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Measuring Capital
OECD MANUAL 2009

Chapter 5

Depreciation or Consumption of Fixed Capital

5.1. Concept and scope

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

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

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

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

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

Some clarifications are needed.

- First, a decline in value during the accounting period can be understood as the sum of two components, as has already been indicated in Section 3.2. One component is the price change that reflects the price movement of the asset class under consideration, *given a particular age* (and measured, for example, by comparing the price of a new asset at the beginning of the period with the price of a new asset at the end of the period). Another component is the price change that reflects the ageing of the asset *given a* *particular price level for the asset class* (and measured, for example, by comparing the price of a new asset with the price of a one-year old asset). Whether only the latter measure should be used to capture depreciation or whether also the former price movement should be included in a measure of depreciation, has be subject to debate and will be discussed further in the section on "depreciation and obsolescence". At this point it is sufficient to signal that the present *Manual* captures depreciation as the price change due to ageing, thereby controlling for the overall movements in asset prices. This fits with the idea in the national accounts that economic flows within a period should be measured with regard to a given set of average prices of this period, also spelled out in the SNA: "*Consumption of fixed capital must be measured with reference to a given set of prices,* i.e. *the average prices of the period*".

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

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

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

5.2. Measuring depreciation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 5.3. **Computing depreciation**

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

5.3. *Price and volume of depreciation*

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

5.4. *Depreciation and obsolescence*

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

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

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

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

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

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

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

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

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

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

5.5. *Determining depreciation parameters*

5.5.1. *Derived from age-efficiency profiles*

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

5.5.2. *Direct determination of age-price profiles*

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

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

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

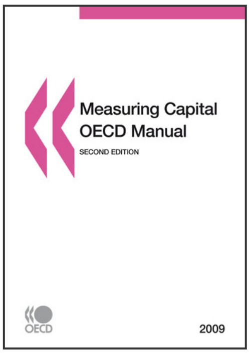
Second, when a pattern of constant percentage decline in asset values is chosen for the age-price profile ("geometric pattern"), a simple method to obtain geometric coefficients is the double-declining balance method where the rate decline is given by the following expression: $\delta^i = 2/\overline{T}^i$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

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

Notes

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

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



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