THE MEASUREMENT OF CAPITAL THROUGH A FIXED ASSET ACCOUNTING SIMULATION MODEL (FAASM)

BY MICHAEL JAFFEY

Statistics Canada

In this article the author describes a method of estimating the capital stock of the corporate sector which is being developed at Statistics Canada. The method uses a "Fixed Asset Accounting Simulation Model" or FAASM. FAASM provides estimates of the capital stock by inferring the actual service lives of fixed assets, and using these with price indexes to revalue assets on a constant price basis. FAASM is thus an alternative to the widely used Perpetual Inventory Method. By also inferring accounting lives using the depreciation accounts, it has other important outputs. These latter get only passing mention here. Since FAASM exploits the available data in a comprehensive, systematic way, its service life and capital stock estimates may eventually, after system development and improvement in operation, approach the limits of attainable accuracy.

1. INTRODUCTION

The factor of production capital, in contrast to the factor labour, is not now measured with reasonable accuracy. The method used by virtually all countries that publish capital stock estimates is the "perpetual inventory model" (PIM). It relies on three data inputs, capital expenditures, the capital goods price index, and service lives. There are problems with all three of them, although it is mostly the difficulty of accurately surveying lives that has raised doubts on the reliability of the present estimates.

Instead of requesting life data from companies, it is possible to infer lives from data from their fixed asset accounts, the account balances as well as the capital expenditures. This has been done in French and Canadian studies (Mairesse, 1972; Atkinson and Mairesse, 1978; Tarasofsky et al., 1981; and Cette and Szpiro, 1988). What is new in the approach presented here is the systematic exploitation of this principle—extended to include changing vintage lives, and accountants' assumed lives as well as actual lives—in a simulation model. There are two versions. The partial version yields estimates of the capital stock. The full version also produces other outputs which, though important in their own right, receive only passing mention here.

Note: I am greatly indebted to my colleague, Terry Gigantes, who referred me to the work of Tarasofsky and his associates, the starting point for the present analysis, and who collaborated in internal Statistics Canada working papers; and to David Slater, for his indispensable support and valuable perspectives. Among the many others to whom thanks are due, space limits me to mention only Abe Tarasofsky and Jacques Mairesse, who discussed their prior work with me; Derek Blades, who drew my attention to the French work and reviewed early drafts; Julia Lelik of Peat Marwick; Fred Gault, Jack Wilson, Richard Landry, and Kuen Huang of Statistics Canada; Aly Elfar, Emil Asistores, and Marcel Uson of Bell Canada; and Michael McCracken, John Sargent, Bert Waslander, Derek Harris, John Caldwell, and Paul Ambrose.
FAASM's capital stock estimates are, by mathematical necessity, accurate under two main conditions: price index accuracy, and data accuracy. The important, but separate, question of the price index is not addressed here. Data accuracy requires an integrated annual survey of company fixed asset accounts, designed to screen out distortions and errors.

After a brief description of the PIM and a discussion of the nature of service lives, the author describes how the Fixed Asset Accounting Simulation Model (FAASM), now being developed at Statistics Canada, has the potential to generate up-to-date and reliable service life and capital stock estimates. Finally an example of the use of FAASM is given, employing data for the Canadian telephone utilities.

2. The Perpetual Inventory Model

In considering how the capital stock is to be measured, we should start with the fixed asset accounts of companies. These, practically speaking, are the sole source of data for any method of capital stock estimation, including the life data used in the PIM. For any group of fixed assets it chooses to distinguish, a corporation's fixed asset accounts show:

\[
\begin{align*}
G_t &= \text{gross fixed assets} \\
A_t &= \text{accumulated depreciation} \\
N_t &= \text{net fixed assets at end of year } t
\end{align*}
\]

at original (historic) prices. In principle, if accounting were at "current cost," gross and net stocks could be estimated by statistical agencies simply by aggregating, respectively, these \( G_t \) and \( N_t \) values. Practical problems would be the distortions in the accounts, described in Section 4, non-uniformity in companies' use of price indexes, and the fact that the net stock obtained, though a useful measure, would not be a "true net." Accounting net is based on each company's assumed lives and particular depreciation methods. Arriving at true net requires somehow determining actual lives, and deciding on some acceptable, uniform, depreciation rule.

The only practical way of estimating the capital stock is through some statistical agency model. This could be based on the basic perpetual inventory process of company accounts:

\[
G_t = G_{t-1} + I_t - d_t
\]  

where \( I_t \) is capital expenditure and \( d_t \) is discards, during year \( t \). But, for a statistical agency to use this to estimate the capital stock would impose a large data burden. Initially a survey of the age distributions of fixed assets would permit calculation of a revalued \( G_{t-1} \). This would be updated annually through a survey of the age distributions of \( d_t \) also revalued.

Fortunately we can circumvent these problems by replacing equation (1) with the exactly equivalent age distribution equation:

\[
G_t = \sum_{k=0}^{t} I_k S_{k_t}
\]  

96
where $S_k$, is the proportion of the vintage of capital goods, $I_k$, surviving at time $t$. As can be seen from the diagram above, $S_k$, is in fact the survival curve of $I_k$. The PIM uses an approximation of this, replacing the irregular and changing $S_k$, with some survival function $\phi$, usually expressed in terms of a fixed mean value, $L$:

$$G_t = \sum_{k=0}^{L} I_k \phi_k(L). \quad (3)$$

Sometimes statistical agencies make the further approximation of zero-dispersion of lives (all items in a group of assets have the same life), in which case equation (3) assumes the simple form

$$G_t = \sum_{k=t-L+1}^{t} I_k \quad (4)$$

Given the commonly used assumption of straight-line depreciation, the corresponding equation for accumulated depreciation is

$$A_t = \frac{1}{L} \sum_{k=t-L+1}^{t} (t - k + 1)I_k \quad (5)$$

Using some assumed value of $L$, and the deflated $I_k$ series, equations (4) and (5) give estimates of the gross and net capital stocks (net stock is gross stock less accumulated depreciation).

3. **The Nature of Service Lives**

Before proceeding further it is necessary to clarify the concept of service life. To avoid unnecessary complexity, zero-dispersion is assumed. Figure 2 shows two types of life: actual, $L_k$, (period in service); and accounting, $LA_k$ (predicted by corporations). Lives, shown as falling here, may change in either direction. The subscript "k" refers to the vintage of capital goods whose life is indicated.

**Actual Lives**: The interval from $t'$ to $t$ encompasses the vintages of capital expenditure comprising the present stock. $J$, is the age of its oldest marginal item, about to be discarded. It is clearly the life, $L_{t'} = L_{t'-J}$ of capital goods of the $t'$ vintage — "cohort" in the parlance of human mortality statistics. Figure 2(a) shows the curve, $L_k$, of such vintage lives. $L_r$, is its latest measurable value. The $BC$ part of the curve is unknowable. It must be predicted in order to calculate depreciation required for estimating the net stock.

\footnote{For simplicity, the equations of this paper use a conventional notation based on integer lives. A somewhat more complex notation has been developed for FAASM in terms of non-integer values.}
J, might, alternatively, be plotted on a graph as the age of capital goods "dying" now, at t. It is only at t that the value of $L_r$ is determined, through the discard decision, under present economic and technological conditions, to discard, and possibly to replace or expand, with modern equipment. (Note that when lives are dispersed, $J_r$ and $L_r$ are means which are only approximately equal.)

Accounting Lives: $L_{Ak}$, shown in Figure 2(b), is corporations' predictions made at purchase—"life expectancies at birth"—of $L_k$, for calculating depreciation expense in their main accounts. (For large corporations in Canada, these are generally different from lives used for tax purposes, which are irrelevant here.) Though shown here as above $L_k$, it may be below. Prediction errors are understandable: When $L_{Ak}$ is set, the latest knowable life is $L_{Ak}$, $J_r$ years in the past. "Knowable" does not mean "known", and corporations may not have analyzed their discards to determine trends in actual lives. Knowledge of $L_{Ak}$ is not essential for estimating the capital stock, but has a variety of uses discussed later.

Footnote: Such analysis is performed by, for example, telephone utilities, for which depreciation expense is of great importance. Marston, Winfrey, and Hempstead (1953) is a leading reference work on retirements analysis.
**PIM Life, L:** Figure 2(c) compares the PIM's \( L \) with \( L_k \) and \( LA_k \). (\( L \) is shown above here, but it could be below.) \( L \) is intended to be actual life, \( L_k \). The distinction between knowable and unknowable presumably has no meaning in the PIM, since lives are assumed not to change. The PIM does not concern itself with accountants' depreciation lives, \( LA_k \), as such, though statistical agencies may sometimes be guided by these values in assuming \( L \), for lack of better data.

The PIM's constant life, \( L \), seems clearly unsatisfactory: "Estimates of economic lives are regarded as the weakest aspect of the simulation exercise. In most countries, no recent, comprehensive and empirically based set of estimates of capital asset lives has been compiled" (Ward, 1976). The U.S. Bureau of Economic Analysis depends mainly on data compiled in connection with the administration of federal income tax laws, specifically on the 1942 edition of Bulletin F (Ward, 1976, and Bureau of Economic Analysis, 1987).

The imprecise practice of assuming a constant life is perhaps explained by the difficulty of the PIM approach in measuring life directly. It seems especially inappropriate now, given the apparently rapid introduction of new technologies. The assumption of constancy may greatly affect the estimates of capital stock growth rates.

If we could survey lives accurately, annually, we could improve the PIM by replacing \( L \) in equations (4) and (5) with \( J_i \) and \( L_k \), to give

\[
G_i = \sum_{k=1}^{t} \frac{I_k}{L_k} \quad (6)
\]

\[
A_i = \sum_{k=1}^{t} \frac{I_k}{L_k} \quad (7)
\]

An acceptably close measure of \( J_i \) might be the weighted average age of discards, \( d_i \), obtained from their age distribution. However, surveying this age distribution may impose a large data burden. A large company's annual discards, \( d_i \), in a single asset class, has an average magnitude in the millions of dollars. This total would generally comprise a number of assets, acquired at different dates, each in turn including a possibly large number of parts replaced, or added, (renovations, retrofits, capacity increases) over the years. In the first year of implementation, surveyed \( J_i \) would permit estimation of only a single, year \( t \), gross stock. Until the system had operated for some years, it would be difficult to establish the \( L_k \) trend (see Figure 2(a)), necessary for estimating the net stock from equation (7), and for re-estimating past stocks. Compounding these difficulties would be the accounting distortions described in Section 4c.

**4. THE FIXED ASSET ACCOUNTING SIMULATION MODEL (FAASM)**

In this section I describe a method which circumvents the difficulties of direct life measurement by means of a model that simulates corporate accounts, through life inference.

\[3\text{Where company practice is to charge replacements to expense rather than to capitalize them, the survey burden is reduced.}\]
4a. Prior Use of Company Accounts to Determine Service Lives

There is a widely-held view (e.g. Ward, 1976, p. 26) that company accounts are of little value in capital stock estimation, both because accounting is at historic prices, and because of variations and anomalies of accounting practice. In fact, they can be used indirectly, to determine lives which can then be used to estimate stocks. As Blades (1983) notes in a review of life determination methods, historic price accounting need be no obstacle to life determination, provided data anomalies are removed.

The study by Tarasofsky and his associates (1981) brought to the writer's attention the possibility of inferring lives. These researchers estimated a value of accounting life, assumed to equal actual life, \( L \), for the total business sector, all asset categories combined, of 19 years, in comparison with about 28 years assumed in the Canadian capital stock estimates. (Interestingly, all the studies of lives based on company accounts, those reviewed here, as well as the present telephone utilities study, seem to indicate service lives shorter than current PIM assumed values.)

French work, discovered only later by the writer, used life inference methods more like those of this paper. Mairesse (1972), in establishing the lives assumed in the French PIM capital stock estimates, relied to some extent on company accounts, despite a severe shortage of suitable data. In his later study with Atkinson (1978), equipment lives in manufacturing were determined using an equation similar to (3). Though coherent and consistent results were arrived at, the exercise had to be limited to a relatively small number of firms, judged to be largely free of data distortions. The values of \( L \) determined were sufficiently close as to confirm those established by Mairesse in 1972, so the latter remain in force for the French PIM estimates.

Cette and Szpiro (1988) studied the recent trends of lives in French industry, using the simple form of life inference described below, based on equation (6). The extent to which data distortions were excluded is not clear.

All the prior work reviewed here measured only actual lives, not, in addition, accounting lives. The equations used a constant mean life parameter. The importance of data problems in limiting the use of company accounts is emphasized by Mairesse, in his 1972 study particularly, and he identified categories of data distortions similar to those discussed below in Section 4c.

4b. The Principle of Life Inference

That lives can be inferred from fixed asset accounts, despite their being at historic cost, is simply demonstrated. For example, equation (6) has three variables, \( G_i \), \( I_i \), and \( J_i \). If \( G_i \) and \( I_i \) are known, the single unknown, \( J_i \), can be calculated. We therefore do not need to attempt to gather data on lives if, instead, we survey the readily accessible \( G_i \) total in the accounts.

In practice we would probably use more accurate expressions for \( G_i \), based on the equation (2) given earlier. \( G_i \) no longer depends on a single life, \( L_i = J_i \), but on a series of survival curves, \( S_{sk} \). To permit life inference, an approximate form of equation (2) is used, assuming some specified survival shape, and some
functional form for the trend of the mean life, \( L_k \), for example,

\[
G_i = \sum_{k=0}^{r} I_i \phi_k(\alpha, \beta, \gamma, \delta)
\]  

(8)

where \( \alpha \) and \( \beta \) are the \( L_k \) parameters (assuming some two parameter trend like a straight line, S-curve, or negative exponential), and \( \gamma \) and \( \delta \) are the dispersion parameters, fractions of \( L_k \) representing the lower and upper dispersion limits respectively. Assuming \( \gamma \) and \( \delta \) and some survival shape based on empirical evidence, we can solve for the \( L_k \) trend parameters, \( \alpha \) and \( \beta \). Whereas before, to determine the single unknown, \( J_i \), a single year’s data value, \( G_i \), sufficed, now two years’ such values, \( G_i \) and \( G_{i-1} \), are required.

Instead of assuming a specific survival shape, we may treat \( \gamma \) and \( \delta \) as the parameters of some assumed standard functional form for such a shape, e.g. a normal distribution. Now, given four years of \( G \) data, we can solve not only for the trend of \( L_k \), but also for the approximate life distribution. Theoretically, then, we can infer something about survival functions without the need for direct observation. Given more years of data, we might solve for more than four parameters, allowing greater accuracy of trends and distributions. Econometric estimation methods might be employed.\(^4\)

Equation (8), unlike equation (6) for zero-dispersion, by embodying the life trend, appears to facilitate re-estimation of the past stock.

Just as it is possible to infer actual lives and survival functions from \( G \), equations and data, we can infer accounting lives, \( L_{Ak} \), if we have, in addition, the corresponding depreciation equations and data, both \( A_i \), accumulated depreciation, and \( D_i \), annual depreciation. Now the situation is more complex. While there is only one, universally used, \( G \), equation, (1), there is a variety of \( A \), and \( D \), equations, reflecting the particular depreciation methods used by corporations. Moreover, the equations are more elaborate. Accounting life inference is not discussed in this paper.\(^5\)

In the present study, both \( L_k \) and \( L_{Ak} \) have been inferred from data using zero-dispersion equations. For \( L_{Ak} \) a straight-line trend was assumed. A programme of experimental simulation is required to develop inference techniques based on equations like (8). This must then be extended to the more complex situation where accounting lives are involved.

4c. The Errors to which Inferred Lives are Subject

The errors to which inferred lives are subject can be seen from the equations from which they are determined. In the inference of actual lives from equation (8), there are three sources of error: (i) Deviation of equation (8) from the rule governing corporate accounting equation (1); (ii) \( G \) data distortions due to corporations’ own deviations from equation (1); and (iii) \( I_k \) data distortions.

\(^4\)Since submission of this paper, equation (8) has been successfully used for the inference of \( \alpha \) and \( \beta \), given assumed survival shape and \( \gamma \) and \( \delta \) values. The inference of \( \gamma \) and \( \delta \) has not yet been tried, but may raise some theoretical questions and require more than the four years of \( G \) data here indicated.

\(^5\)However, see Jaffey and Gigantes, 1987, for discussion of inference of accounting lives.
In addition to these distortions of $G_i$ and $I_k$ in corporation accounts are the errors in surveying them, ignored here, familiar survey errors in an area of readily accessible information. The three error categories are discussed in turn.

(i) Deviation of Equation (8) (Survival Curve Approximations)

Under the zero-dispersion assumption, when equation (8) becomes equation (6), simulation experiments by the writer show that if actual, real world lives have a normal distribution, gross capital stock is estimated with a small downward bias, say 3 percent, given the rates of price increase and investment growth of recent decades. If, however, some irregular, say, bimodal, distribution exists, this bias may be considerably larger. The corresponding net stocks, as calculated using equation (7), have substantial upward biases.

To eliminate these biases, in practice the equations discussed above, incorporating dispersion and life trend, would be used. Then, with some empirical knowledge of actual survival functions in each industry, most of the error due to the equation approximations could probably be eliminated. Even assuming simple, rule-of-thumb, distributions will substantially reduce the bias. The accuracy improvements theoretically possible through inference of distributions without empirical knowledge, have not yet been investigated.

(ii) Distortions of Gross Fixed Assets, $G_i$

It can be seen from the basic equation (1) that $G_i$ may suffer errors from three sources: “extraneous” alterations of the $G_i$ value in the accounts, outside the basic process of equation (1); errors in the $d_i$ data; and errors in the $I_k$ data. The most important extraneous alteration of the $G_i$ value is owing to revaluations, for example, in the course of company acquisitions. Due to inflation this produces an upward bias in $G_i$.

There are two main sources of discard error. The more important is “unrecorded discards,” resulting from the failure to remove from the accounts difficult-to-estimate parts of facilities, e.g. a replaced roof or a road surface. Unrecorded discards give an upward bias to $G_i$ in the accounts. This bias cannot be exactly eliminated even in principle, because, unlike all the other distortions mentioned here, there is no record of them. The best one can hope for is to estimate approximately their importance, industry by industry. Unrecorded discards constitute, in effect, a breakdown in accounting procedure—and there are others—that set an ultimate limit to the accuracy of capital stock estimation by any method. This includes the attempt to improve the PIM approach of direct measurement of lives, discussed in Section 3.

The second discard distortion is “retirements pending disposal,” for which there is a delay before sale or scrapping, at which time they are deleted from the $G_i$ account.

The third of the three sources of distortion in $G_i$, errors in $I_k$, is also an independent source of error in estimating life, discussed in the next section.

(iii) Distortions in the Capital Expenditures Series, $I_k$

Two types of $I_k$ error are frequently referred to as major sources of PIM inaccuracy, inter-industry sale and leasing of fixed assets. Four other $I_k$ problems
are noted here as potentially important. In Canada, corporations may enter into their accounts the value of fixed assets purchased, net of government subsidies and investment tax credits, instead of at the gross value relevant for capital stock estimation. Other significant distortions may lie in the charging of large replacement parts as expense, and in mergers. Finally, there may be definitional problems, as between “annual capital expenditures,” “annual additions to fixed assets in service,” and “year-end balance of construction-in-progress,” entities which may differ greatly in magnitude.

It is possible that $I_k$ errors will not have a major effect on life inference, because the two $I_k$ effects on life, the indirect effect through $G_i$, and the direct effect, tend to be mutually compensatory. If, for example, companies’ $I_k$ values are downward biased, so will be their $G_i$ values. Then when lives are inferred from equation (8), the downward bias of $G_i$ will tend to offset the downward bias in $I_k$. $I_k$ errors probably have a more important effect in the final step of capital stock estimation, step (ii) described in Section 4h.

The errors to which the inference of accounting lives, $LA_k$, is subject are not discussed here. They are analogous, but more complex.

4d. The Principles of the Simulation Model

Occasional studies, like those described in Section 4a, are rendered difficult not only by the account distortions just discussed, but also by the gaps and inconsistencies in existing data series, some of which may be gathered in separate, difficult-to-reconcile surveys. Moreover, such episodic study cannot provide comprehensive, up-to-date coverage. Full exploitation of life inference is made possible by embodying it in a simulation model, in conjunction with an annual data survey that screens out the distortions.

The rationale of the simulation system is as follows. It has three components: $A$, account values; $B$, equations representing the fixed asset accounting procedures that yield those values; and, $C$, service lives, which are the equation parameters. If the model is an analogue of the corporate fixed asset accounts, the three elements will simultaneously replicate their real world counterparts. Further, given their mutual dependency, if the model is capable of replicating any two elements, then it should reproduce the third element. Simulation in this way appears to be no more than the expression of scientific method, linking variables, laws, and parameters.

In FAASM, initial investigation of corporations determines accounting procedures, $B$. An annual survey transfers data values, $A$, to the model. The model then finds the values of $C$ that will cause equality between model-calculated $A$ and data $A$. The same model could, in principle, achieve the analogue condition in the “PIM-mode,” i.e. through $B$ and $C$ replication, and calculating account totals, $A$. However, as already explained, the accurate observation of $C$, lives, is difficult.

We can see that there are three conditions for the accuracy of FAASM-determined lives: accurate survey of data, $A$; accurate formulation of the model’s equations, $B$, in terms of lives; and stating the equations in a form soluble for lives. The latter is possible only by imposing regularities on the myriad diversity
of actual lives, reducing them to a handful of life distribution and trend parameters.

Through continuing simulation, FAASM is a learning system, its life parameters becoming more accurate with time. It should be economical in its data requirements. Even at initial implementation, using zero-dispersion equations and a single year's data, a considerable amount is learnt. From equation (6) we arrive at a single $L_k (= J_k)$ value, and from the corresponding $A_k$ and $D_k$ equations a trend of $L_k A$ values, from which we can also guess at the $L_k$ trend [see Figure 2(a)]. By repeating the process for only a few succeeding years, our trends become considerably more accurate. In practice, using equations like (8), embodying trend and distribution, we learn even more, including some direct knowledge of the past $L_k$ trend at the outset.

4e. Partial and Full FAASMs

The simulation model has two versions. The partial version uses the $G_i$ and $I_k$ accounts, and embodies only actual lives, $L_k$. The full version adds the $A_k$ and $D_k$ accounts, and accounting lives, $L_k A_k$.

Partial FAASM suffices in the estimate of true stocks, both gross and net, which depend only on $L_k$. True net stock has two parts, a known true value which can be calculated only in retrospect for the years preceding $t'$, and for later years, a "best judgment" true net, at least partly using the best judgement predicted $L_k$ [see Figure 2(a)]. Partial FAASM will also provide estimates of true capital consumption, hence, residually, of true profit, for use in the GDP estimates. (These components in the Canadian national accounts are now based on depreciation expense reported by companies, which may be substantially different.)

Full FAASM can complement the partial version in estimating true stocks. By providing $L_k A_k$, corporations' own predictions of life, it helps establish the "best judgment" part of the $L_k$ trend, needed for estimating the true net stock. Full FAASM also permits a second net stock measure, or "accounting" net, based on $L_k A_k$, of what would appear on the corporate balance sheets if current cost accounting were in force. True and accounting net capital stocks yield, respectively, true—for recent years, best judgment—and accounting rate of return on capital. The former is presumably the underlying long-term return. However, perhaps in the shorter run, accounting return may better relate to decisions on investment and output.

Full FAASM's outputs go beyond the capital stock estimates just discussed. Graphs like Figure 2(b), by perpetually monitoring accounting versus actual life trends, provide insights into industry technological change, market forces, and accounting policies. Measures of the over- or under-statement of profits because of under- or over-charging of depreciation, respectively, are also shown. The extent of old, fully depreciated, plant (perhaps because of stagnation), or of plant disposed of not yet fully depreciated (perhaps because of rapid technological change and competition) would also be indicated. Full FAASM could also serve as an aid in setting corporation tax lives, by making available to government more accurate estimates of both actual and accounting lives.
4f. The Annual Data Survey

FAASM requires an annual survey of the totals in companies’ fixed asset accounts, $G$, $I$, $D$, and $A$. Partial FAASM, whose survey is described here, gathers only $G$ and $I$. (The additional survey features for full FAASM are analogous.) To meet FAASM’s data accuracy condition, the survey is in the form of an annual reconciliation statement, based on the $G$ equation, (1). Owing to the distortions or adjustments in the accounts, described in Section 4c, the values in the corporate accounts are not our “true” $G$, but instead $G'$, such that

$$G' = G'_{t-1} + I_t - d_t + X_t$$

where $X_t$ is the total of distorting entries in the $G$ account during the year (the sum of $G$, $I$, and $d$ distortions). By using a survey form that employs this equation we can screen out the distortions, thereby arriving at true $G_t$ and $I_t$. At implementation of FAASM, an initial survey would be required to permit an approximate estimate of inherited distortions. The importance of inherited errors would diminish with time.

This reconciliation form of survey would not entirely eliminate errors, as some of the corrections supplied by corporations would surely be approximate, especially for $d_t$. In addition to screening out distortions, the reconciliation would also increase accuracy by imposing mutual consistency of all the data items. The long-standing difficulties of $I$ reporting, described in Section 4c, with regard to capital leases, government capital assistance, and definitional problems, would be resolved. Study of the remaining difficulties, second-hand assets, operating leases, and expensed capital items, would be facilitated by FAASM’s integrating framework.

Solution of the definitional problems would be sought by supplementing the equation (9) reconciliation with a similar construction-in-progress reconciliation. $G$ would be defined as including only fixed assets in service, and $I$ as additions to this stock. $I$ then would have two components, $IP$, items directly entering service on purchase, and $T$, completed construction work, transferred from the construction-in-progress account. The latter is expressed thus:

$$W_t = W_{t-1} + C_t - T_t$$

where $W_t$ is the balance of construction-in-progress, and $C_t$ is construction in year $t$. Note also the relationship:

$$CE_t = IP_t + C_t$$

where $CE_t$ is annual capital expenditure. It should be possible through a further “retirements pending disposal” reconciliation, similar to equation (10), to segregate these items from the $G$ data. There is a view that capital stock estimates are sometimes upwardly biased through inclusion of these permanently inactive items.

How practical is it to perform this annual reconciliation type of annual survey? The French statistical agency, INSEE, already uses a relationship similar to equation (9) at the enterprise level, broken down by asset class, solely for the
purpose of improving accuracy of reporting (they do not in addition utilize the data in a simulation model). Preliminary investigation indicates that Canadian enterprises perform such reconciliations in preparing their annual financial statements. In order to provide industry detail, FAASM would need this at the level of the constituent establishments. This could probably be provided by most companies, but further investigation is required. Where gaps exist, the statistical agency would need to interpolate from the available data.

The asset class breakdown of FAASM capital stock estimates will depend upon the detail in which establishment fixed asset accounts are kept. In Canada, for large companies, this is probably more detailed than the present breakdown of the capital stock estimates, into buildings, engineering construction, and machinery and equipment. This also needs to be investigated further.

4g. Formulating FAASM Equations

The other condition for FAASM accuracy is the formulation of equations that faithfully reproduce company accounting processes, in a form soluble for lives. This should present no serious problems with partial FAASM, with its simple, universal, \( G_r \) equation. However, for full FAASM, with its \( A_r \) and \( D_r \) equations, reflecting diverse company depreciation methods, a substantial effort will be required. This is not discussed here.

FAASM's development, operation, and continuing improvement—and updating to reflect changing accounting procedures—will require consultation with accountants and service life analysis specialists, now usually employed only by utilities. The national professional accounting body might play a role.

4h. The Accuracy of FAASM Estimates of the Capital Stock

The precise factors affecting accuracy can be seen from the equations used. Consider the estimate of the gross stock, using equation (8) to determine the life parameters, and then using the same equation including the price index, \( P_k \), to calculate the stock:

\[
KG_r = \sum_{k=0}^{t} \frac{I_k}{P_k} \phi_{kr}(\alpha, \beta, \gamma, \delta)
\]

This is subject to the following types of error:

(i) Errors in the lives inferred from equation (8), discussed in Section 4c, due to
   (a) Approximations built into the equation; and
   (b) Errors in \( I_k \) and \( G_r \) data.

(ii) Errors in the capital stock estimated from equation (12), due to
    (a) Errors in the \( I_k \) data
    (b) Errors in \( P_k \).

To what extent will it be possible to eliminate these errors? Following FAASM’s initial development stage and continuing improvement in operation, it should be possible to reduce (i) and (ii-a) type errors to quite a low level. The

*Possibly FAASM adaptations will need to be devised for industries with atypically volatile investments and discards, and for new industries without clear mortality patterns.
main remaining errors in gross capital stock estimates will be due to (ii-b), the
price index. Estimates, using full FAASM, of accounting net stocks, based on
accounting lives, would probably have larger errors, owing to the greater com-
plexity and diversity of equations and data.

Even for countries where the quality of company accounting is not high, it
seems likely that results from a FAASM approach would be more accurate than
those based on the under-utilization of the same source data through the intermit-
tent, piecemeal PIM approach of direct measurement of service lives.

5. A Case Study: Application of FAASM to the Canadian Telephone Utilities

A simple version of full FAASM was applied to this industry, using already
available, published, Statistics Canada data. The zero-dispersion assumption
was used, which may produce large biases when applied, as here, to undisaggre-
gated industry totals. The data were uncorrected for distortions, though there is
some evidence that these are small in this industry. Despite these shortcomings,
the results seemed sufficiently tantalizing to present here.

Figure 3 shows the lives arrived at. Owing to the zero-dispersion assumption,
the gap between actual and accounting lives is exaggerated, especially in the
erlier years. Nonetheless, there is evidence from data on expected lives in the
1985 and 1986 Capital Expenditures Surveys, from the composite depreciation
rates given in Bell Canada's Annual Report, and from discussions with Bell
Canada, that these results have considerable validity. Actual lives are about half
those now assumed in the PIM. Lives of vintages from 1959 onwards have been
falling at a considerable rate, reflecting decisions since 1976 to discard assets
progressively earlier.

Figure 4 shows the gross and accounting net capital stocks estimated by
FAASM, compared with the published PIM values. The differences, especially
as regards recent growth rates, are large. (The zero-dispersion simplification does
not produce much error in the gross stock, but for the net the error may be
substantial.)

Despite this case study's shortcomings, its results are encouraging. Notable
are their coherence, internal consistency, and clear patterns and trends, and their
support by independent empirical evidence.

7This version contains equation (6) for $G_r$, and corresponding equations for $A_r$ and $D_r$, assuming
standard straight-line depreciation, plus equations reflecting telephone utilities' depreciation pro-
cedures, incorporating changing group lives. The standard equations were required to determine
equivalent accounting lives, $L_{A_r}$ (see note 7).

8The more elaborate inference techniques discussed in Section 4b should permit replacement of
the set of $L_{A_r}$ trends with a single non-linear trend. Figure 3 shows, in fact, "equivalent" vintage
accounting lives; what they would have been if telephone utilities used standard, straight-line
depreciation.

9The relatively high $L_{A_r}$ indicates undercharging of depreciation. This, in fact, has been true
of some telephone utilities, though probably not Bell Canada. For U.S. telephone utilities, such
under-depreciation resulted in a "$26 billion time bomb on (the utilities') balance sheets", for which
the Federal Communications Commission awarded rate relief. This shortfall was the result of faster
obsolescence of facilities occasioned by deregulation, which exposed the utilities to competition.
(Forbes Magazine, July 29, 1985.)
6. Summary and Conclusions

The present PIM approach of directly surveying lives has inherent difficulties. There is the "changing identity problem": each asset may have changed since original purchase as a result of replaced parts, additions, retrofits, and renovations over the years. To measure these in order to arrive at a correctly weighted average life may involve a large data burden.

Such weighted average lives may instead be inferred in a simulation model, FAASM. Through exploiting the available source data in a systematic, scientific way, FAASM life estimates may eventually approach the limits of attainable accuracy.

The partial form of FAASM, based on actual lives, suffices for capital stock estimation. The practical problems of implementation do not appear to be serious. Ultimately, if the problems of the price index are also addressed, it may be possible to measure capital, and the rate of return on capital, quite accurately.

Full FAASM offers important additional benefits. Though there appear to be no serious theoretical problems, the amount of effort to overcome practical difficulties may prove substantial. Further investigation is required. To what extent, and to what standards of accuracy, full FAASM will be implemented will surely be a question of cost effectiveness.
* Accounting net stock, based on LAk. A more appropriate comparison would be with a best judgment, true net stock based on a projection of Lk on Figure 3. True net stock would be about 20% lower.

Figure 4. Telephone Utilities' Capital Stock, in 1971 Constant Dollars Comparison of PIM and FAASM Measures.
How FAASM might be extended from the corporate to the other sectors, unincorporated business and government, needs to be explored. One way would simply be to use corporate sector lives suitably adjusted.

REFERENCES


Bureau of Economic Analysis, Fixed Reproducible Tangible Wealth in the United States, 1925-85, Chapters 1 to 4 on Methodology, Bureau of Economic Analysis, June 1987.

The Canadian Institute of Chartered Accountants Handbook (quasi-legislative accounting standards).


