50**	1,15	**37**	1,45
6	**11**	2,11	**11**	2,41	**12**	2,23	**10**	1,75	**14**	2,07	**13**	1,88	**12**	2,14
7	**28**	1,58	**30**	1,43	**29**	1,45	**31**	1,46	**34**	1,43	**31**	1,45	**32**	1,44
8	**33**	1,33	**31**	1,24	**28**	1,10	**30**	1,15	**35**	1,28	**34**	1,32	**34**	1,21

Type of good

Type	Description
2.	Industrial buildings
3.	Civil engineering works
4.	External transport equipment
5.	Internal means of transport
6.	Computers
7.	Other machinery and installations
8.	Other tangible fixed assets

Despite the high level of aggregation the results give an impression of the stronger and weaker points of the methodology, and also of the quality of the results. In the following part comments will be given on the results for the different types of goods. Also results on a two-digit industry level are discussed.

Industrial buildings

Results for the expected service lives of industrial buildings are encouraging. The average discard pattern is stable, both the α-value and the expected service life do not show strong fluctuations. However, 1995 and 1996 show some surprising results. The strong decrease in the age of discards in 1995 (due to high discard values) is followed by a strong increase the next year. This may be the result of business cycle influences on the trend in gross fixed capital formation. Gross fixed capital formation may be postponed during the downturn of the business cycle. Discards of capital goods were accelerated, and old buildings that were not discarded yet are now replaced, resulting in high hazard rates for these vintages. The methodology chosen tries to correct for this influence of economic development. This example shows however that the correction method does not completely eliminate this effect. Table 4.2 gives the expected service lives of industrial buildings for a selection of industrial activity classes.

Table 4.2 Expected service lives industrial buildings, period 1991-1996

	e.s.l.	alpha
Manufacture of food, beverages and tobacco	**43**	1,61
Manufacture of paper and paper products	**55**	1,69
Manufacture of products of petroleum and coal	**46**	1,62
Manufacture of chemical products	**39**	2,02
Manufacturing industry (total)	**47**	1,53

The α-value for the industrial buildings in manufacturing of chemical products is relatively high. This indicates that not many chemical buildings are discarded in the first years they are used. However, for older vintages the hazard rate progressively increases resulting in high discard values for the industrial buildings.

Civil engineering

First of all, estimating service lives on civil engineering (non-industrial buildings, and structures) is very difficult. Data are obscured by very old vintages still found. It is questionable if these capital goods get the right vintage in the survey. It is likely that these very old assets have already been "upgraded" in such a way that at least part of the total value should have a much younger vintage. As an example one can think of building a new fence round a parking lot, replacing an older fence. It is questionable if the old fence is registered as a discard for the parking lot. Furthermore the fence should obtain the vintage of the year it is built, and not taken as part of the parking lot (with a vintage of its own). As a result, a small discard value in a certain reference period (part of the parking lot being removed for example) is divided by a large amount of remaining capital stock (old parking lot including old fence plus the new fence with the parking lot vintage attached), thereby implying a very small hazard rate. As a consequence, the estimated expected service life becomes very high.

Calculation on a lower (two-digit) level seems to confirm these presumptions. Discards of 'other buildings and structures' hardly occur. This means few hazard rates are known in each reference period. The integrated hazard rate is then highly distorted by certain peak values.

External transport equipment

At the level of total manufacturing industry, the results are quite consistent. However, at a lower level of aggregation a more erratic pattern emerges. This is probably due to the strong influence of the second-hand market. Especially external transport equipment is often leased or rented. After a number of years (long before the actual service life has expired), these capital goods are discarded. They are sold on a second-hand market, and then used again by another enterprise, which does not necessarily belong to the same industry class. Especially for this type of goods, analyses at a micro level may give further insights. At this micro level the destination of the discarded value is known (demolition, second-hand market or ‘unknown’), and these additional data can be used to analyse the influence of the second-hand market.

Another important aspect is the influence of lease and rent. Especially for external transport equipment, the role of lease is substantial. At the micro level, information both on capital goods owned and capital goods ‘in use’ is available.

Internal transport equipment

For total manufacturing, the discard pattern of the last two reference periods deviates strongly from the years before (see table 4.1). No clear reason was found for this deviation.

Table 4.3 shows the differences among several industrial activity classes. It is interesting to note the progressively increasing hazard rate ($\alpha > 2$) for the internal means of transport in the basic metal industry.

Table 4.3 Expected service lives internal means of transport (period: 1991-1996)

	e.s.l.	alpha
Manufacture of food, beverages and tobacco	**58**	1,36
Manufacture of textiles	**27**	1,55
Manufacture of paper and paper products	**24**	1,66
Manufacture of products of petroleum and coal	**31**	1,85
Manufacture of chemical products	**43**	1,35
Manufacture of basic metals and fabricated metal products	**23**	2,14
Manufacturing industry (total)	**37**	1,45

Computers

On the average, the expected service life of computers increases somewhat over time (see table 4.1). This is a rather surprising finding. However, it may be the case that at present most enterprises do not discard their computers as fast as they used to do. They may upgrade their existing stock, or at least do not discard their old computers, but use them for other purposes. Another explanation may be that PC’s, now that they have become quite cheap, are recorded as small tools and are thus not included in the capital stock any longer. What remains are the mainframes and special computers used in the industrial production process. Those computers typically have relatively long service lives. Of course outliers may also strongly influence the results.

At the industry class level, the estimated service life for computers in the basic metals industry is very high. This is mainly due to the small number of discards in the last two reference periods.

Table 4.4 Expected service lives computers (period: 1991-1996)

	e.s.l.	alpha
Manufacture of food, beverages and tobacco	**13**	2,37
Manufacture of textiles	**15**	1,90
Manufacture of paper and paper products	**10**	2,84
Manufacture of products of petroleum and coal	**10**	2,01
Manufacture of chemical products	**13**	2,07
Manufacture of basic metals and fabricated metal products	**16**	2,72
Manufacturing industry (total)	**12**	2,14

As one would expect, computers have an progressively increasing hazard rate. The older the computer, the higher the probability it will be out of date and need to be replaced.

Machinery and equipment

Results for machinery and equipment are quite stable in time at the level of total manufacturing industry. At a two-digit level the results vary significantly by the kind of activity.

Table 4.5 Expected service lives machinery and equipment (period: 1991-1996)

	e.s.l.	alpha
Manufacture of food, beverages and tobacco	**28**	1,67
Manufacture of textiles	**28**	1,83
Manufacture of paper and paper products	**29**	1,42
Manufacture of products of petroleum and coal	**37**	1,94
Manufacture of chemical products	**32**	1,59
Manufacture of basic metals and fabricated metal products	**49**	1,56
Manufacturing industry	**32**	1,44

The expected service life is relatively high in the manufacturing of basic metals and fabricated metal products. This might be caused by the same mechanism as the high expected service lives for civil engineering. At a certain (predetermined) age, large installations are taken out of production, and large maintenance takes place. Although this large maintenance also involves replacing old parts, it is questionable if the scrapped old parts are reported as discards. Furthermore it is uncertain whether the renewed part of the machinery will get as its vintage the year of investment or the vintage of the remaining ‘old’ part of the large installation.

Other tangible fixed assets

Other tangible fixed assets is a heterogeneous class. The heterogeneity may be the cause of the relatively low alpha-value (implying a relatively large tail of the distribution). Differences in the results of the underlying industry classes are large, both in expected service lives and in the shape of the distribution.

Table 4.6 Expected service lives other tangible fixed assets (period: 1991-1996)

	e.s.l.	alpha
Manufacture of food, beverages and tobacco	**27**	1,45
Manufacture of textiles	**40**	1,47
Manufacture of paper and paper products	**36**	1,20
Manufacture of chemical products	**38**	1,47
Manufacture of basic metals and fabricated metal products	**19**	2,19
Manufacturing industry	**34**	1,21

The alpha-value for establishments manufacturing basic metals and fabricated metal products for example is quite high. This also results in a very low expected service life of 19 years.

4.2. Business and fiscal data

In the service lives applied by enterprises to calculate their depreciation on tangible and intangible assets, a distinction must be made between the fiscal and the business point of view. From the business point of view, the starting point is the legislation concerning annual business reports. In this study about 100 annual reports have been analysed.
Service lives from the fiscal point of view are based on taxation policy.

4.2.1. Business data.

The legislation on annual accounts and annual reports for enterprises, states that annual depreciation on tangible fixed assets must be calculated applying a method based on the expected service lives. Service lives may be computed from either a technical or an economic point of view. The method of depreciation will be judged by means of "accepted" practice in general.

Buildings
In several annual reports it is mentioned that no depreciation is calculated on buildings that are not for own use; they are considered as a portfolio investment. Depreciation on buildings for own use is calculated using a straight line method during the service life. A possible residual value is not taken into account.

Information on this item is provided by 47 annual reports:

>15 – 25 years	32 %
>25 – 35 years	34%
>35 – 45 years	25%
45 years	9%

Very roughly this implies a an average service life of 35 years.

Two annual reports explicitly mentioned depreciation on major improvements, using a service life between 10 and 15 years.

Other construction
Data on other construction hardly are mentioned in the annual reports. In most cases they are probably included in buildings. Only one example is available using a service live of 30 years for parking lots and roads.

External transport equipment
In the case of passenger cars calculations probably include estimates for a residual value. The number of observations is limited to 8, showing service lives ranging from 3 to 8 years.
For airplanes (including spare engines) a service life of 10 to 25 years is reported, reckoning with a residual value between 0 and 25% of the initial expenditure. For trains a service life of 25 years is used by the national railways.
In case of ships service lives in the range 10 – 25 years are reported.

IT-equipment
For main frame computers and personal computers a service life between 3 and 5 years is reported (11 observations).

Other machinery and equipment

In case of other machinery and equipment 29 reports provide information on service lives.

<= 10 years	52%
>10 – 15 years	31%
>15 – 20 years	10%
> 20 years	7%

A very rough estimate implies an average service life of 12 years.

Other tangible assets

An example of other tangible assets is office equipment. 24 annual reports provide information on service lives.

<=5 years	50%
>5 – 10 years	50%

A very rough estimate implies an average service life of 5 years.

Intangible assets

Intangible assets mentioned in the annual reports are expenditures on the emission of shares, research, goodwill. In case of purchased goodwill the service life is ranging from 10 to 40 years (10 observations).

Reported service lives of software range from 2 to 5 years.

4.2.2. Fiscal data

Fiscal authorities state that expenditure on capital goods must be written off during the period that the enterprise gets benefits from them. Only capital goods which are owned (or which appear on the balance sheet) by the enterprise should be reported. Several methods for the calculation of depreciation are allowed (straight line, degressive, step wise). In case of straight line depreciation the annual percentages must be closely related to the expected service life and the residual value. In daily practice the following service lives are accepted:

Industrial buildings:	20 – 30 years
Dwellings/shops:	50 years
Passenger cars:	5 years
Machinery and equipment	10 years

It is interesting to note that an estimation based on survey data, typically, yields longer service lives than what can be derived from business reports and fiscal practice.

4.3. International data

The report "Methods used by OECD countries to measure stocks of fixed capital" published by the OECD (1993) presents an overview of service lives applied in a number of OECD-member states. Detailed data are available for machinery, especially in manufacturing industries. That table is copied in this text.

Table 4.7 Average service lives of machinery and equipment (excluding vehicles) (years)

	Canada	United States	Japan	Australia	Austria	Belgium	Finland	France	Germany	Iceland	Italy	Norway	Sweden	United Kingdom
Agriculture	15	17	6	13	18	15	-	10	15	14	18	20	15	13
Forestry	10	-	5	13	18	15	5	10	14	14	18	20	20	-
Fishing	3	-	-	13	18	15	-	16	14	14	18	6	-	12
Petroleum and gas	20	13	7	16	20	15	20	17	15	-	18	15	30	12
Coal mining	20	12	7	16	20	15	20	17	15	-	18	25	30	15
Iron ore mining	20	14	9	16	20	15	20	21	15	-	15	25	30	25
Other mining and quarrying	20	14	8	16	20	15	20	17	15	-	15	25	30	24
Food and beverages	9	20	11	19	22	15	20	17	15	22	18	25	20	26
Tobacco	15	21	11	19	22	15	20	17	16	22	18	25	20	26
Textiles	26	16	10	19	17	15	19	21	16	22	18	25	20	28
Clothing	21	15	11	19	17	15	19	21	12	22	18	25	20	24
Leather	15	15	10	19	17	15	19	21	16	22	18	25	20	24
Lumber and wood products	26	12	10	19	15	15	18	21	12	22	18	25	15	23
Furniture	26	14	10	19	15	15	18	21	12	22	18	25	15	23
Paper and paper products	22	16	12	19	18	15	17	21	16	22	16	25	30	32
Printing and publishing	30	15	12	19	15	15	17	21	15	22	16	25	30	32
Chemicals	22	16	8	19	18	15	18	17	16	22	16	25	15	29
Petroleum and coal products	26	22	13	19	18	15	18	17	19	22	18	25	30	23
Rubber	15	14	9	19	18	15	18	17	15	22	15	25	15	24
Plastic products	15	14	9	19	18	15	18	17	16	22	15	25	20	24
Clay and stone products	26	19	9	19	17	15	15	17	13	22	16	25	35	24
Glass	26	19	9	19	17	15	15	17	14	22	16	25	35	24
Other non metallic mineral	26	19	9	19	17	15	15	17	14	22	16	25	30	24
Basic metals	22	27	13	19	20	20	15	21	17	22	15	25	35	26
Metal products	21	24	11	19	20	15	15	17	14	22	20	25	25	26
Non-electrical machinery	21	25	12	19	20	15	15	17	13	22	16	25	25	25
Electrical machinery	22	14	10	19	20	15	15	17	15	22	16	25	25	25
Motor vehicles	30	14	11	19	20	15	15	17	14	22	16	25	15	27
Other transport equipment	30	17	11	19	20	15	15	17	14	22	16	25	15	27
Instruments etc.	13	14	11	19	-	15	20	21	16	22	18	25	20	24
Other manufacturing	13	17	11	19	-	15	20	21	16	22	18	25	20	24
Electricity	35	26	15	25	18	20	25	17	18	-	18	25	35	39
Gas	35	14	15	25	18	20	25	17	16	-	18	-	35	20
Water	35	14	12	22		20	25	17	16	-	-	25	35	27
Construction	10	12	5	13	8	15	10	13	10	14	18	12	10	26

Canada United Japan Australia Austria Belgium Finland France Germany Iceland Italy Norway Sweden United

		States												Kingdom
Wholesale and retail trade	20	11	10	16	20	15	15	21	12	22	-	15	15	30
Railways	28	27	-	30	-	15	-	13	23	-	-	12	35	25
Road: passenger	10	15	-	-	-	15	-	13	11	-	-	15	-	25
Road: freight	10	11	-	-	-	15	-	13	11	-	-	15	-	25
Air: aircraft	10	16	-	18	-	15	-	13	11	14	-	15	-	8
Air:airports etc.	10	-	-	18	-	15	-	13	11	-	-	-	-	15
Water: vessels	35	27	-	19	-	15	-	13	21	-	-	17	-	10
Water: harbours, docks, canals	-	-	-	19	-	15	-	13	-	-	-	25	40	25
Warehousing	25	11	10	-	-	15	-	13	-	-	-	15	-	25
Broadcasting	15	21	6	19	-	15	-	13	-	-	-	15	-	20
Telephone and telecommuni-cations	25	16	8	19	-	15	-	13	12	-	-	20	15	20
Financial etc. and business services	15	12	-	13	20	15	10	17	13	-	-	15	20	21
Public administration	20	15	-	15	15	15	-	17	15	-	-	20	20	20
Education	20	11	-	15	-	15	-	17	11	-	-	20	20	20
Health	15	11	-	15	-	15	-	17	14	-	-	20	20	15
Personal services	-	10	-	15	20	15	-	17	-	-	-	15	20	30

Source: OECD

Table 4.7 shows that there are big differences in estimates for service lives of machinery between the presented countries, up to 300%. Japan applies the smallest service lives for compiling the capital stock: 5 - 15 years. The UK and Canada apply the largest values: 9 - 35 years (leaving out the extreme value of 3 for fishing).

Although the differences between countries are very large, the pattern of service lives by industry harmonises. Public utilities (gas, water and electricity) generally have the largest service live, followed by manufacturing and mining and quarrying. Service industries and agriculture have clearly smaller service lives.

Table 4.8 Average service lives of buildings and other construction separately (years)

	Buildings						Engineering construction				
	Canada	United States	Finland	Italy	Norway	Sweden	Canada	United States	Finland	Norway	Sweden
Agriculture	40	38	-	-	75	80	-	38	60	33	60
Forestry	20	-	40	-	75	-	30	31	30	75	25
Fishing	25	-	-	-	45	-	25	31	60	8	-
Petroleum and gas	25	15	-	35	60	-	30	16		60	-
Coal mining	25	23	25	35	60	60	30	31	30	60	80
Other mining and quarrying	25	24	25	32	60	60	30	31	30	60	80
Manufacturing	40	32	40	38	60	60	48	31	45	60	80
Electricity	50	40	50	35	75	75	55	30	30	75	50
Gas	50	40	50	35	-	75	55	30	30	-	80
Water	50	40	50	-	-	75	70	26	30	90	80
Construction	25	37	40	40	60	75	30	31	30	-	-
Wholesale and retail trade	50	36	50	-	60	75	55	31	30	-	80
Hotels and restaurants	50	32	50	-	60	65	55	31	30	-	-
Railways	50	47	-	-	75	80	55	51		75	75
Road: passenger	50	38	-	-	-	60	55	31		-	80
Road: freight	60	38	-	-	-	60	65	31		-	80
Transport by air	40	39	-	-	75	75	50	31		-	80
Transport by water	50	39	-	-	-	-	50	31		75	80
Warehousing	50	38	-	-	-	-	-	31		-	80
Broadcasting	50	32	-	-	-	75	-	31		-	40
Telephone and telecommunications	50	40	-	-	75	75	55	27		75	40
Financial etc. and business services	50	36	50	-	60	75	-	-	10	-	-
Public administration	50	50	50	-	75	75	55	-	70	-	80
Education	50	36	50	-	75	75	-	-		-	-
Health	50	43	50	-	75	75	-	-		-	-
Personal services	50	34	50	-	60	75	-	-		-	-

Tables 4.8 and 4.9 show that in case of buildings and other construction, the differences are relatively much smaller compared with machinery. The USA generally show the smallest service lives for both buildings and other construction. Norway and Sweden score relatively high. No clear pattern of service lives over industries can be concluded from these tables.

Table 4.9 Average service lives of buildings and other construction

	Australia	Belgium	Germany	France	Iceland	United Kingdom
Agriculture	43	30	69	40	45	30
Forestry	43	30	69	-	45	50
Fishing	43	30	69	-	45	50
Petroleum and gas	31	-	41	35	-	16
Coal mining	31	30	41	35	-	41
Other mining and quarrying	31	30	41	40	-	60
Manufacturing	39	31	41	37	45	60
Electricity	38	40	62	40	45	34
Gas	38	40	61	35	45	46
Water	72	40	77	40	45	83
Construction	45	30	47	30	45	80
Wholesale and retail trade	51	30	65	30	45	80
Hotels and restaurants	51	30	69	30	45	80
Railways	67	30	41	40	-	100
Road: passenger	-	30	43	40	75	50
Road: freight	-	30	43	40	75	50
Transport by air	32	30	43	40	75	40
Transport by water	48	80	43	40	45	20
Warehousing	-	-	-	-	45	50
Broadcasting	50	30	-	-	45	75
Telephone and telecommunications	50	30	38	40	45	75
Financial etc. and business services	58	30	68	30	85	80
Public administration	54	80	77	30	85	75
Education	51	80	64	30	85	75
Health	51	40	69	30	85	75
Personal services	51	40	-	30	85	80

Also for the other fixed assets big differences in applied service lives are shown. Belgian sevice lives are relatively low. Data detailed by industry are not available.

Table 4.10 Average service lives of other fixed assets (years)

	Canada	United States	Japan	Australia	Belgium	Finland	France	Germany	Iceland	Norway	Sweden	United Kingdom
Vehicles												
Farm tractors	10	9	-	-	7	9	13	18	17	20	15	10
Fishing boats	25	27	-	-	7	10	22	20	37	-	-	25
Other ships	35	27	-	-	15	10	22	26	37	-	-	20
Buses	10	14	-	-	7	10	10	10	14	7	6	10
Rolling stock	28	28	-	-	15	10	25	34	14	35	35	30
Road freight vehicles	10	10	-	-	7	10	10	8	14	7	3	10
Passenger cars	6	10	-	-	7	10	10	8	14	6	2	10
Aircrafts	10	16	-	-	15	10	16	10	14	15	15	10
Dwellings												
1- 4 unit structures												
new	-	80	45	60-90	80	55	-	70	85	90	75	100
Additions and alterations	-	40	-	40	-	-	-	-	85	90	-	10
5+ unit structures												
new	-	65	50	60	80	55	-	70	85	90	75	100
Additions and alterations	-	32	-	40	-	-	-	-	85	90	-	40
Computers	-	8	-	-	-	-	-	8	14	-	15	-
Office machinery	-	8	-	-	-	-	-	9	14	-	10	-

4.4. Conclusions on service lives

In this chapter an attempt will be made to compile a “best-practice” table for service lives per type of asset and industry.

Dwellings
On dwellings no observed data are available. Looking at the OECD-tables an average of 75 years seems to be an acceptable estimate.

Buildings
In *agriculture*, buildings are often a combination of dwellings and sheds. A service life comparable to dwellings seems to be reasonable. The service life of cowsheds, pigsties, etc. will be much smaller. Agricultural organisations in the Netherlands use service lives in the range of 20 to 30 years. On the average a service life for buildings in agriculture of 45 years will be used.

In case of *fishing* no data are available. The OECD-data suggest a larger service life for this industry compared to manufacturing. A service life of 50 years will be used.

For *mining and quarrying* no directly observed data are available. The OECD-data agree on a smaller service life for this industry compared to manufacturing (average 47 years based on direct observation). A service life of 40 years will be used.

In case of *manufacturing* the estimates resulted from direct observation are included in the best-practice table. For those industries in manufacturing, where no separate estimates are available, the average for total manufacturing (47 years) is used.

In case of *public utilities* and *construction* also the average service life of total manufacturing resulting from direct observation is used.

For service industries ranging from trade to other services no directly observed data are available. In general the service lives of buildings is expected to be larger than in manufacturing. Generally the OECD-data confirm this idea. An estimate of 60 years will be used.

Other construction
The estimation of service lives of other construction based on directly observed data, is not without problems and the results for manufacturing are not reliable. From annual reports an estimate of 30 to 35 years for parking lots and roads is derived. The same service life is applied by the national railways in case of railroads. An estimate of 35 years will be used for all industries.

External transport equipment
External transport equipment is a heterogeneous category consisting of passenger cars, lorries, trains, ships, aeroplanes, etc. all having their own service life. The average service life for *manufacturing* resulting from direct observation is 10 years. In *agriculture*, the share of farm tractors and lorries, which have a larger service life, will be larger than in manufacturing. Therefore a service life of 12 years is assumed.
In case of *transport*, different estimates must be made. For ships a service life of 25 years will be used, based on data from annual reports. This estimate will also be used for *fishing* industry. For aeroplanes also a service life of 25 years will be used. The same service life is used for trains. Both estimates are based on annual reports.
For other *service* industries external transport equipment will mainly consist of passenger cars, which will have a smaller service life. A average of 8 years is used.

Machinery
The average service life for machinery in *manufacturing* based on direct information is 32 years. In case of industries within manufacturing for which no separate estimates are available, this 32 years average will be imputed. The extreme value for basic *metal and metal products* gives reason to make a split. Possibly basic metal will have a large service life (ovens), while manufacturing of metal products has a service life comparable to other industries in manufacturing.
The OECD-data suggest that service lives in agriculture and mining and quarrying are somewhat smaller than in manufacturing. The same holds for *construction and service industries.*
Public utilities will get the average service life of manufacturing.

Computers
Directly observed data for manufacturing result in an average service life for computers of 12 years. This seems to be high, but main frame computers used in industrial processes will probably have a relatively large service life. On the contrary, industries owning a lot of personal computers, will have a much smaller service life. An estimate of 5 years is used, based on annual reports.

Other tangible assets
Other tangible assets consists of furniture, etc.. For industries not covered by direct observation a service life of 10 years is assumed, based on annual reports. *For manufacturing, public utilities and construction*, estimates of chapter 4 are used.

Intangible assets

Based on annual reports a service life of 3 years is applied for all industries.
For mineral exploration, a service life of 10 years is used, based on the report of the task force on intangible assets:

Following the general approach in business accounting, unsuccessful exploration is capitalised, but is written off in the same year, which means a one-year service life. For successful exploration, the service life of the deposit itself can be used. Unfortunately practical problems and missing data forces national accounts to look for a second best solution.

For example:

** whether exploration is successful or not, only becomes clear at the end of the project, which can take more than one year. So it is not clear which part of annual expenditure should be written of in the same year.*

** in most cases separate data for unsuccessful exploration are not available so only an estimate for total mineral exploration can be made.*

A second best solution is to apply a weighted average of the service life of successful mineral exploration and unsuccessful exploration. Dutch data for 1995 show that ca. 75% of test borings is unsuccessful. Assuming a service life for a deposit of 40 years, a weighted average of round about 10 years for total mineral exploration results. This complies with business accounting practices in the Netherlands, in which a service life of 10 years is used.

Table 4.11. “Best-practice” service lives

	Ttangible assets							***Intangible assets***	
	dwellings	*buildings*	*other construction*	*external transport*	*machinery*	*computers*	*other assets*	*software*	*mineral exploration*
Agriculture/forestry		45	35	12	15	5	10	3	
Fishing		50	35	25	15	5	10	3	
Mining and quarrying		40	35	10	20	12	25	3	10
food and beverages		43	35	10	28	13	27	3	
textile/leather		47	35	10	28	15	40	3	
paper/paper products		55	35	10	29	10	36	3	
petroleum + products		46	35	10	37	10	38	3	
chemical industry		39	35	10	32	13	38	3	
basic metal+ products		47	35	10	49	16	19	3	
other manufacturing		47	35	10	32	12	34	3	
publ. Utilities		47	35	10	32	12	34	3	
construction		47	35	10	20	12	34	3	
trade		60	35	8	15	5	10	3	
Hotel, restaurants etc.		60	35	8	15	5	10	3	
Transport		60	35	*)	15	5	10	3	
Banking and insurance		60	35	8	15	5	10	3	
Rented dwellings	75	60	35	8	15	5	10	3	
Rented buildings		60	35	8	15	5	10	3	
Commercial services		60	35	8	15	5	10	3	
government		60	35	8	15	5	10	3	
Health care		60	35	8	15	5	10	3	
other services		60	35	8	15	5	10	3	

*) ships: 25 years
aeroplanes: 25 years
trains: 25 years
other: 10 years

5. Discard patterns

In the standard application of the PIM the main assumption is that the total investment of a particular asset does not deteriorate during the expected service life of that asset and is discarded as a whole after that period of time. That is, the survival function of an asset is -for the standard-PIM method- simply a step function. In this chapter alternative approaches are presented for the discard patterns, using more elaborate survival functions, allowing for both earlier and later retirement of the assets. In section 5.1, the gross capital stock, the depreciation model and the net capital stock will be defined for a general survival function and illustrated by a simple example. In section 5.2 these definitions will be applied to four types of assets in the chemical industry, using five different survival functions, including PIM. Section 5.3 contains experiments concerning the change of the expected service life, while keeping the survival function fixed. For the sake of brevity, only the standard-PIM survival function is used to show the effects of changing the expected service life. Additionally, in section 5.4 the gross capital stock will be considered in more detail: the modernness of the stock is illustrated by subdividing the stock in a particular year into vintage-classes. Finally, in section 5.5 some conclusions will be given.

5.1. Survival functions

In the (standard) Perpetual Inventory Method, a simple step function is used for the survival function of a certain asset. (See figure 5.2) That is, denoting the expected service life of an asset by d, an asset lasts exactly d years.

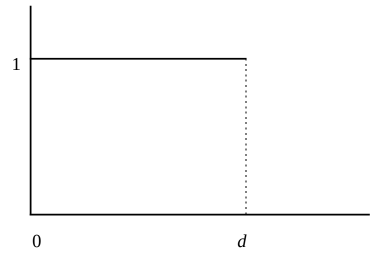

Figure 5.2: PIM-Survival function

Using a probabilistic point of view, the survival function equals the tail of the probability function of the service life of an asset, i.e.,

(5.1) $S(t) = 1 - F(t)$

where $S(t)$ is the survival function and $F(t)$ the probability distribution of the service life of the asset. Since $F(t)$ equals the probability that the service life of an asset is less than or equal to t, it follows in case of PIM that the probability that an asset has a service life less than or equal to l equals 0 for all values $l < d$ whereas the probability that it has a service life less than or equal to d is 1. I.e., with probability 1, the service life of an asset (in case of PIM) equals d. Moreover, the expected service life d then indeed equals the expectation of the service life of an asset, with respect to the probability distribution F.

In Figure 5.3 the shapes of the other four survival functions we will be using in our experiments are shown. In each case, *d* denotes the expected (mean) service life. See annex 4 for more information on the exact formulas and the exact values for the parameters used in the experiments.

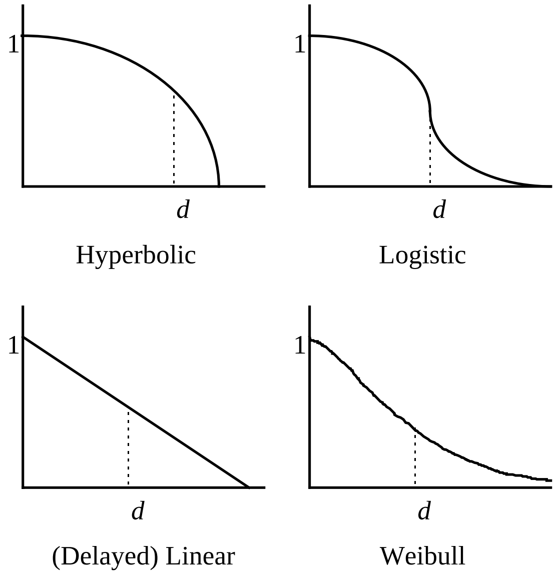

Figure 5.3: Four survival functions

In the following subsections gross capital stock, a simple model for depreciation and the resulting net capital stock will be given when using a general survival function like the ones introduced in the present section.

gross capital stock

Using a survival function *S*, the gross capital stock can be estimated using the following formula:

(5.2) $$GCS_t = \sum_{j=j_0}^{t} I_j S(t+1-j)$$

where GCS_t denotes gross capital stock at the end of year *t*, I_j the investment with vintage year *j*, j_0 the first year with a reported investment and $S(t+1-j)$ the amount of the investment of vintage year *j* that has survived at the end of year *t*. Note that *t* + 1 – *j* equals the actual service life of an asset from vintage *j, at the end of year t, i.e., just before year t* + 1. Moreover, for the sake of simplicity of the formulas, price changes are assumed to be zero.

In Table 5.7 the gross capital stock for the different survival functions is illustrated, in the case of only one investment in year 2. Note that the values of gross capital stock are the values *at the end of the year;* that is at the end of the year of the investment, part of the investment is already disposed of, except in case of PIM,

Table 5.7: Gross Capital stock for the different survival functions

		GCS_t				
	I	PIM	Lin	Hyp	Log	Wei
1	0	0	0	0	0	0
2	100	100	90	96.6	94.5	94.8
3	0	100	80	92.2	87.3	84.1
4	0	100	70	86.0	78.3	70.8
5	0	100	60	77.1	68.0	56.9
6	0	100	50	62.9	56.8	43.9
7	0	0	40	36.6	45.6	32.5
8	0	0	30	0	35.2	23.2
9	0	0	20	0	26.3	16.0
10	0	0	10	0	19.1	10.7
11	0	0	0	0	13.5	6.9
12	0	0	0	0	9.4	4.3

Consumption of fixed capital

A frequently used model for estimating consumption of fixed capital in case of PIM is simply assuming that each year during the life of an asset, an equal amount of the investment is written off. However, since the gross capital stock is calculated at the end of each year, this simple model yields the same consumption of fixed capital for the assets acquired in January as for the ones acquired in December of that year. At the National Accounts Department of Statistics Netherlands, this problem is circumvented by defining the consumption of fixed capital in the following way (see also eq. 3.3):

$$(5.3) \qquad CFC_t = \frac{1}{2}\left(\frac{GCS_t}{d} + \frac{GCS_{t-1}}{d}\right)$$

When using a general survival function *S*, part of an investment is discarded before it has reached the expected service life and part of the assets will have a service life longer than the expected service life. In defining the depreciation, this effect should be taken into account. Therefore, consider the following simple depreciation model.
Since the *actual* service life of an asset is not known beforehand, the depreciation is assumed to be equal for each year in the period of acquirement until the *expected* service life. In case an assets service life is shorter than its expected service life, the remaining value of that asset will be depreciated *at once*. Moreover, when an asset has reached the age of its expected service life, its complete value has been depreciated and hence no more depreciation is necessary. Formally, the consumption of fixed capital is hence defined by:

$$(5.4) \qquad CFC_t = \frac{1}{2}\left(\sum_{j=t-d+1}^{t} cfc(t;j) + \sum_{j=t-d}^{t-1} cfc(t-1;j)\right)$$

with $cfc(t;j)$ is the consumption of fixed capital at the end of year *t* of an investment of the vintage year *j*, i.e.,

$$(5.5) \qquad cfc(t;j) = \begin{cases} \frac{I_j}{d} S(t+1-j) + \left[S(t+1-j) - S(t-j)\right]\left(d-(t-j)\right)\frac{I_j}{d} & if \quad t-d < j \le t \\ 0 & otherwise \end{cases}$$

where the first term denotes the “standard” consumption of fixed capital and the second term equals the amount of discarded assets times its “remaining” expected service service lives the value for each of these years.

Note that indeed the total value of the investment is written off:

$$(5.6) \qquad \sum_{t=j}^{j+d-1} cfc(t;j) = I_j$$

Moreover, formula (5.3) is obtained when substituting the PIM-survival function in (5.4).
Using this simple model for the estimation of consumption of fixed capital, the gross capital stock of Table 5.7 is depreciated as given in Table 5.8.

Table 5.8: Consumption of fixed capital for the different survival functions

		CFC_t				
t	*I*	PIM	Lin	Hyp	Log	Wei
1	0	0	0	0	0	0
2	100	10	14	11.4	12.2	12.1
3	0	20	26	22.4	23.8	24.8
4	0	20	22	21.4	22.1	23.7
5	0	20	18	19.9	19.4	19.5
6	0	20	14	17.2	15.7	14.2
7	0	10	6	7.7	6.8	5.7
8	0	0	0	0	0	0
9	0	0	0	0	0	0

Net Capital Stock

Having defined the gross capital stock and the consumption of fixed capital for general survival functions, the net capital stock can then be calculated. Formally the net capital stock is defined as the gross capital stock minus the accumulated consumption of fixed capital. Since the total value of an investment is completely written off after the expected service life, it is no longer present in the *net* capital stock although it is still present in the *gross* capital stock. Hence, combining Table 5.7 and Table 5.8 yields:

Table 5.9: Net Capital Stock with the different survival functions

		NCS_t				
t	*I*	PIM	Lin	Hyp	Log	Wei
1	0	0	0	0	0	0
2	100	90	86	88.6	87.8	87.9
3	0	70	60	66.2	64.0	63.1
4	0	50	38	44.8	41.9	39.4
5	0	30	20	24.9	22.5	19.9
6	0	10	6	7.7	6.8	5.7
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

5.2 Capital stock of the chemical industry

For the chemical industry, annual gross fixed capital formation is available for the period 1949 until 1995 for four different types of assets[1]. Furthermore, the gross capital stock of these assets in 1948 was estimated earlier. Since no information was available on the vintages of that gross capital stock, it

[1] Type 1: industrial buildings, Type 2: civil engineering, Type 3: machinery, Type 4: transport equipment.

was assumed that in each of the *d* years preceding 1948, the same amount of assets was acquired, where *d* is the expected service life of the specific asset. That is, each year was appointed an investment of GCS_{1948}/d . The time series of investments of the four types of assets are shown in annex 5.
In Table 5.10 the expected service life *d* used in the experiments is given for the various types of assets.

Table 5.10: Expected service lives in chemical industry, The Netherlands

Type of asset	*d*
Type 1 (buildings)	55
Type 2 (civil engineering)	35
Type 3 (machinery)	19
Type 4 (transport equipment)	13

Using these expected service lives and the five survival functions given in section 5.1, gross capital stock, consumption of fixed capital and net capital stock were calculated for the four types of assets. The following figures show the results for assets of type 3 (machinery) whereas the results of the other types appear in annex 6. The abbreviations of the used methods are: PIM (= Standard Perpetual Inventory Method), DL (=Delayed Linear), Hyp (=Hyperbolic), Log (=Logistic) and Wei (=Weibull). For a full description of the associated survival functions, see annex 4.

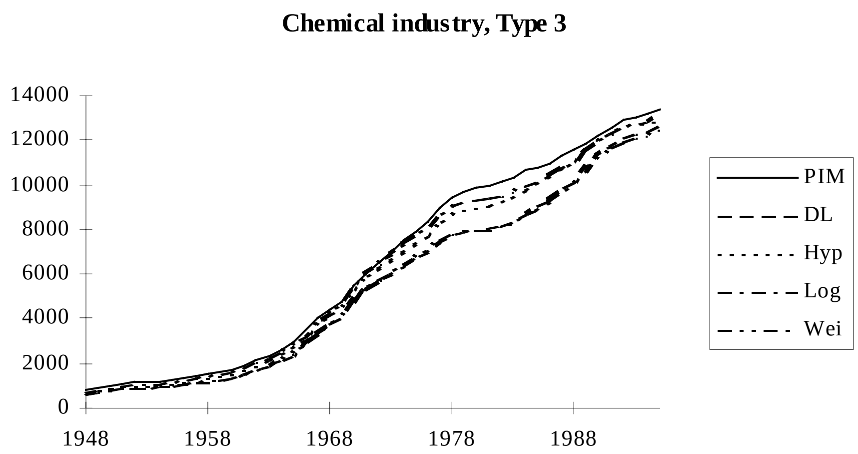

Figure 5.4: Gross Capital Stock, Type 3

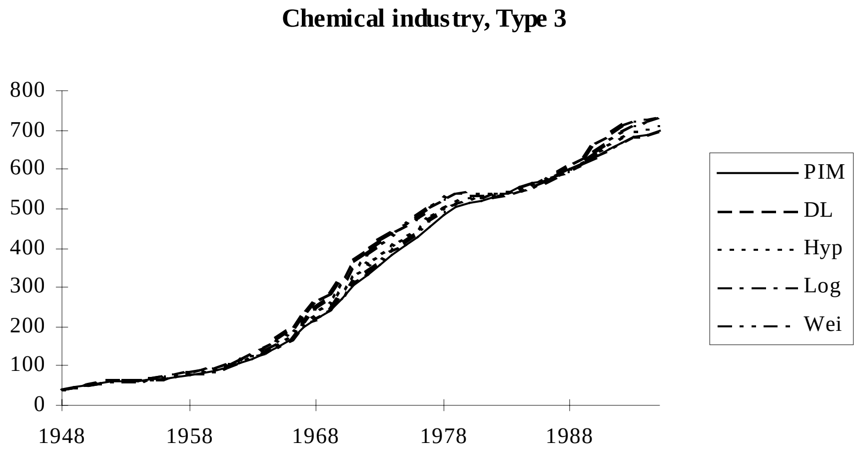

Figure 5.5: Consumption of fixed capital, Type 3

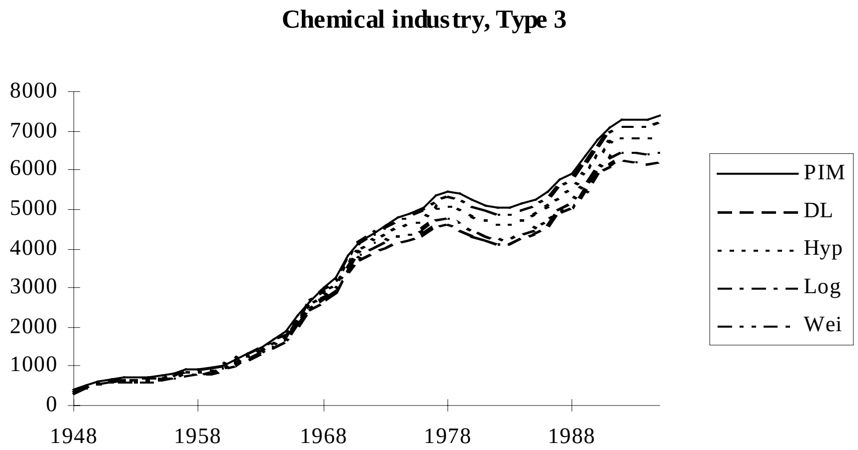

Figure 5.6: Net Capital Stock, Type 3

To illustrate the magnitude of the differences, the relative differences with respect to the PIM-method were calculated. For the gross capital stock this is formulated by:

$$(5.7) \qquad \frac{GCS_t^m - GCS_t^{PIM}}{GCS_t^{PIM}} \times 100\%$$

where m is any of the methods DL, Hyp, Log or Wei. Similar formulas were used to illustrate the magnitude of the differences for depreciation and for net capital stock. This resulted in the following figures:

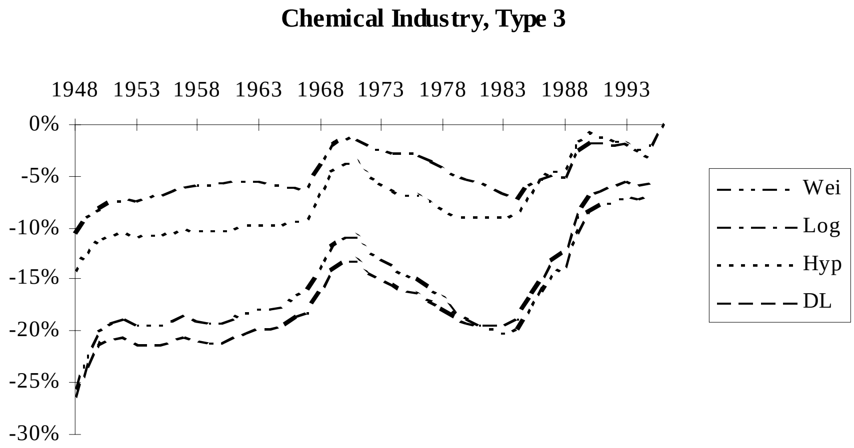

Figure 5.7: Relative differences with respect to PIM for Gross Capital Stock

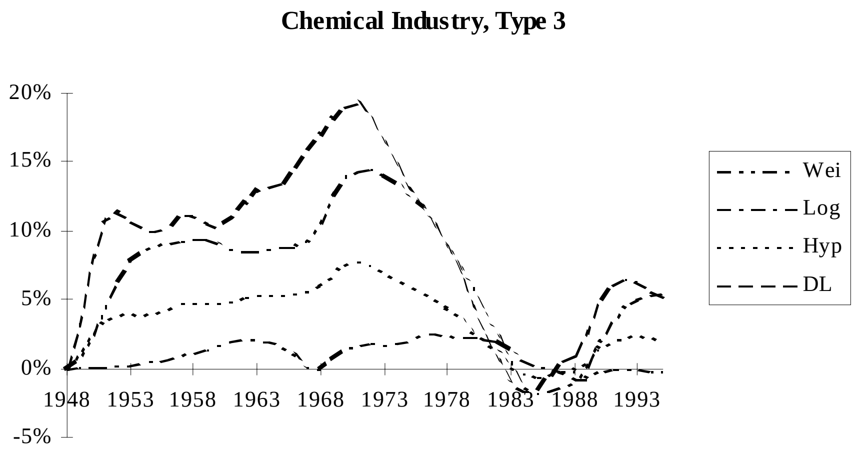

Figure 5.8: Relative differences with respect to PIM for Consumption of fixed capital

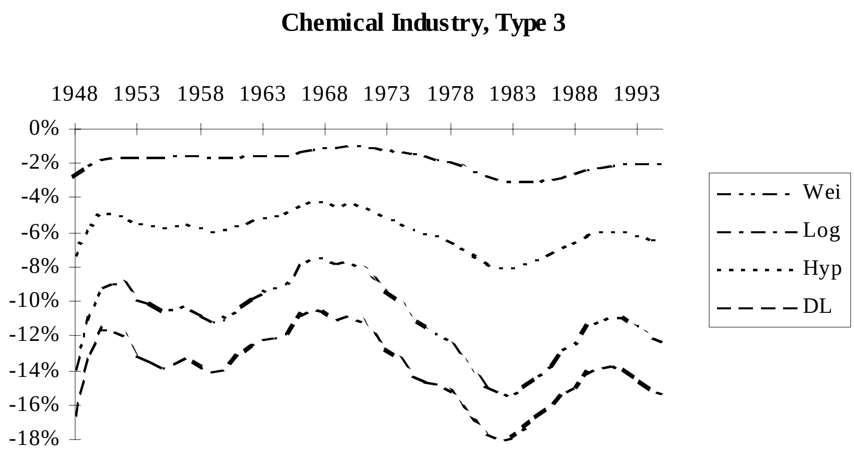

Figure 5.9: Relative differences with respect to PIM for Net Capital Stock

5.3 Changing the expected service life

The expected service life *d* of an asset is an important parameter, appearing in each of the used survival functions. Moreover, in our model of depreciation, the expected service life plays an important role as well. Hence, it seems reasonable to investigate the behaviour of the various models for differing expected service lives. For the sake of brevity, only the dependence of standard PIM on the expected service life will be presented and only for Type 3 assets. The choice for standard PIM was also motivated by the fact that the effect of changing the expected service life is greater for models in which the discard pattern is concentrated around the expected service life.
As a consequence of our assumption on the investments in the years before 1948 (i.e., the *d* preceding years are assigned equal investments), the length of the time-series depends on the expected service life *d*. To eliminate the "start-up" effects of this assumption, the Capital Stock and the consumption of fixed capital will only be calculated from 1978 onwards, the year at which that effect of the longest expected service life of 30 years has disappeared.
The following figures show the gross capital stock, consumption of fixed capital and net capital stock while using an expected service life of 10, 15, 20, 25 and 30 years.

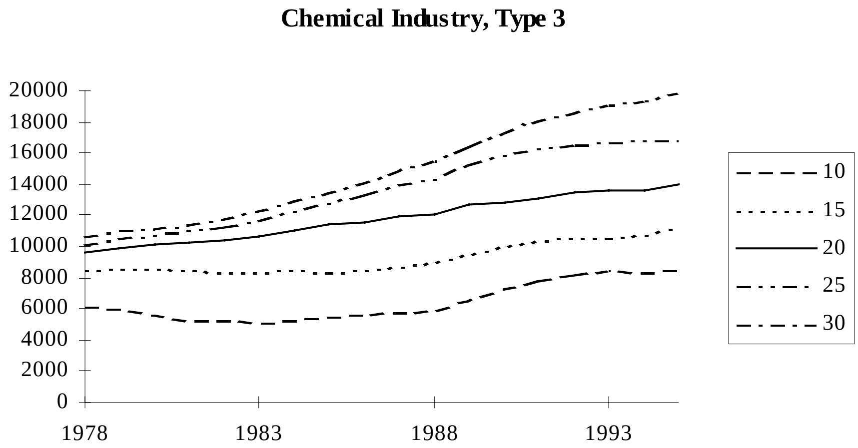

Figure 5.10: Gross Capital Stock with four expected service lives

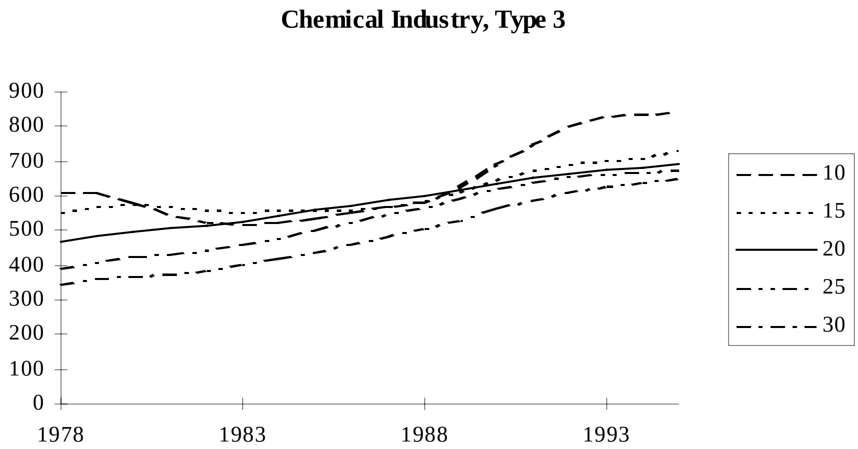

Figure 5.11: Consumption of fixed capital with four expected service lives

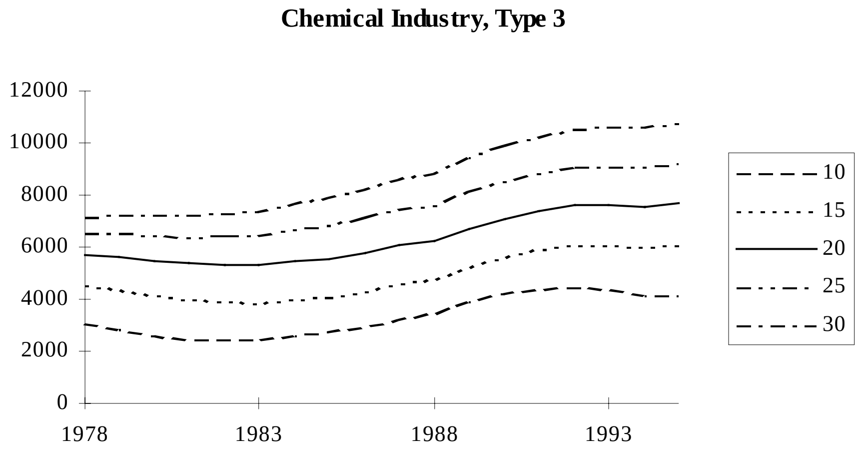

Figure 5.12: Net Capital Stock with four expected service lives

Again the size of the differences can be quantified by the relative differences with respect to the curve corresponding to the expected service life of 20 years (the service life for this asset, used at Statistics Netherlands, is 19 years). This results in:

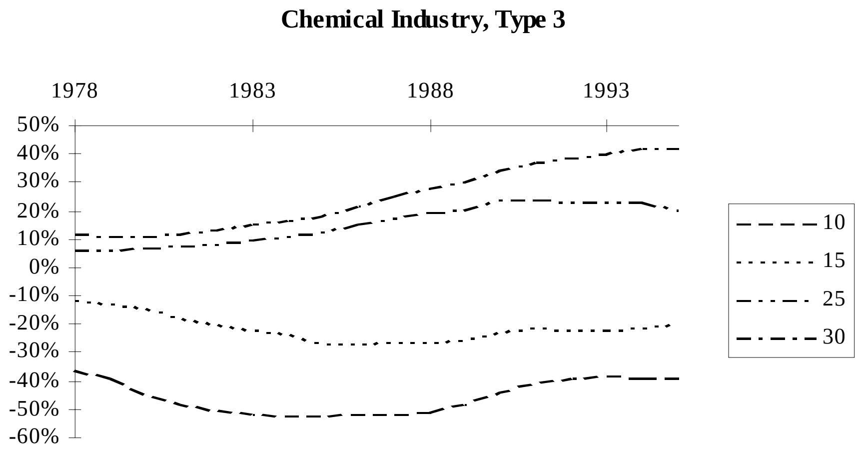

Figure 5.13: Relative differences with respect to d = 20 for Gross Capital Stock

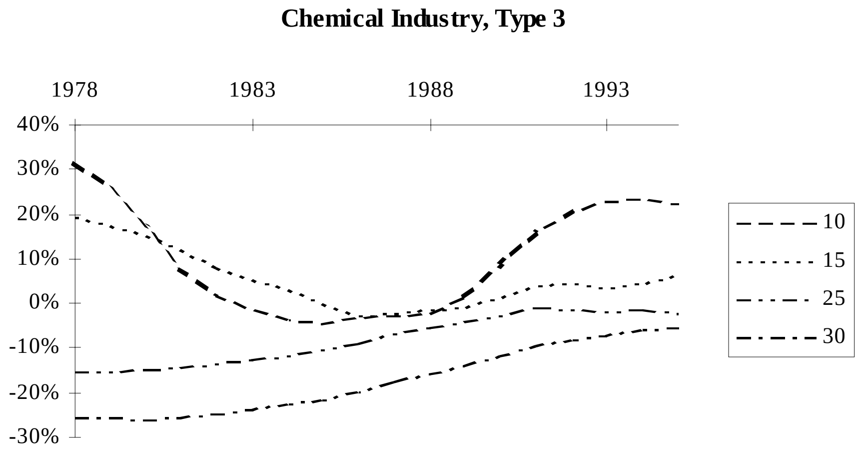

Figure 5.14: Relative differences with respect to *d* = 20 for Consumption of fixed capital

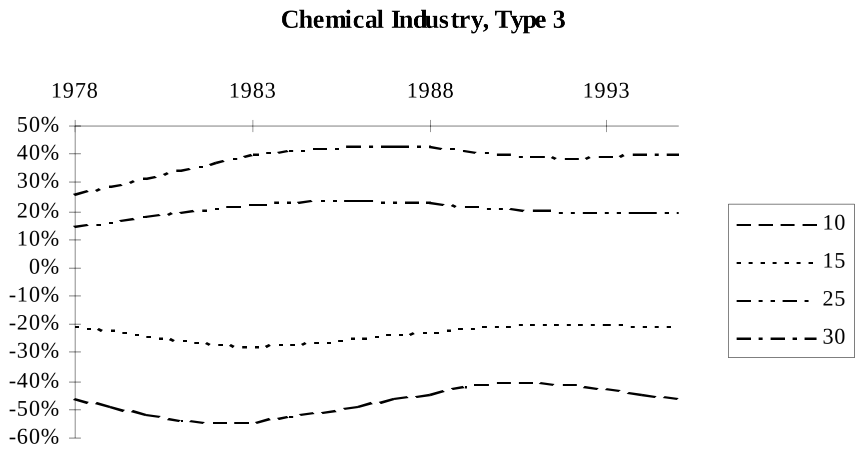

Figure 5.15: Relative differences with respect to *d* = 20 for Net Capital Stock

5.4 Modernness of capital stock

The quality of different methods to estimate the (gross) capital stock is usually measured in terms of accurateness of the estimated total and/or the estimated changes over the years. However, direct measurements of capital stock at manufacturing industry show that the modernness of the stock, i.e., the way old and new assets are present in the stock, may vary per type of asset. Since the net capital stock does not contain assets that are completely depreciated, the measured stock should be compared with the calculated gross capital stock. Obviously, the use of more elaborate survival functions, allowing assets to have a shorter or longer actual service life, will influence the estimated modernness of the stock. To show this effect, the modernness of the stock at the end of 1995 of assets of type 3 (machinery) of the chemical industry was calculated for each of the five survival functions that were introduced in section 5.1. To that end, classes of vintage years were formed and the part of the gross capital stock stemming from each of these vintage classes was calculated. That structure of the gross capital stock is given in Figure 5.16.

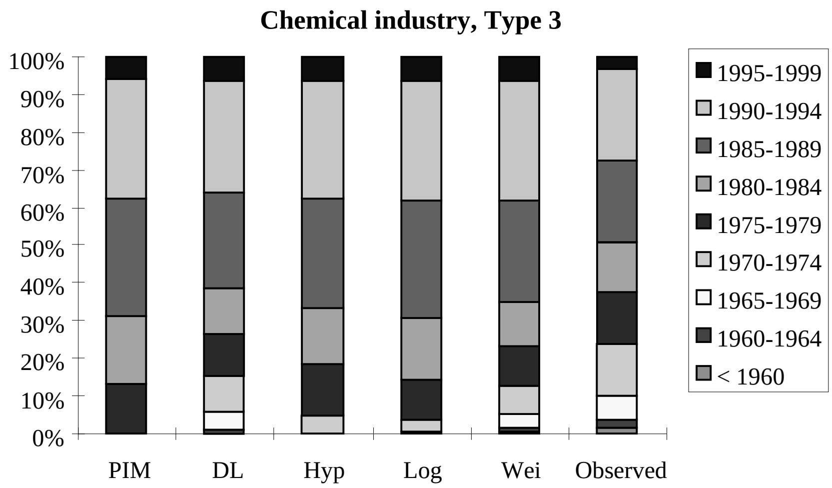

Figure 5.16: Modernness of gross capital stock at the end of 1995

The column "observed" is the modernness of the capital stock as given by statistics on tangible capital stock, available at Statistics Netherlands. Figure 5.16 shows that the use of a survival function that is not too much concentrated around the expected service life (as in case of the (Delayed) Linear and the Weibull model) results in a capital stock with a substantial amount of older assets. This seems to resemble the modernness of the observed capital stock.

5.5 Conclusions on discard patterns

In this report, the consequences of the use of more elaborate survival functions were considered. It turns out that these consequences can be substantial, even though the parameters as used in this study are chosen arbitrarily (i.e., without thorough knowledge of the underlying processes). In the calculation of both Gross and Net Capital Stock, the relative difference of any of the methods with standard PIM can be as large as 20%.
It is often argued that changing the (estimated) expected service life of an asset, is of greater influence than changing the survival function. In this report it is shown that this is indeed the case, *if one is willing to change the expected service life considerably*. If the expected service life is changed only by a few percentage points, the effect is not that substantial. On the other hand, if the expected service life is doubled (or halved), the effect is quite large.
Usually, the effects of different survival functions are measured in terms of (changes in) the actual level of Capital Stock. In section 5.4 it was shown that a different way of evaluating these effects is given by considering a subdivision of the Capital Stock in vintage-classes. It turns out that the traditional PIM does not reproduce the older vintage-classes sufficiently enough, compared with actual measurements of the capital stock. Survival functions with a longer tail (i.e., that allow assets to last considerably longer than the expected service life) perform better in this respect. However, to what extent may differ between the various types of assets.
The results of this report suggest that more elaborate survival functions deserve more attention. The Delayed Linear survival function could be used as an approximation to any of the other survival functions used in this report and performs quite well when considering the subdivision of the Capital Stock into vintage-classes. It is suggested that this Delayed Linear approach is used instead of standard PIM, with parameters that might differ between the types of assets. Further research should yield accurate values for these parameters. However, accurate (estimates of the) expected service lives are very important as well. Some effects of erroneous values of expected service lives can be smoothed using survival functions (allowing some deviation around that value), but not all. Especially when the actual expected service life differs considerably from the used value, it is not plausible that survival functions can remedy these consequences.

6. Depreciation methods

In addition to service lives and discard patterns, one can add another parameter to PIM calculations: depreciation pattern. In the calculations of which the results are presented in the chapters above, a straight-line depreciation is applied. This means that every year a proportional part of a vintage of assets is written off.
In a recent paper Blades analysed how well different methods approximate "actual depreciation". This chapter gives a very brief overview of the method and conclusions of this paper.

Blades derives "actual depreciation" from a model which uses six different patterns of income flows to determine annual depreciation as the difference between successive asset values.
The model used to relate income flows to asset values is given in the well known formula (6.1).

(6.1) $$K_j = \sum_{t=j}^{d-1} Y_t \,/\, (1+r)^{t-j} \qquad j = 0, .., d-1$$

where: K = the market price of the asset at j years after the time of purchase
Y = the annual income that the purchaser expects to earn from the asset
r = the internal rate of return or the discount rate
d = the number of years that the purchaser expects to use the asset

"Actual depreciation" in year t is defined as:

(6.2) $$DEP_t = K_t - K_{t+1}$$

Blades uses six different income patterns to estimate "actual depreciation":

a) Constant income flow during the whole period
b) Income falls by a constant amount each year
c) Income falls by an increasing rate
d) Income falls at a constant rate
e) Income falls at a decreasing rate
f) Income rises for each of the first five years and then declines

"Actual depreciation" is calculated using the model and the different income patterns and compared with the depreciation derived from the initial value of the asset combined with different depreciation methods.
Four methods are included in the analysis:

i) Straight line depreciation: a constant percentage (one d^{th}) of the initial value of the asset
ii) Geometric depreciation: a constant rate of decline to the initial value of the asset is applied
iii) Double-declining balance: a alternative geometric depreciation using previous year's depreciated value
iv) Sum of digits: depreciation declines linearly over the life of the asset such that accumulated depreciation equals its initial value

For more details on income patterns, depreciation methods and calculations reference is made to the paper by Blades.

The main conclusion of Blades is:

"This paper has shown how capital assets will depreciate given six different income patterns. For all except one of the income patterns considered, straight-line depreciation is clearly the best model to estimate annual depreciation. "Best" here means that straight-line depreciation produces annual estimates of depreciation that, averaged over service life of the asset, are closer to actual depreciation. The one exception is when income declines geometrically over service life of the asset. "

7. **Conclusions and recommendations**

Service lives are an important parameter in the Perpetual Inventory Method (PIM). However estimates of service lives, based on statistical information are scarce. Mostly fiscal data and/or bookkeeping practices are the sources of information. In this paper estimates of service lives based on directly observed data on capital stock and discards are presented. In addition fiscal sources and annual business reports are explored. Combination of all sources resulted in a table containing "best-practice" service lives by type of asset and by industry.

It is often said that in PIM service lives are the only relevant parameter and that the influence of discard patterns is negligible. As a consequence a simple step function is most widely used in the PIM. However this paper shows that discard patterns seriously influence the results of PIM calculations. Different discard patterns result in significant differences in the levels of capital stock. From this point it is hard to say which discard pattern is the "best". A different way of evaluation is considering a subdivision of the capital stock in vintage classes. It turns out that the traditional PIM does not reproduce the older vintage classes sufficiently enough, compared with actual measurement of capital stock.. Survival functions with a longer tail, like the Weibull and the Delayed linear perform much better in this respect.
Based on these experiences, the application of the delayed linear distribution in the PIM is recommended. The Delayed Linear survival function provides an approximation to any of the other survival functions used in this report and performs quite well when considering the subdivision of the capital stock into vintage-classes. Another advantage of the delayed linear method is that calculations are less troublesome.

The paper by Blades shows that in most cases a straight-line depreciation provides the best approximation of the "actual depreciation".

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Annex 1. BRIEF DEFINITIONS OF THE CLASSIFIED ASSETS

1. TANGIBLE PRODUCED FIXED ASSETS

A. Dwellings
Buildings that are used entirely or primarily as residences. Includes associated structures such as garages. Houseboats, caravans etc. used as principal residences of households are also included, as are uncompleted dwellings and dwellings of the military. Costs of site clearance and preparation are also included.

B. Non-residential buildings
Buildings other than dwellings used to house enterprises. Includes fixtures, facilities and equipment that are integral parts of the structure. Uncompleted buildings , costs of site clearance and preparation are also included.

C. Other structures
Structures other than buildings. Site clearance and preparation is also a part of other structures. Examples are highways, bridges, roads, waterways, pipelines etc.

D. External transport equipment
Equipment for moving people and objects on public roads, per rail, on water or through the air. For example motor vehicles, trailers, ships, trams, rolling stock, aircraft etc. etc. Transport equipment that only incidentally use public roads, such as tractors, are registered under other machinery.

E. Computers
Data processing, electronical machinery that is freely programmable for the user, including all periphals, such as printers and terminals.

F. Other machinery and equipment
Machinery and equipment not elsewhere classified. Examples are copying machines, medical instruments, machine tools etc. etc.

G. Cultivated assets
- livestock that are kept for the products they provide year after year. They include breeding stocks, dairy cattle, draught animals and animals used for wool production, racing or entertainment.
- trees cultivated for the products they yield year after year. For example fruits, nuts, sap, resin and bark and leaf products.

H. Other tangible produced fixed assets
Tangible fixed assets not elsewhere classified. Examples are furniture, containers, silo's, racks, pallets and storage tanks.

2. INTANGIBLE PRODUCED FIXED ASSETS

A. Mineral exploration
The value of expenditures on exploration for petroleum and natural gas and for non-petroleum deposits. This includes prelicence costs, licence and acquisition costs, appraisal costs and the cost of drilling and boring, as well as the costs of aerial surveys, transportation etc.

B. Computer software
Computer programs, program descriptions and supporting materials for both systems and application software. It includes not only purchased software but also software developed on own account.

C. Entertainment, literary or artistic originals
Original films, sound recordings, manuscripts, tapes, models, etc., on which drama performances, radio and television programmes, musical performances etc. etc. are recorded or embodied. Included are works produced on own account.

D. Other intangible produced fixed assets
New information, specialized knowledge, etc., not elsewhere classified, whose use in production is restricted to the units that have established ownership rights over them or to other units licensed by the latter.

Annex 2. Example of calculations using the Perpetual Inventory Method

Starting point:

Gross capital stock in year 0	: 0	mln.
Gross fixed capital formation in year 1	: 100	mln.
Expected service life	: 5	years
Price index	: 1,00	

Based on these data, calculations using the PIM result in the following table:

year	gross fixed capital form.	gross capital stock	consumption of fixed capital	net capital stock
0	0	0	0	0
1	100	100	10	90
2	0	100	20	70
3	0	100	20	50
4	0	100	20	30
5	0	100	20	10
6	0	0	10	0

Gross capital stock equals 100 mln in the years 1 - 5

Consumption of fixed capital in year 1: $\{(GCS_0 + GCS_1)/2\}/5 = \{(0+100)/2\}/5 = 10$
Consumption of fixed capital in year 2 - 5: $\{(GCS_{t-1} + GCS_t)/2\}/5 = \{(100 + 100)/2\}/5 = 20$
Consumption of fixed capital in year 6 : $\{GCS_5 + GCS_6)/2\}/5 = \{(100 + 0)/2\}/5 = 10$

in which: GCS_t = gross capital stock in year t

Net capital stock equals gross capital stock minus accumulated consumption of fixed capital

Annex 3. Asset life model

It is assumed that the discard pattern can be described most accurately using a Weibull distribution. The Weibull distribution is perhaps the most widely used service life distribution model because of its appropriateness and its convenience of mathematical handling. This appendix gives the characteristics of the Weibull distribution. Furthermore it provides the theoretical background for the way the estimates for the service lives are obtained.

Weibull distribution

The probability density function of the Weibull distribution is:

$$f_W(x) = \alpha\lambda \cdot (\lambda x)^{\alpha-1} \cdot e^{-(\lambda x)^{\alpha}} \text{, for } x \geq 0 \tag{A3.1}$$

λ – size parameter;
α – shape parameter.

The survival function can be derived using $S_W(x) \equiv 1 - \int_{y<x} f(y)dy$ from (A3.1):

$$S_W(x) = 1 - \int_0^x \alpha\lambda \cdot (\lambda y)^{\alpha-1} \cdot e^{-(\lambda y)^{\alpha}} dy = e^{-(\lambda x)^{\alpha}} \tag{A3.2}$$

$S(0)=1$ and $S(\infty)=0$. Furthermore $S(1/\lambda) = e^{-1} \approx 0.368$ independently of α.

Given the Weibull distribution parameters, the expected service life equals

$$E_W(X) = \frac{1}{\lambda} \cdot \Gamma(1+\tfrac{1}{\alpha}) \tag{A3.3}$$

The Gamma function $\Gamma(1+\frac{1}{\alpha})$ equals one for $\alpha = \infty$ and for $\alpha = 1$. The Gamma function attains its minimum value (0.8856) when $\alpha \approx 2.16$. The value is almost constant for the range $2 < \alpha < 6$.

Dubey (1966) has obtained the following result: let $X_1, \ldots, X_n$ be independent and identically distributed random variables. Then $\min(X_1, \ldots, X_n)$ has a Weibull distribution if and only if the common distribution of the X_i's is a Weibull distribution. The Weibull distribution arises theoretically as a limit law for the smallest of a large number of independent non-negative random variables. Here it can be assumed that the limit law is directly related to the net present value (NPV) of future revenues per unit of time generated by a capital asset. The service life comes to an end when the NPV falls below a limit value. The latter process strongly suggests a Weibull distribution of service lives that we have chosen as a working hypothesis.

Characteristics Weibull hazard rate function

The hazard rate function gives the probability a capital good will be discarded as soon as it reaches age *x* (this is the so called 'instantaneous risk'): $h(x) \equiv \lim_{\delta \downarrow 0} \frac{P(x \leq X < x + \delta \mid X \geq x)}{\delta}$, and thus[2]:

$$h(x) = \lim_{\delta \downarrow 0} \frac{P(x \leq X < x + \delta)/\delta}{P(X \geq x)} = \frac{\lim_{\delta \downarrow 0}\left(\left[F(x+\delta) - F(x)\right]/\delta\right)}{1 - F(x)} = \frac{F'(x)}{1 - F(x)} = \frac{f(x)}{1 - F(x)} = \frac{f(x)}{S(x)}$$

Since $f(x) = F'(x) = -S'(x)$, we get:

$$h(x) = \frac{-S'(x)}{S(x)} = -\frac{d}{dx} \ln S(x) \qquad \text{(A3.4)}$$

The Weibull hazard rate or conditional failure intensity function can be obtained by combining (A3.1) en (A3.2):

$$h_W(x) = \frac{f_W(x)}{S_W(x)} = \frac{\alpha\lambda \cdot (\lambda x)^{\alpha - 1} \cdot e^{-(\lambda x)^{\alpha}}}{e^{-(\lambda x)^{\alpha}}} = \alpha\lambda \cdot (\lambda x)^{\alpha - 1} \qquad \text{(A3.5)}$$

The Weibull hazard rate function (A3.5) reflects three distinctive service life characteristics.

1. A decreasing hazard rate corresponds to $0 < \alpha < 1$;
2. A constant hazard rate corresponds to $\alpha = 1$.
3. An increasing hazard rate corresponds to $1 < \alpha < \infty$

This case can be subdivided into:
   a) a degressively increasing hazard rate: $1 < \alpha < 2$
   b) a linearly increasing hazard rate: $\alpha = 2$
   c) a progressively increasing hazard rate: $\alpha > 2$

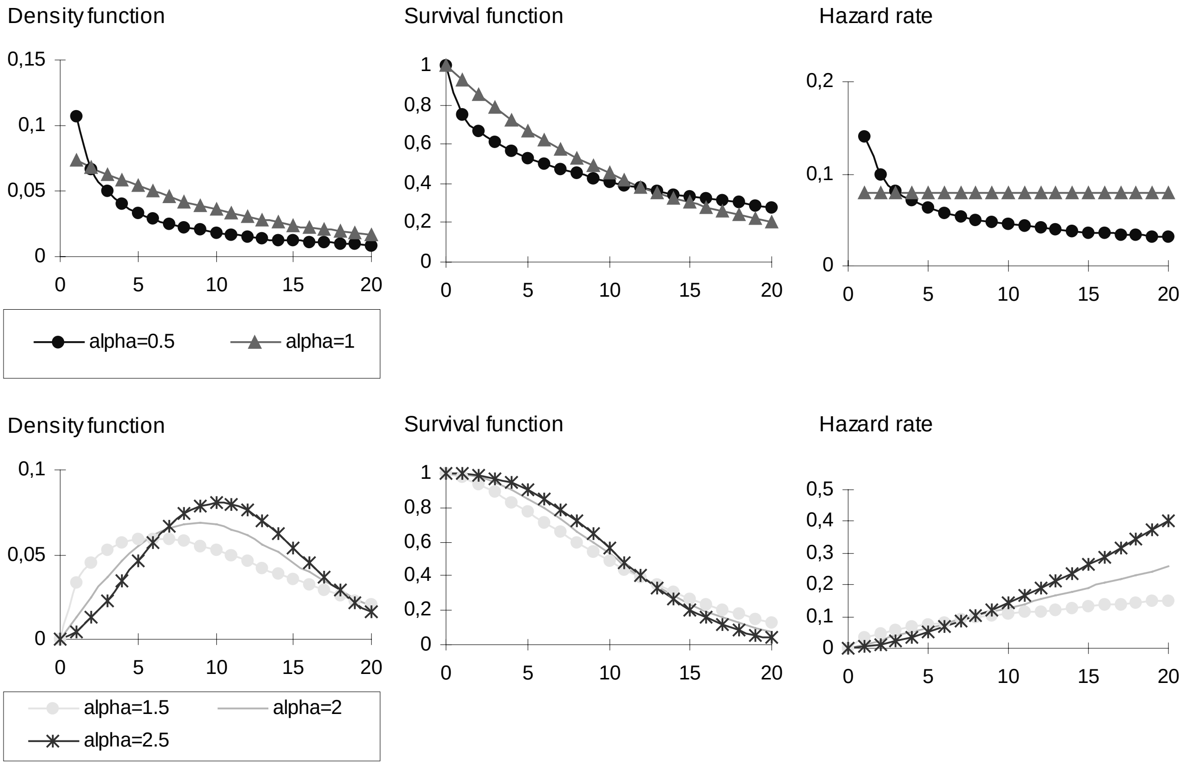
For the five distinguished cases the graphs in figure 1 give illustrative examples. The three graphs on the first row concern non-increasing hazard rates (cases 1 and 2), the three graphs on the bottom row concern increasing hazard rates (case 3). On the *x*-axis the age is the age of the capital good, the *y*-axis contains the function values. The value for λ is arbitrarily set at λ=0.08. For the different values of α for the expected service life (e.s.l.) and for the median service life (m.s.l.) it follows that

α	e.s.l.	m.s.l.
0.5	25.0	6.0
1	12.5	8.7
1.5	11.3	9.8
2	11.1	10.4
2.5	11.1	10.8

In our results non-increasing hazard rates almost do not occur. This is in accordance with our expectation, because the older a capital good, the larger the probability it will be discarded the following year. With a few exceptions (for example computers) the α-value found in our calculations is close to 1.5.

[2] Using $P(A \mid B) = \frac{P(AB)}{P(B)}$

Figure 1 Weibull probability distribution



Integrated hazard rate

Using (A3.4), the following hold for the *integrated hazard rate*:

$$H_w(x) \equiv \int_0^x h_w(y)dy \overset{\text{(using (A3.4))}}{=} -\int_0^x \frac{d}{dy}\ln(S_w(y))dy = -\ln\left(S_w(x)\right) = (\lambda x)^{\alpha} \qquad \text{(A3.6)}$$

since $S_w(0) = 1$. From (A3.6) it follows:

$$\ln\left(H_w(x)\right) = \alpha \cdot \ln(\lambda) + \alpha \cdot \ln\left(x\right) = \beta + \alpha \cdot \ln(x) \qquad \text{(A3.7)}$$

with $\beta \equiv \alpha \cdot \ln(\lambda)$.

The natural logarithm of the integrated hazard rate of a Weibull distribution therefore is linearly dependent on the natural logarithm of the service life. Using the discard and capital stock enquiry results a Weibull model can be fitted to the model estimating the following linear equation

$$\sum_{i=t-x}^{t} \frac{R_{t,i}}{GCS_{t-1,i}} \approx \sum_{i=t-x}^{t} h_w(t-i) = \sum_{y=0}^{x} h_w(y) = \hat{H}_w(x) \quad \text{voor } x = 1,2,\ldots,t \qquad \text{(A3.8)}$$

Combining equations (A3.7) and (A3.8) empirical data can be used for estimating the parameter values of the most appropriate Weibull distribution. This is done by computing parameter estimates best fitting the following linear equation (see also paragraph 4.1.3 of the main text)

$$\ln\left(\sum_{i=t-x_k}^{t} \frac{R_{t,i}}{GCS_{t,i} + R_{t,i}}\right) = \beta + \alpha \cdot \ln(x_k) + \Delta_{H,k}$$

(A3.9)

Worked example illustrating methodology

This paragraph contains an example (with imaginary figures) illustrating the methodology used for estimating service lives using observed data. We assume the following data on gross capital stock and discard values are reported for reference date 31 December 1997 (all in prices 1997).

Imaginary data for illustrating methodology

j	x_j	$GCS_{1997,j}$	$R_{1997,j}$	$h(x_j)$	$\hat{H}(x_j)$
1996	1	95	1	0,010	0,010
1995	2	100	2	0,020	0,030
1994	3	80	2,5	0,030	0,060
1993	4	80	3	0,036	0,096
1992	5	60	4	0,063	0,159
1991	6	70	7	0,091	0,250
1990	7	50	5,5	0,099	0,349
1989	8	50	6	0,11	0,456
1988	9	30	4	0,12	0,574
1987	10	40	6	0,13	0,704

x_j – age of capital good with vintage *j*, for this example $x_j = 1997 - j$

$GCS_{1997,j}$ – gross capital stock of vintage *j* in use at 31 December year 1997.

$R_{1997,j}$ – value of retirements of vintage *j* during year 1997.

$\hat{h}(x_j)$ – estimate for the hazard rate, determined by $h(x_j) = \dfrac{R_{1997,j}}{GCS_{1997,j} + R_{1997,j}}$

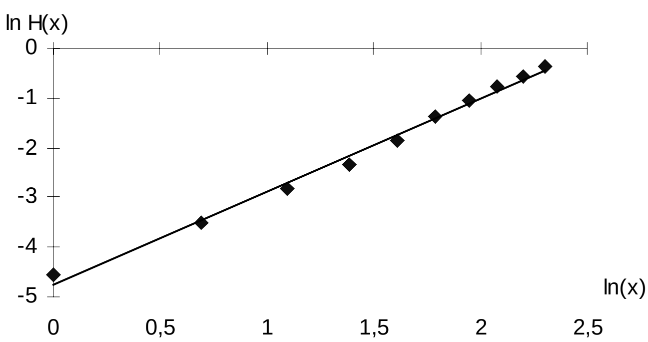
$\hat{H}(x_j)$ – estimate for the integrated hazard rate: $\hat{H}(x_j) = \sum_0^{x_j} h(x)$

Next, using linear regression the equation $\ln \hat{H}(x) = \beta + \alpha \cdot \ln(x)$ is estimated, resulting in (standard error in parentheses):

$$\ln \hat{H}(x) = -\underset{(0.09)}{4.75} + \underset{(0.06)}{1.88} \cdot \ln(x), \qquad R^2 = 0.99$$

See also figure 2.

Figure 2 Plot of ln *H*(*x*) versus ln *x* (regression line included)



From these parameter estimates the best estimates for the Weibull parameters are calculated as follows:

$$\hat{\alpha} = a = 1.88$$

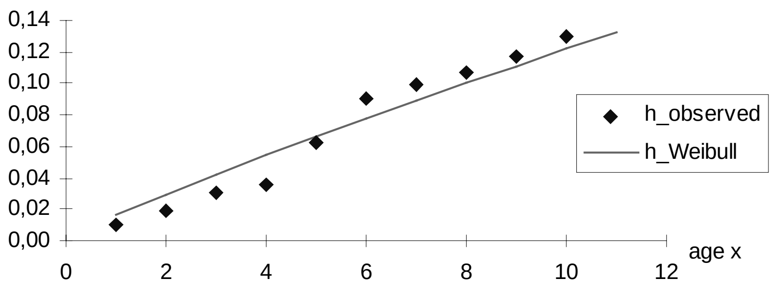
$$\hat{\lambda} = e^{b/a} \approx e^{-4.75/1.88} \approx e^{-2.53} \approx 0.079$$

From this for the expected service life it follows that:

$$\hat{E}(X) = \frac{1}{\hat{\lambda}} \cdot \Gamma(1 + 1/\hat{\alpha}) = \frac{1}{0.079} \cdot \Gamma(1 + 0.53) = \frac{0.89}{0.079} \approx 11{,}2$$

Figure 3 shows a graph confronting the Weibull distribution using the estimated paramters with the original hazard rates.

Figure 3 Observed hazard rate versus Weibull estimate



Annex 4. Survival functions

This appendix contains additional information on the survival functions, used in the experiments.

Perpetual Inventory Method (PIM)

Expected service life d.

$$S_{PIM}(t) = \begin{cases} 1 & 0 \le t \le d \\ 0 & t > d \end{cases} \tag{A4.1}$$

(Delayed) Linear (DL)

Expected service life d, deviation Δ. In experiments Δ was taken to be equal to 2d, i.e., start of depreciation at t = 0, so no “delay”.

$$S_{DL}(t) = \begin{cases} 1 & 0 \le t \le d - \Delta/2 \\ -\dfrac{t - (d + \Delta/2)}{\Delta} & d - \Delta/2 < t \le d + \Delta/2 \\ 0 & d + \Delta/2 < t \end{cases} \tag{A4.2}$$

Hyperbolic (Hyp)

Shape parameter $\beta \in$ (0,1). Additionally, parameter T is chosen such that the expected service life is equal to d.

$$S_{Hyp}(t) = \begin{cases} \dfrac{T - t}{T - \beta t} & 0 \le t \le T \\ 0 & t > T \end{cases} \tag{A4.3}$$

with $T = d\beta^2 \big/ \left(\beta + (1-\beta)\log(1-\beta)\right)$. In the experiments, β = 0.8 was taken.

Logistic (Log)

Shape parameter α > 0. Additionally, parameter C is chosen such that the survival function starts at 0 with the value 1.

$$S_{Log} = \frac{1}{C}\left(1 + \frac{e^{\alpha(d-t)} - e^{-\alpha(d-t)}}{e^{\alpha(d-t)} + e^{-\alpha(d-t)}}\right) \qquad t \ge 0 \tag{A4.4}$$

with $C = 1 + \left(e^{\alpha d} - e^{-\alpha d}\right) \big/ \left(e^{\alpha d} + e^{-\alpha d}\right)$. In the experiments, α = 0.2 was taken.

Weibull (Wei)

Shape parameter α > 0. Additionally, parameter λ is chosen such that the expected service life equals L.

$$S_{Wei}(t) = \exp\left(-(\lambda t)^{\alpha}\right) \qquad t \ge 0 \tag{A4.5}$$

with $\lambda = \exp\left(\Gamma(1 + 1/\alpha)\right) \big/ d$, where Γ denotes the Gamma-function. In the experiments, α = 1.7 was taken.

The following figure shows the shape of the five survival functions with the parameters used in the experiments, with expected service life d equal to 55.

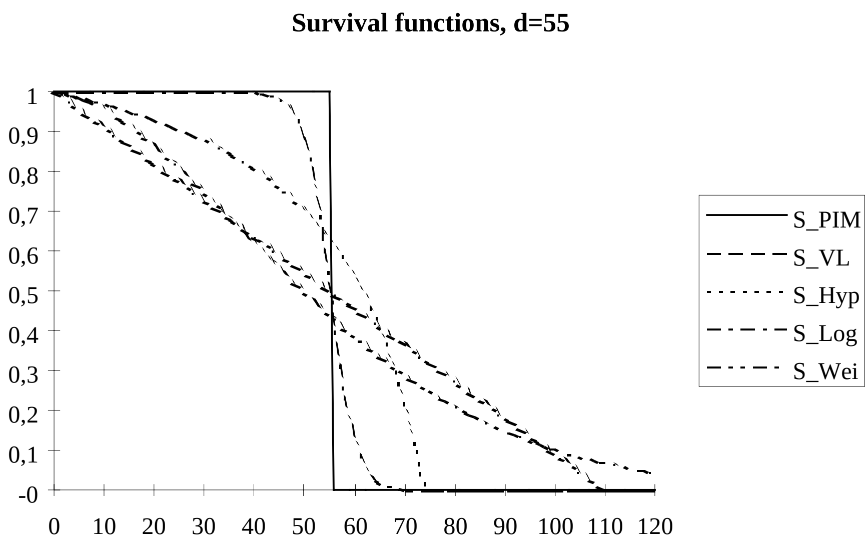


Figure 4.1 : Survival functions with expected service life d = 55

Annex 5. Time series of gross fixed capital formation in chemical industry

Time-series of investments in the chemical industry, The Netherlands. Type 1 is industrial buildings, Type 2 is civil engineering, Type 3 is machinery and Type 4 is transport equipment.

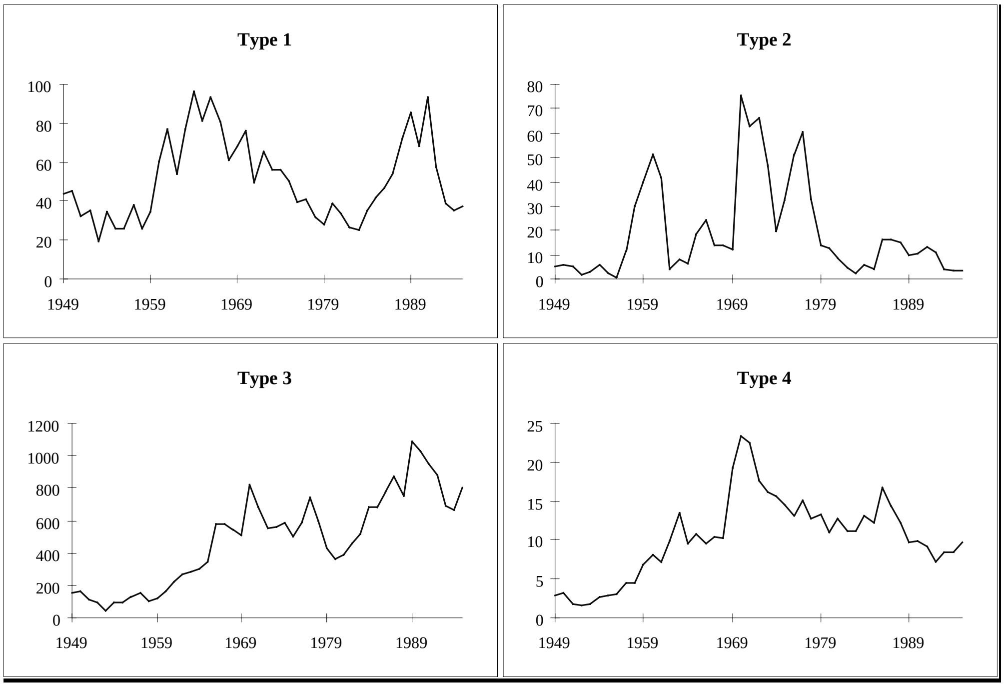


Figure 5.1: Gross fixed capital formation in the chemical industry, The Netherlands

Annex 6. Gross capital stock, consumption of fixed capital and net capital stock for buildings, other construction and transport equipment in chemical industry.

Figures of Gross Capital Stock, Depreciation and Net Capital Stock for Type 1, 2 and 4 of assets of the chemical industry, The Netherlands.

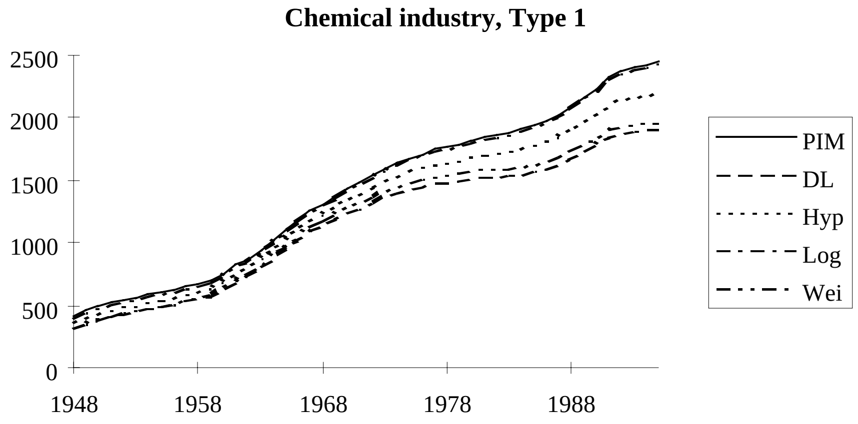


Figure 6.1: Gross Capital Stock, Type 1

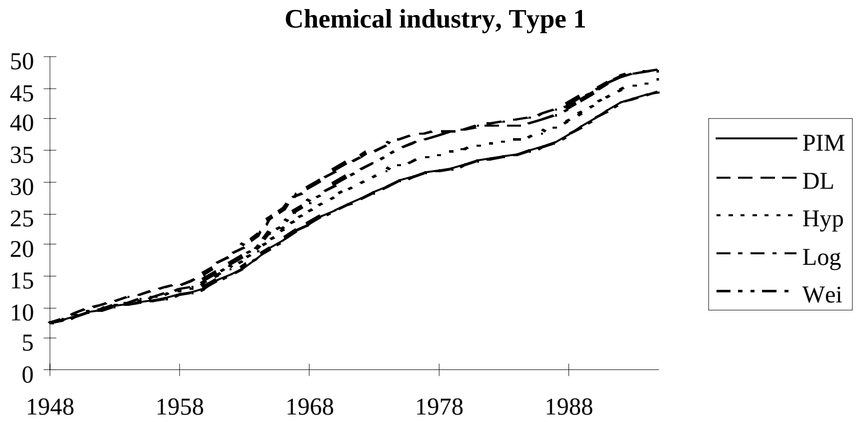


Figure 6.2: Consumption of fixed capital, Type 1

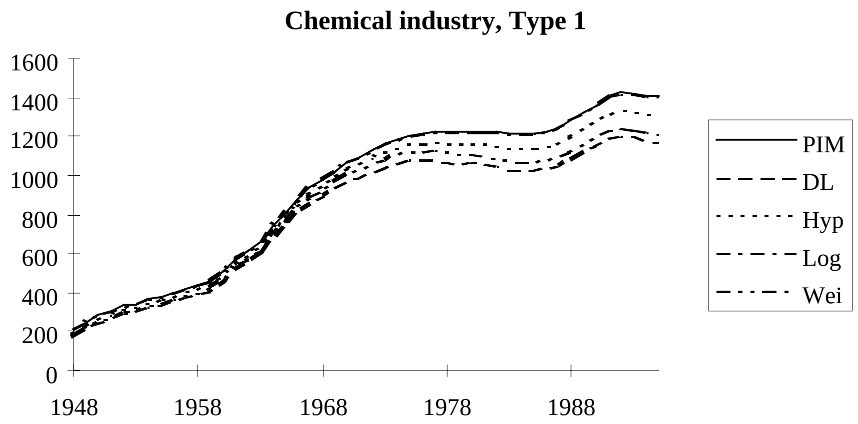


Figure 6.3: Net Capital Stock, Type 1

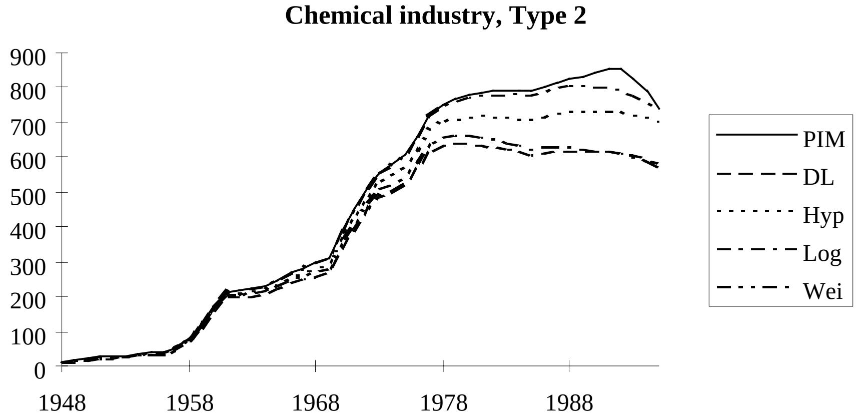


Figure 6.4: Gross Capital Stock, Type 2

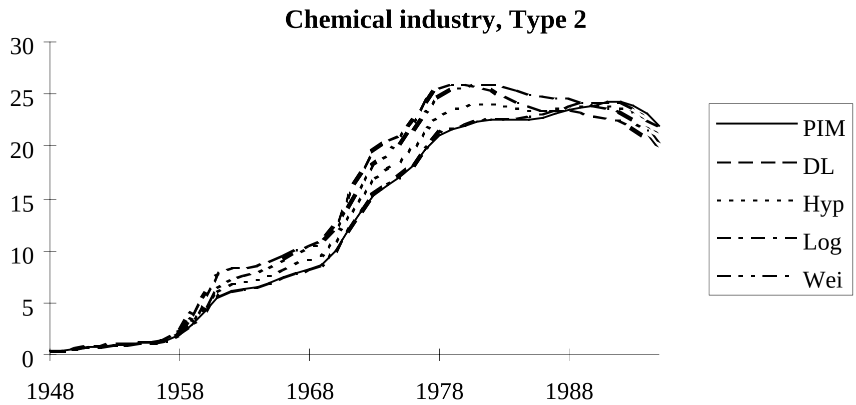


Figure 6.5: Consumption of fixed capital, Type 2

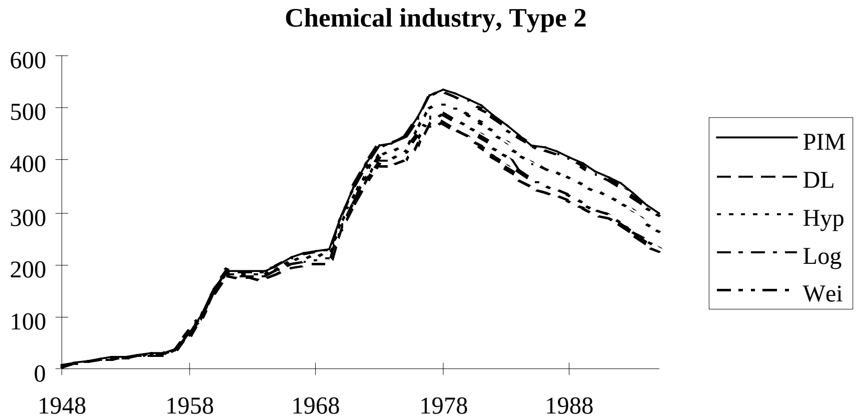


Figure 6.6: Net Capital Stock, Type 2

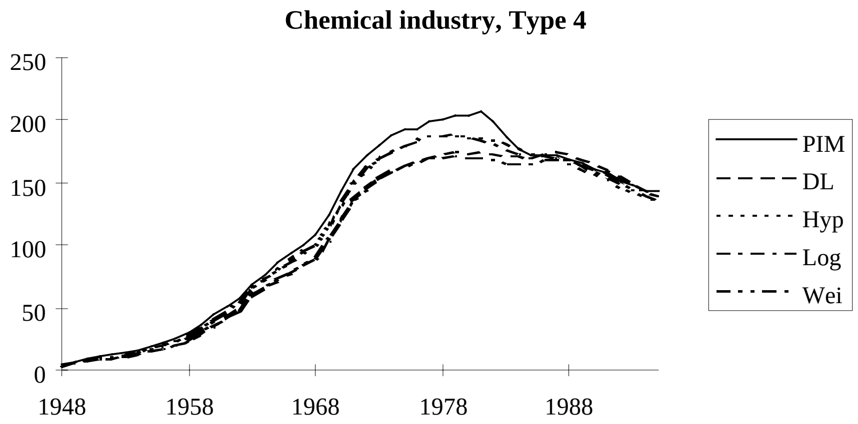


Figure 6.7: Gross Capital Stock, Type 4

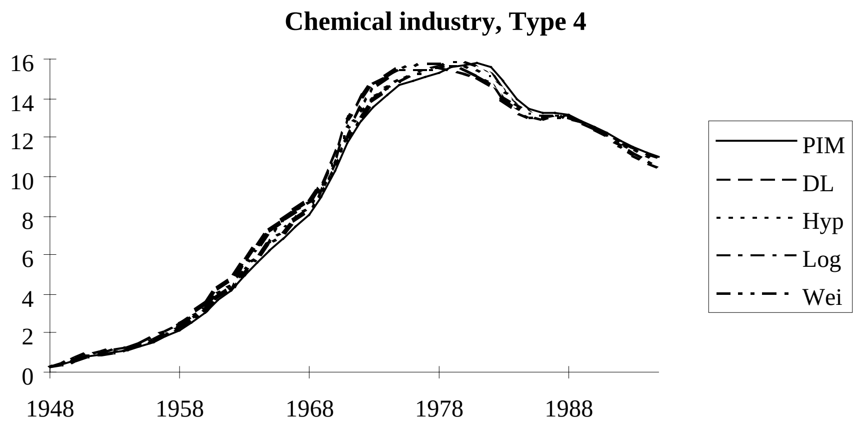


Figure 6.8: Consumption of fixed capital, Type 4

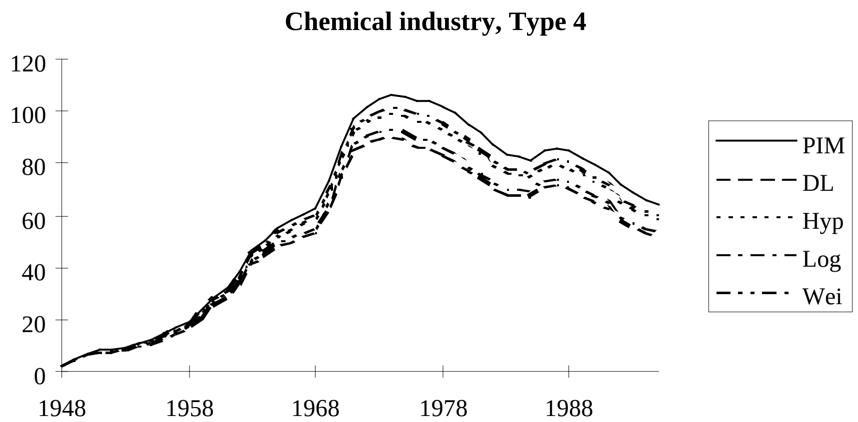


Figure 6.9: Net Capital Stock, Type 4