NOTES ON THE MEASUREMENT OF REAL CAPITAL IN RELATION TO ECONOMIC PLANNING MODELS[1]

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Economic planning can in principle be seen as consisting of two phases: first a description of all possible development paths, and second a choice of "the best one" from among these possibilities. In the present paper the measurement of real capital is discussed in relation to the needs of the first of these two phases. In section 2 of the paper it is argued that the most relevant measure of capital for this purpose is the gross value of the existing capital stock, i.e. the total value without accounting for depreciation. In section 3 of the paper different ways of estimating this gross capital stock are discussed. In sections 4, 5 and 6 there follows a discussion of how one can correct the capital measures for changes in efficiency with age, for "embodied technical progress" and for different durabilities. The latter correction leads to concepts which are equivalent to measuring "capital services" as a factor of production. The treatment of maintenance and repair will be important for the interpretations of some of these "corrections." The final section of the paper suggests a model which requires data on vintages of capital.

1. *Introduction*

Numerical data on a country's real capital can be useful for many purposes. In this article we shall examine the question only in relation to the construction of economic models for planning purposes.

The planning models which have been utilized in Norway are basically of the relatively short-run type. They reflect relationships between current inputs of various production factors and production results, relationships between production and income formation, and relationships between income, prices, and demand for consumer goods, as well as definitional or accounting relationships.[2] Economic planning should in principle consist of delineating the possible development paths for a future short- or long-term period, and then from these possibilities choosing the one which is, in some sense, the best. For determining the various possible results it is necessary (but not sufficient) to determine *the production possibilities*. In order to accomplish this one must be acquainted not only with the relationships between current inputs and outputs; one must also know the limits to the production possibilities which are imposed by the amount

1. This is a translation of the first seven sections of a memorandum from the Institute of Economics at the University of Oslo, dated April 14, 1966. An extended version of the last section of the memorandum, which treats the concept of capacity and its measurement, will be published separately. The authors gratefully acknowledge the assistance of Mr. Finn Førsund.

2. See *Nasjonalbudsjettet 1966* (The National Budget 1966), Enclosure 1, Parliamentary Report No. 1 (1965–66), p. 5.

and quality of the production equipment and production plant, i.e., the real capital which, at a given time, is at hand in the sectors of production. This latter has not been built into the models used in Norway up to the present time. Among the reasons for this are both the theoretical and practical problems which arise in connection with the measurement of real capital and/or production capacity.

The viewpoint adopted here considers the measurement of real capital as a tool for delineating production possibilities. It may perhaps be useful to reflect further on the question as to whether measurements of the stock of real capital are really needed for this purpose.

Let us first think of the question in relation to short-term planning. We can perhaps define such planning as planning for such a short period of time that the investment activity which is started in the planning period does not influence production possibilities within that planning period significantly. The production possibilities in the planning period will then be determined by the quantity and quality of capital which is available at the beginning of the period and changes in this capital as a result of investment activity begun prior to this time (together with the supply of other production factors).

Given these assumptions it is obvious that the short-run planning question will to a great extent be one of utilizing production possibilities which are decided by previously determined or executed, or in any case started, expansions of the production facilities. If we knew a relationship between the volume of real capital and production capacity (total or split up into different production sectors), knowledge of the capital stock would obviously be of significance for the problem of short-term planning.[3] It is, however, the production capacity which is directly decisive in this connection. The question whether we need figures for the stock of real capital is thus the same as the question whether we can estimate the production capacity better by using a circuitous method via the measurement of the stock of real capital than by attempting a more direct estimate of production capacity. In countries where one has statistics of production capacity and its degree of utilization, methods are usually employed which do not take the circuitous route via the measurement of real capital.[4]

In long-term planning the problems will appear to be somewhat different. There one will usually plan as if the capacity available at each point of time is fully utilized, while the short-term problem was to achieve this utilization. At the same time the production capacity developed in the planning period will

3. We are thinking here of production capacity as a figure expressed in the same unit as production which gives an upper limit for the latter, and we are assuming that it depends only on the production equipment, i.e. the real capital. The possible limits of production which may result from a limited supply of other production factors must, of course, also be taken into consideration. This can be accomplished, however, through constraints in addition to those expressing the production capacities in the various branches. (See Ragnar Frisch: *How to Plan*, Memo No. 380, December 13, 1963, The Institute of National Planning, Cairo, Chapter 6, p. 20.)

4. In the United States two of the best known measurements, McGraw-Hill's and Wharton School's, are direct estimates, while index series based on accounting data usually choose the indirect method or a measurement of the stock of real capital. The most well-known of these latter series is probably the one prepared by Daniel Creamer for the National Industrial Conference Board.

play a large role, in addition to the production capacity represented by the capital equipment existing at the beginning of the period. One cannot estimate future production capacity by any such direct methods as suggested above for the short-run problem. One may perhaps ask if capital *stock* figures are necessary in this connection. It is investment which provides the change in production capacity. If one then in some way had determined directly production capacity in the initial situation, it could perhaps suffice to estimate or plan future investment in order to delineate the future production possibilities.

There are two things to add to this:

First, one must obviously know the relationship between investment and the change in production capacity, which is another expression of the relationship between real capital and the level of production capacity. In order to establish this relationship one will, of course, be considerably more certain with historical data of capital stock and production capacity than if one did not have such statistics on capital. Statistics on capital are, in other words, needed in order to obtain a basis for an econometric estimation of the relationship.

Secondly, the increase in production capacity which is caused by investment is a net of one positive and one negative component. The positive component consists of the increase in production capacity resulting from gross investment, while the negative component results from older production equipment either declining in efficiency or being scrapped, and in this way leading to a reduction in production capacity. In order to say something about this reduction in production capacity it is obviously necessary to have some knowledge of the stock of real capital at the beginning of the planning period. This last point indicates that we should obtain statistical information on the capital stock in order to be able to calculate the decline in production possibilities caused by the reduced efficiency or scrapping of production equipment in future years. This is apparently closely related to one of the "traditional" motives for preparing estimates of the capital stock in various countries, namely to obtain a basis for calculating depreciation in connection with the preparation of national accounts figures.[5] There is, however, the essential difference that depreciation calculated for national accounts purposes is not necessarily a relevant measure of the reduction in production capacity which we need for the kind of planning we have in mind here. This is a familiar theme in economic literature and we return to it in the following sections.[6]

2. Main Types of Measures of the Volume of Real Capital

When we utilize a concept of capital as a means of saying something concerning production possibilities, it is obvious that we need some measure of

5. As far as we can gather this was also the background for the calculations made concerning the development of real capital in Norway, even if these figures are also used for other purposes. See Odd Aukrust and Juul Bjerke: Real Capita land Economic Growth 1900–1956, *Articles*, No. 4, Central Bureau of Statistics, Oslo, 1958. (Also published in *Income and Wealth*, Series VII.)

6. The factor is mentioned in a footnote on page 7 in the above cited article by Aukrust and Bjerke. It is a decisive point in E. D. Domar's well-known article, "Depreciation, Replacement and Growth," which is reproduced as Chapter VII in E. D. Domar: *Essays in the Theory of Economic Growth*, New York, Oxford University Press, 1957.

volume. This entails that we must have measures which are corrected for price changes. If we do not restrict ourselves to purely physical measurements—something which is only possible when we have very detailed specifications of categories of real capital—this means in practice that we must operate with volume indicators calculated by means of a set of constant prices. This raises some special problems which we shall not discuss here, but which are dealt with to some extent in the literature on the subject. Geoffrey Dean sums it up in this manner[7]:

> "In choosing the prices of a specific period, a particular weighting is given to the individual items; comparisons over time will be affected by the extent to which prices of the items diverge. This is the familiar index number problem. In aggregating capital assets, however, the main problem arises from the effects of time not on the prices of new assets but on the condition of old ones. The capital stock is composed of investments from many periods and consequently of assets which vary in age, in the intensity with which they have been used and in the extent to which they have become obsolete; . . . . ."

A rather extensive account of how these problems are solved in practice is provided by Adam Kaufman in an article[8] describing the large censuses of capital which were undertaken in the Soviet Union a few years ago. The problems are also discussed in the previously mentioned article by Aukrust and Bjerke. Throughout the following discussion, the expression "value" will mean the value calculated with such a set of constant prices.

The main types of measure of real capital volume which we might estimate are the following:

1. The depreciated value (the net value) of the existing stock of real capital.

2. A measure which reflects the existing capital stock's future potential earnings. Here one would usually discount in such a way that the value of capital is set equal to the discounted value of the expected future yield.

3. The gross value of the existing stock, i.e., the total value of the existing stock, without accounting for depreciation, or expressed differently: that value which the existing stock would have if all units were new.

This grouping corresponds in the main to that used by Vernon Smith.[9] A brief discussion of these measures (and a few others) is also presented by Zvi Griliches.[10]

Of these main types it is the first which can most easily be integrated into the national accounts statistics, since depreciation here corresponds to the

7. Geoffrey Dean: "The Stock of Fixed Capital in the United Kingdom in 1961," *Journal of the Royal Statistical Society*, Series A, Vol. 127, 1964, p. 327.

8. Adam Kaufman: "The Soviet Capital Stock Inventory and Revaluation," in *Measuring the Nation's Wealth, Studies in Income and Wealth*, Vol. 29, National Bureau of Economic Research, Appendix 1, Part D, p. 229.

9. Vernon Smith: "The Measurement of Capital," in *Measuring the Nation's Wealth, Studies in Income and Wealth*, Vol. 29, National Bureau of Economic Research 1964, p. 332.

10. Zvi Griliches: "Capital Stock in Investment Functions: Some Problems of Concept and Measurement," *Measurements in Economics*, Studies in Mathematical Economics and Econometrics in Memory of Yehuda Grunfeld, Stanford University Press, 1963.

depreciation which is subtracted from gross income in order to arrive at net income in the national accounts. Figures of this type can be obtained—and are in practice obtained—either by means of book values of real capital, or through fire insurance valuation, or by cumulating gross investment figures and subtracting depreciation calculated in some way or other.

Most of the studies dealing with the volume of real capital in a country are based on such net calculations. Tibor Barna, who has utilized fire insurance values in his analyses, also discusses the two other methods mentioned above.[11] On the use of book values he states:

> "As regards estimates based on adjusted book values, it is difficult to see how book values can be adjusted without much fuller information than is generally available. Book values are, as a rule, at original cost and it is impossible to bring them to a given level of prices without knowing the composition of the total by years of vintage. Moreover, assets are generally written off too fast, and assets completely written off, but in use, escape inclusion in the estimates whether a correction is made for changes in the price level or not . . . . All in all, I feel that estimates derived from book values have inherent defects."

He also has a few comments concerning the so-called perpetual inventory method. This is a kind of gross calculation method (see below) but can also be the first step in net calculations.

> "The latter method (perpetual inventory) appears attractive and the one which could be most easily followed in a number of countries. However, the lengths of life of assets which are used in published estimates are based on convention and not on empirical observation; and this may be a source of important errors in the results."

In the use of fire insurance valuations it appears that insurance practices in the various countries are decisive as to whether this measure should be characterized as a net or gross measure. In Norway it is thought to be most reasonable to classify it as a net measure since insurance practices tend increasingly towards insuring an asset for its value at the moment, i.e., a kind of depreciated value for older tangible assets. However, different practices can prevail for different tangible assets. The most thorough discussion of the use of fire insurance valuations is found in another article by Tibor Barna.[12]

A measure of capital which expresses the expected future yields can probably be most easily thought of as being established on the basis of market observations where there are developed second-hand markets for tangible assets of varying ages. Otherwise this measure raises great observational difficulties. We shall return to certain aspects of this kind of measure later.

The gross value of capital may conceivably be established either by registering the existing tangible assets at the value they would have if they should be

11. Tibor Barna: "On Measuring Capital," in *The Theory of Capital*, London 1961, pp. 76–78.

12. Tibor Barna: "The Replacement Cost of Fixed Assets in British Manufacturing Industry in 1955," *Journal of the Royal Statistical Society*, Series A, 1957, Vol. 120, pp. 8–10.

acquired as new now, or by cumulating the figures for gross investment without subtracting depreciation. The full original value of an asset will then be included in the total until the asset becomes obsolete or for some other reason is scrapped.

Of the three concepts it is the third, i.e. the gross value, which is most relevant for the purpose we have in mind here.

If we first think of the depreciated value, we must raise the question as to whether depreciation as traditionally calculated corresponds to the reduction in a tangible asset's production capacity. It is obvious that this is not the case. Depreciation, in addition to reflecting a possible reduction of the production efficiency with age, also reflects the reduction in value which is due to the fact that the asset gradually has a shorter remaining lifetime. This last point is irrelevant for the measurement of the *current* production possibilities which the tangible asset represents. (The fact that the asset has a shorter or longer remaining lifetime, is, of course, interesting in connection with long-term planning, but this ought to be treated in a way which does not disturb our concept of capital as a means of measuring current production capacity.)

The objection raised here against depreciated value is also relevant in connection with the second main type of measure which is indicated above. It is obvious that the discounted value of future yields will gradually decline as the tangible asset ages, without a corresponding reduction in the current physical production efficiency of the asset. This measure will, in addition, also be influenced by other elements which are irrelevant for the delineation of production capacity, for which the existing capital stock provides the basis. For example, changes in the interest rate used in discounting the future yields and changes in expectations concerning future techniques of production will both influence this measure, but will have no significance for current production capacity. One may perhaps elucidate this further as follows: In connection with long-term planning we are interested in what we received in return for the sacrifices we have incurred in order to build up the stock of real capital. We then need some knowledge of the relationship between sacrifices in this sense and the yields which result from these sacrifices. This it should be possible to obtain by estimating a production function which expresses how much the capital (together with other production factors) yields in the form of production. If we now had precise data of the type which is stated in point 2 above, and if all expectations are met, there would in principle exist an exact relationship between this type of capital measurement and the future production flow. This would represent a *definitional* relationship, and not a production function. The relationship between this measure of capital and current production possibilities would demand a further breakdown in time intervals of the flow of production which can originate from the capital stock, but this too would not be a calculation which is related to the concept of a production function.

If we used this kind of figure for capital, we would thus obtain a type of relationship between capital stock and production. But this would not help us in connection with the planning problem, where we have to weigh sacrifices related to the expansion of the stock of real capital against what we receive in return for them.

If we should utilize a measure for capital of type 2 above for planning purposes, we would therefore not avoid a measurement of capital stock also from the sacrifice point of view. However, instead of operating directly with a traditional production function, one could in this case imagine operating with a relationship between capital measured from the sacrifice side and capital as an expression of the discounted value of future yields. Next one would have to utilize definitional relationships and some kind of periodization in order to draw conclusions concerning current production capacity. It is not impossible that such a procedure might have some merit, but at the present time it is difficult to see that it can be practically and theoretically well-founded.

For the planning problem it seems more natural to attempt to find a connection directly between a measure of capital which in some way measures the sacrifice caused by the expansion of the capital, and what the sacrifice yields in the form of production. This indicates that one ought to use a measure of capital which is based on acquisition prices which at least to some extent reflect the costs of production of the capital equipment.

Our conclusion is that the best starting point for the measurement of capital with the purpose of delineating production possibilities in connection with economic planning would be the gross value of the existing capital stock at any given time. This reflects the sacrifice aspect, and every tangible asset is included in this concept of capital stock as long as it is usable in production. This conclusion is well-known in economic growth theory, and in many formal models of economic growth both the net capital stock and gross capital stock now appear as variables, each with their respective roles, and with the gross stock as an argument in the production function.

The result has been that in recent years, in addition to the more traditional attempts to measure the net stock of real capital, we have also seen some attempts to measure the gross stock. We shall treat this aspect in more detail in the next section.

It should perhaps be noted that even though the conceptual definitions and methods of measurement generally must be regarded in connection with the choice of a theoretical model, the considerations which we have here taken into account concerning the concept of capital will probably be valid regardless of whether one should choose to work with a model with fixed production coefficients, including a fixed capital coefficient, or if one operates with production functions with substitution possibilities. It will not be sufficient, however, in all models to use one figure as an expression of the capital stock at each point of time. In the last section of this article we shall elaborate on a method of describing the production structure which comprises certain characteristics from both the production models mentioned above and which raises certain requirements of splitting up the capital stock according to age.

3. *Further on the Gross Stock of Real Capital*

Let us consider time as divided into periods. When we consider a period t, we will also let t designate the point of time which marks the beginning of the relevant period.

Let us introduce the following symbol:

(3.1) $k_{t,\tau}$ = the quantity of capital which is created in period τ and which is still present at the point of time t.

The symbol can refer either to a sector of the economy or to the total economy. There is also nothing preventing our splitting up the quantity of capital according to type. A rough classification might be buildings and machinery. Generally we could introduce the symbol $k^i_{t,\tau}$ where i designates the type of capital.

If the oldest capital in existence at the point of time t is θ_t years old, the gross stock of capital at point of time t will be:

$$K_t = \sum_{\tau=t-\theta_t}^{t-1} k_{t,\tau}. \tag{3.2}$$

This sum includes all existing capital at full value (measured in base year prices) without subtracting depreciation.

If all capital which is created one year has the same life, $k_{t,\tau}$ will be equal to gross investment in period τ. We then simply have

$$K_t = \sum_{\tau=t-\theta_t}^{t-1} J_\tau \tag{3.3}$$

where J_τ is gross investment in the year τ.

More generally we can assume that there exists a certain survival curve for capital (possibly specified by category as mentioned above).[13] This survival curve can be expressed by a series of figures $l_1, l_2, \ldots, l_\theta$ which represent that fraction of an investment dose which still exists as real capital at the beginning of the first year, at the beginning of the second year . . . , at the beginning of year θ after the investment dose was produced. (We may assume $l_1 = 1$). We then have

$$K_t = \sum_{\tau=t-\theta}^{t-1} l_{t-\tau} J_\tau. \tag{3.4}$$

We could here let the survival figures depend on the investment period by letting the l's have one more subscript. For the sake of simplicity, however, we disregard this in the following.

It appears from the above that one can acquire knowledge of the gross stock of capital at a point of time in two different ways.

1. One may undertake a census of all existing (usable) real capital at the point of time in question. For such a census one need in principle not know anything about the expected lifetime and possible survival rates of the type $l_1, l_2, \ldots, l_\theta$. The most important problem in this case would be the previously

13. The survival curve will be dependent on how we treat repairs and maintenance. If these are calculated as gross investment we would arrive at higher figures for gross investment and greater "mortality" than if we calculate repairs and maintenance as a part of the current input in production. This question is touched upon in section 4.

mentioned aggregation problem, i.e. to get all capital units on a common price basis.[14]

2. The other way of acquiring knowledge of the stock is to cumulate previous gross investments. Here one must in principle know the survival curve for tangible assets in order to obtain a correct cumulation according to formula (3.4). (As noted this might be accomplished for various sectors separately and with a breakdown according to type of real capital.) Some knowledge of the survival curve must be obtained through special investigations. If one does not know such survival rates, but is of the opinion that it is an adequate approximation to say that all real capital of the same type has a certain common lifetime, one can simply cumulate gross investment figures according to formula (3.3).

It should be noted in this connection that one has a problem not only concerning the scrapping of real capital, but also concerning additions of new real capital. For purposes of measuring capital as a factor of production new real capital should not be included in the gross capital stock unless it is completed and ready for use. Capital goods in the process of being produced should not be included. The natural method of accomplishing this is to let tangible assets in the process of being produced be registered as a separate entry, or by including them with inventories of other types of goods. This latter method is actually used in the Norwegian national accounts.[15]

The most satisfactory foundation for statistics of the gross stock of capital is probably obtained by combining the two methods which are described above. It is, of course, inconceivable to undertake a new census every year. What one can aim at is to take censuses at spaced intervals and then establish figures for capital stock in the interim periods by cumulating gross investment figures. One will probably arrive at certain differences so that one must make an estimated adjustment in order to have the two sets of figures one obtains from the two methods agree. A great uncertainty in the cumulated investment figures will probably be the survival rates and it will therefore be reasonable to a great extent to adjust these.

In various countries one finds examples of the construction of gross stock figures with the aid of all the methods mentioned here.

The Soviet Union and Japan are the two countries in particular which have undertaken capital censuses on a large scale.

At the end of 1959 a "capital inventory and revaluation" was undertaken in the Soviet Union "covering all state and cooperative enterprises and organizations which were on a self-sustained budget and which were required to set aside allowances for depreciation, with the exception of collective farms".[16] At approximately the same time a housing census was also carried out and two years later a census equal to the 1959 census was carried out for collective

14. See in this connection J. W. Kendrick: "Problems of a Census of National Wealth," *The Review of Income and Wealth*, Series 12, No. 1, March 1966, pp. 57–70.

15. *Nasjonalregnskap 1865–1960* (National Accounts 1865–1960), Central Bureau of Statistics, Oslo, 1965, p. 31.

16. Information concerning the Soviet capital censuses has been obtained from Adam Kaufman, *loc. cit.*

farms and "interfarm enterprises operated jointly by two or more collective farms." Thus it was only private capital (excluding housing) and some administrative institutions which were not included in the censuses. As far as we understand these censuses had a twofold purpose. The first was to establish the gross stock of real capital measured at July 1, 1955, prices. Furthermore, the degree of "physical wear-and-tear" for these stocks was measured in order to arrive at figures for net stocks of real capital.

Fixed capital in the Soviet censuses is defined as "means of work (in contrast to objects of work which come under the category of working or circulating funds) participating repeatedly in the flow of production, or durable goods of lasting use." This includes, however, only capital which is produced by labor so that, for example, land is excluded from the definition. The censuses are complete since all tangible assets (according to the definition above) are included aside from minor items with a short lifetime and/or low acquisition costs.

The determination of replacement values of assets was the most important statistical operation in the censuses. For this purpose 138 "price handbooks" were prepared. These handbooks noted prices of an "all-inclusive assortment of machines, equipment, and rolling stock, included imported machines and equipment no longer produced by the Soviet machine-building industry." The prices were set in such a way that two types of obsolescence were taken into account: "lesser current cost of production of a given asset," and "the appearance of new similar assets of greater efficiency . . . ." In addition to the above mentioned price determination method, an indirect method was used for "buildings, structures and transmissions." Here one used "generalized indicators," i.e. price per unit of volume, area, length, etc., varying with durability, type of material and so on.

The most commonly used method in determining the degree of physical wear-and-tear was to have experts and technicians estimate the various tangible assets' physical condition and the degree of wear-and-tear as a percentage of replacement value. Only where a physical inspection was not possible were indirect methods utilized. Book values and the norms for determining length of life which are commonly used in accounting were purposely disregarded.

The capital was classified by types, which again were distributed among the basic sectors into which the economy had been divided and further among branches within each sector. The data gathered appear to make it possible to examine almost all aspects of capital stock, such as volume, structure, age, serviceability, geographic distribution, etc.

Japan has for some time carried out more or less extensive capital censuses. The most recent were in 1955 and 1960. These censuses, however, aim at measuring the net stock of real capital. Since they differ from the Soviet censuses by being based on samples, and since the methods can be useful also in finding gross stock figures, we find it natural to consider these censuses as well.

The purpose of the 1960 census was "estimating the value of national wealth at the end of 1960, to make clear the structural change of wealth and the level of investment and, at the same time to trace the yearly investment amount since 1955".[17] Capital was defined as "—all goods produced and stocked for use in production process. Assets included were machinery, equipment, plants, buildings, construction and works, and producers' stock of raw materials, semifinished and finished goods, and the net of international assets and liabilities."

In determining which prices one should use in the evaluation of real capital, it was decided that "adjusted replacement cost prices are preferable to original cost prices . . . . Assets were valuated at an adjusted cost of replacement price at the end of 1955. This price is the difference between the outlay necessary for replacement of the assets by a similar asset through manufacture or purchase and a figure representing the value of that part of the asset which was consumed. To calculate adjusted cost of replacement prices, investigations for individual assets were made." In specifying the lifetime of the fixed assets the physical lifetime was chosen ". . . rather than the combined lifetime of assets weighted by both physical and invested value of each asset composing a set."

The main features of the 1955 census can be summarized as follows:

1. The economy was divided into a general government sector, a corporate sector, an unincorporated business sector, and a household sector.

2. The census was carried out on an ownership basis (i.e. not on a user basis).

3. Adjusted replacement value was obtained by utilizing price indexes and depreciation rates corresponding to the remaining lifetime of the assets.

4. The definition of capital assets was kept close to that utilized in the national accounts.

Some of the features of the Japanese censuses clearly reflect the fact that they aim more at estimating *wealth* than capital stock as a production factor. The 1960 census basically followed the same lines.

Most estimates of gross capital stock for other countries are found by using indirect methods instead of direct censuses like those described above. The best known is the previously mentioned perpetual inventory method which consists in cumulating gross investments over the estimated life-time for a certain type of capital. Studies using this method have been carried out in many countries, particularly in the United States by Raymond Goldsmith,[18] in Great Britain by Philip Redfern[19] and Geoffrey Dean,[20] and in West Germany by Rolf Krengel.[21]

17. Information concerning the Japanese censuses is from Yataka Shimizu: "Wealth Surveys in Japan," in the previously cited *Studies in Income and Wealth*, Vol. 29, pp. 277–290.

18. Raymond W. Goldsmith: "A Perpetual Inventory Method of National Wealth," *Studies in Income and Wealth*, Vol. 14, National Bureau of Economic Research, 1951.

19. Philip Redfern: "Net Investment in Fixed Assets in the United Kingdom, 1938–1953," *Journal of the Royal Statistical Society*, Series A, Vol. 118, 1955.

20. Geoffrey Dean, *loc. cit.*

21. Rolf Krengel: "Die Entwicklung des Anlagevermögens der westdeutschen Industrie von 1924 bis 1955," *Wirtschaftsforschung und Wirtschaftsführung*, Festgabe für Ferdinand Friedensburg, Duncker & Humbolt 1956.

A very weak point in all these calculations, however, relates to the estimates of asset lives. The previously noted study by Tibor Barna has for the United Kingdom given an estimate of capital stock which is 50 per cent higher than Redfern found. Barna is of the opinion that approximately half of this difference can be attributed to Redfern's incorrect (too low) estimates of the lifetimes. Barna states[22]:

"In Redfern's estimates for British industry, plant and machinery is divided into five classes with lengths of life 45, 30, 22, 17 and 14 years. He assumes that gross investment in recent years has been distributed between these classes in the proportions of 15, 39, 40, 2 and 4 per cent respectively. This gives an average expected life of 28–29 years.

"The empirical data described above give also an average life of 28–29 years for plant. The main difference between the assumed and the empirically-observed lives is therefore not in the average but in the distribution around the average; while it is assumed that plant dies at specific ages (notably 22, 30 and 45 years) in fact death is evenly spread over a range of about 60 years."

Goldsmith and others who have employed his method have usually based the treatment of the assets' mortality on the simplified assumption that the assets have a rectangular survival curve, i.e. that "assets behave as if they had zero mortality up to their expected life, and then abruptly died."[23] This means that one uses the simple formula (3.3) instead of (3.4). Barna (in the article "On Measuring Capital") has criticized this assumption. His own sample investigation of the mortality of capital in British industry supports the assumption that there exists a linear declining survival curve, as opposed to the rectangular one. Furthermore he found "... that important differences exist between survival curves relating to different industries ...." It appeared that the linear survival curve does not begin at 100 per cent at the time of the assets' entry into the stock, but from 100 per cent when the asset was 3–5 years old. A more detailed description of the investigation is found in the mentioned article.

4. Correcting for Changes in Efficiency with Age. Repairs and Maintenance

In the aggregation of assets, using (3.2) or (3.4), each capital unit is included with the same weight as long as it is at all usable. From the production viewpoint this may be unrealistic since older units may be less efficient than new units. (It is also conceivable that efficiency increases during a shorter or longer starting up period.) Here we are exclusively concerned with the change in efficiency due to the assets' increasing age; in particular, we are not considering the fact that a newer asset is better than an older one because the new asset incorporates experience and new technical ideas which were developed in the period between the production of the older and the newer asset.[24] We could

22. Tibor Barna: "On Measuring Capital," *loc. cit.*
23. Vernon L. Smith, *loc. cit.*
24. We will return to this point in the next section.

then imagine a capital stock corrected for efficiency as

$$K_t = \sum_{\tau=t-\theta}^{t-1} \lambda_{t-\tau} k_{t,\tau} = \sum_{\tau=t-\theta}^{t-1} \lambda_{t-\tau} l_{t-\tau} J_\tau \tag{4.1}$$

where $\lambda_{t-\tau}$ expresses the efficiency of a capital unit in its year of use $t - \tau$ in proportion to the efficiency in its first year of use; in other words we may set $\lambda_1 = 1$. This corresponds to considering capital as a "factor ring"[25] where the various vintages are weighted with the aid of technical equivalence figures. It should be emphasized in connection with (4.1) that the λ's do not express what is traditionally included in depreciation figures. Even if we should have $\lambda_1 > \lambda_2 > \lambda_3 > \ldots > \lambda_\theta$, these λ's reflect only the decline in the capital unit's efficiency in *current* production. They do not reflect the decline in *value* which is due to the fact that the asset as it gradually becomes older has a shorter and shorter remaining lifetime.

In the same way that we could have given the survival rates a subscript to indicate that they could be different for different vintages of capital, we could have given the λ's another subscript if we had reason to believe that the reduction in efficiency with age followed a different pattern for different vintages of capital equipment.

The question of such a correction for changes in efficiency with age relates, to a certain extent, to the question of how one chooses to treat the question of repairs and maintenance. If one chooses to treat these items as current input in production, the capital stock will formally appear to be on average older than if we consider repairs and maintenance as a part of gross investment at any given time. Furthermore the effect of these two treatments on the λ's could be somewhat different according to whether we have a case with substitution possibilities in production or if we assume fixed coefficients. Let us first examine the case with substitution possibilities. We assume that our "factor" K_t shall be entered in a production function as a substitution factor together with other production factors. If we then calculate repairs and maintenance as a part of the current input, older capital will appear less efficient inasmuch as it absorbs relatively more of other factors for repairs and maintenance so that a certain combination of older capital and other production factors brings forth a smaller product than a corresponding combination with newer capital. This will be reflected through the λ's dependence on age. If we do not calculate repairs and maintenance as current input, the series of λ's will not decline for this reason, but on the other hand the survival curve (the l's) will appear to decline more steeply. (But the λ's could be declining for other reasons: for example, relatively greater idle time compared to operative time.)

If, on the other hand, we consider the case with limitational factors, the coefficients which will be influenced by whether we treat repairs and maintenance as gross investment or as current input are primarily the coefficients for factors *other* than capital, particularly labor.

If we treat repairs and maintenance as current input, the coefficient for labor input (and other factors which are needed for repairs and maintenance)

25. Cf. Ragnar Frisch: *Theory of Production*, p. 231, ff., Dordrecht 1965.

should obviously be increased as the tangible asset ages. It is difficult to see that one could, in such a theoretical framework, take this effect into consideration through the λ-coefficients which are used to weight the various vintage groups of capital to a common measure of volume. To the extent that repairs and maintenance are significant, and to the extent we do not wish to introduce variations in other input coefficients, it appears, therefore, that the best thing within the framework we are now considering would be to treat repairs and maintenance as a part of gross investment. If we do that, the survival rates $l_1, l_2, \ldots, l_\theta$ must also here be set lower than if we did not include repairs and maintenance in investment, and we obtain then correspondingly higher reinvestments instead of current input. Also in this case the effect derived from such things as relatively increased idleness for older capital could be taken into consideration through the λ's.[26]

The decisions concerning repairs and maintenance are, of course, in themselves very often economically motivated. In principle, therefore, we should have a method where, in the technical description of the production structure, we allow all possibilities of choice to be open, and this would probably mean that neither the λ's nor the l's introduced above could be considered as technically given data. For practical analytical purposes, however, it will always be the case that one at some point or another must stop and say that what lies behind certain coefficients and functional forms is "technically given," even if one knows that a more detailed investigation would reveal that this is also subject to economic considerations and decisions.

5. *Correcting for "Embodied Technical Progress"*

The correction coefficients λ which we introduced in the previous section relate to the reduction in efficiency due to age as such. They would in other words be relevant even if a new tangible asset produced in 1950 and a new tangible asset produced in 1960 had exactly the same productive potential. We know, however, that some technical progress is constantly taking place, so that this potential is not the same for different vintages of capital. We have, in other words, what is often called "embodied technical progress," i.e. a technical progress which is manifested in the qualities and properties possessed by capital equipment of different vintages. If our aim is to construct one figure for the volume of capital (possibly for a single sector and a single category of

26. Gerhard Gehrig, "Eine Zeitreihe für den Sachkapitalbestand (1925 bis 1938 und 1950 bis 1957)" *Ifo-Studien* 1961, Heft 1/2, constructs his figures as if all the λ's and l's are equal to 1, and justifies it in the following way:

> "Die Ausrüstungen sind bis zum Ende ihrer Lebensdauer in Produktionsprozess voll einsatzfähig. Diese Unterstellung ist insbesondere deshalb gerechtfertig, weil ein Leistungsausfall immer wieder durch Reparaturen, die nicht zu den Investitionen zu rechnen sind, behoben werden kann. Der Leistungsausfall, der während der Reparatur ensteht, wird vernachlässigt."

He does not discuss, however, how the changes in the age of capital then influence the need for repairs and maintenance which, with his method, must be included as current input in production.

capital), it is natural to attempt to take into account such technical progress by using correction factors in the aggregation.[27]

This question is tied up with the question of which prices one uses in order to weight the different vintages of capital to arrive at a total stock.

In order to clarify the problem let us think of two vintages of a certain type of machine, and let us assume that a machine is produced with the same sacrifices of production factors in both cases. But the machines of the newest vintage are more efficient than machines of the first vintage. If machines of these two vintages are calculated at the same price, there will obviously be reason to introduce a correction factor when they are weighted in order to arrive at the total capital stock. A certain number of the newest machines will then on the basis of efficiency be equivalent to a larger number of previously produced machines (this in addition to the correction which is taken into consideration through the λ's introduced in the preceding section). This new correction factor should not be related to the machine's age, but to its year of production. If we designate this new correction factor γ_τ for real capital produced in year τ, we would instead of (4.1) obtain

$$K_t = \sum_{\tau=t-\theta}^{t-1} \lambda_{t-\tau}\gamma_\tau k_{t,\tau} = \sum_{\tau=t-\theta}^{t-1} \lambda_{t-\tau}\gamma_\tau l_{t-\tau}J_\tau. \tag{5.1}$$

If, on the other hand, we attempt to take into account this greater production efficiency of new machines by using a correspondingly higher price for these when we weight them with other machines we do not need such separate correction factors. As far as the measurement of capital is concerned it merely represents giving another name to the same procedure as indicated by (5.1). The procedure one chooses, however, will influence how much of the "technical progress" will appear in the figures and the form in which it appears.

Let us first assume that we utilize the method whereby we adjust the prices of tangible assets corresponding to their increased efficiency when we weight them to arrive at a figure for total capital volume. Then we will obtain a "disembodied technical progress" in those sectors producing such capital equipment. The fact that capital as input in the production functions becomes more efficient is then already taken into consideration through the prices we use to weight the different vintages, and correction factors for technical change are not needed "inside" the production functions. When we measure output, however, we will obtain an "unexplained" increase since even a constant number of such tangible assets per year as output will appear as an increasing output flow because those assets produced in a later year are multiplied by a higher price factor than those produced in earlier years.

If, on the other hand, we utilize a constant price for all tangible assets of the same type, even if those produced in later years have greater efficiency than older tangible assets when they were new, we will obtain something which appears as embodied technical progress in the sectors using capital

27. Robert Solow designates a capital stock concept where we have carried out such a correction as an "equivalent capital stock." See "Technical Progress, Capital Formation, and Economic Growth," *American Economic Review, Papers and Proceedings*, 1962.

goods. (The same sector can, of course, be both user and producer of a certain kind of capital equipment.) No disembodied technical progress will appear in this case as a result of this improvement in capital equipment, but we could, of course, have such technical change for other reasons.

If we regard the growth in the economy as a whole (including both the sectors producing capital goods and those using them in the production of other goods), we will, of course, have the greatest growth to explain in the case where the price system we use in aggregating to arrive at the total volume figures reflects the technical improvement of the capital equipment. The point is perhaps best illustrated if we as a simplified example imagine an economy where we at any given time have a certain constant number of machines. Thus the number of new machines produced will always equal the number of new machines to be replaced. Let us furthermore assume that each machine produced has the same efficiency throughout its entire lifetime; this means it is not necessary to use any such λ-coefficients as we introduced in the preceding section. There occurs, however, a technical improvement so that a machine of one vintage is always more efficient than a machine of an earlier vintage. We assume that the machines are utilized both in the production of machines and in the production of consumer goods. It follows that the increase in production which is made possible through the improved efficiency of the machines will result in an increase in production of consumer goods. If we now utilize a set of constant prices in such a manner that we also assume a constant unit price for the machines, the growth we have to explain will be the growth in the flow of consumer goods. This growth will now be explained by "embodied-technical-progress-coefficients" γ. If, on the other hand, we let our system of prices be such that we give a higher price to a machine which is more efficient, we will obtain a total growth to explain which consists of the growth in the flow of produced consumer goods plus the increase in the flow of produced machines resulting from the fact that we here attach higher and higher prices to the machines corresponding to their increasing efficiency. This means that we have a greater growth to explain than in the first case. This growth is explained now by two factors. First, the constant number of machines used in production will now appear as an increasing capital input. The effect of this will correspond exactly to the effect of the embodied technical progress in the first case. Second, we will have a disembodied technical progress corresponding to the growth we now have to explain above and beyond the growth appearing in the first case.

Such correction factors γ as we have here assumed for the various vintages of capital equipment can, of course, also be assumed for other kinds of production factors. Econometric studies where this is attempted have been carried out by Zvi Griliches. According to his investigations very little "unexplained" technical progress would then remain. Whether one is entitled to say that such corrections explain what would otherwise appear as "unexplained technical progress" depends on the method by which one obtains knowledge of the correction factors. There would, of course, be nothing to prevent us from attempting to use various time series for the correction factors until we eventually arrived at something which corresponded so closely to the observed data that nothing "unexplained" remained. This would, however, not be an explanation of the technical progress in the real sense of the word "explanation." It would only be placing an unexplained technological development into a theoretical framework different from the traditional one (something which, from other viewpoints, can be of significant interest). If we, on the other hand, could estimate such correction factors as the γ's above through direct technical studies, we would be closer to a real explanation.

6. A Correction for Different Expected Lifetimes

In the discussion in the preceding sections we have assumed that all tangible assets of a certain type have the same lifetime or, in any case, that we can use the same survival curve for them. This latter entails that they have the same *expected* lifetime.

It is possible, however, that the same type of capital equipment can be made more or less durable, while the asset's production efficiency, as long as it is being used, in all cases is the same. If we aggregate the various pieces of capital by adding up their values at a certain year's prices, a piece which has a short lifetime will then be included in the aggregate at a smaller figure than one which has a long lifetime, inasmuch as one must assume that the production costs for the more durable asset are higher than for the less durable asset. This obviously creates some difficulties when the purpose of the aggregation is to estimate a concept of capital volume which can be utilized as an argument in a production function.

The problem raised here would not appear if we simply could count the number of, say, machines and use this figure as an indicator of the size of the capital stock. As to the effect on the current production capacity, a machine would, of course, be a machine irrespective of whether it lasted a shorter or longer time. In practice, however, we could seldom use such a physical designation of capital stock on a higher level than the pure micro-level. Then we must use a set of prices in order to weight the items in adding them, and that is when the problem we are discussing here arises.

If the durability of tangible assets in such instances was chosen completely arbitrarily, no satisfactory aggregation methods would exist which could take into consideration the aspect mentioned here. In order to aggregate in such a way that this aspect is taken into account, we must presuppose a certain pattern for the choice of durabilities. Professor Haavelmo has proposed an aggregation method which is based on the assumption that the durabilities are determined by profitability evaluations in the market.[28] He illustrates the principle with a simple example. Let us consider two stocks of real capital. Both stocks consist of tangible assets which have the same efficiency in production; the only thing which distinguishes them is that the assets' durability in the first stock is θ_1 and the assets' durability in the second stock is θ_2. (Here we calculate durability as a given figure in both cases. If we had a survival

28. See Trygve Haavelmo: *A Study in the Theory of Investment,* The University of Chicago Press, Chicago 1960, pp. 100–101.

curve with a gradual decline, we could probably interpret θ_1 and θ_2 as expected lifetimes.)

Let K_1^* and K_2^* be the values of the two capital stocks when new. If then both of the types of assets are available and sold on the market, it is obvious that there must exist a certain relationship between the prices of these and their durability. This relationship must depend on the interest rate. With a given interest rate there will, of course, be a certain "excess price" one is willing to pay in order to obtain a tangible asset with a certain increased durability. Haavelmo demonstrates that by employing such an assumption, one obtains a meaningful aggregation by introducing a total volume of capital for the two stocks which can be given in the following manner:

$$K = K_1^* + K_2^* \frac{1 - e^{-\rho\theta_1}}{1 - e^{-\rho\theta_2}}. \tag{6.1}$$

Here ρ is the interest rate (for continuous compounding). This is a meaningful aggregation in the sense that if we know K, we do not need to know the size of each of the two capital stocks separately in order to assess the impact of this total capital on current production capacity.

Formula (6.1) can be interpreted in the following manner: In the total volume measure K the stock K_1^* is included with an uncorrected value. K_2^*, on the other hand, is corrected by a factor which is larger than 1 if $\theta_2 < \theta_1$, equal to 1 if $\theta_2 = \theta_1$, and less than 1 if $\theta_2 > \theta_1$. If the two types of tangible assets have the same durability, the correction factor will have no significance. If K_2^* consists of assets which are less durable than those which compose K_1^*, then K_2^* will be corrected upwards before it is added to K_1^* in order to be included in the total volume measure, and conversely if $\theta_2 > \theta_1$. We can interpret this as if K_2^* has been adjusted to the same durability as K_1^*. In (6.1) θ_1 then appears as a kind of "standard durability."

It is natural to carry this thought somewhat further in order to eliminate the lack of symmetry which results from choosing a particular one of the durabilities as a "standard durability." Why not introduce a "standard durability" which is equal to one period? We can do this by rewriting (6.1) into:

$$\bar{K} = \frac{K}{\frac{1}{\rho}(1 - e^{-\rho\theta_1})} = \frac{K_1^*}{\frac{1}{\rho}(1 - e^{-\rho\theta_1})} + \frac{K_2^*}{\frac{1}{\rho}(1 - e^{-\rho\theta_2})}. \tag{6.2}$$

Let us examine more closely the interpretation of (6.2). It is perhaps best to interpret first the denominators in the fractions in (6.2). The interpretation appears clearly from the following formula:

$$\int_0^\theta e^{-\rho t}\,dt = \left[-\frac{1}{\rho}e^{-\rho t}\right]_0^\theta = \frac{1 - e^{-\rho\theta}}{\rho}. \tag{6.3}$$

The fraction to the right, which has the same form as the denominators in (6.2), expresses the present value of a flow of one unit per time unit over a period of time θ when one discounts with an interest rate ρ.

Let us now interpret K_1^* as a source of z_1 "units of capital services" per time unit in θ_1 periods, and correspondingly K_2^* as a source of z_2 units of capital services per period in θ_2 periods. Reduced to "today" the quantity of capital services in the two stocks of capital will be respectively:

$$z_1 \frac{1 - e^{-\rho\theta_1}}{\rho} \quad \text{and} \quad z_2 \frac{1 - e^{-\rho\theta_2}}{\rho} .$$

If we now assume that the prices of the assets in the two stocks K_1^* and K_2^* are such that each unit of capital services (discounted to "today") is paid at the same price q, we have simply

$$K_1^* = qz_1 \frac{1 - e^{-\rho\theta_1}}{\rho}, \qquad K_2^* = qz_2 \frac{1 - e^{-\rho\theta_2}}{\rho} . \tag{6.4}$$

We are now interested in how many units of capital services we obtain per time unit from these two capital stocks combined as long as they are both in operation. It will be

$$z_1 + z_2 = \frac{1}{q}\left(\frac{K_1^*}{\frac{1}{\rho}(1 - e^{-\rho\theta_1})} + \frac{K_2^*}{\frac{1}{\rho}(1 - e^{-\rho\theta_2})}\right). \tag{6.5}$$

Aside from the factor of proportionality q this is the same as formula (6.2). The method of aggregating assets with different durabilities which is proposed by Professor Haavelmo can thus be regarded equivalent to calculating the quantity of "capital services" per time unit which originates from a given total stock of capital consisting of assets of different durability.[29]

It is of interest to notice that when the interest rate ρ approaches zero, the expression

$$\frac{1}{\rho}(1 - e^{-\rho\theta})$$

will approach θ, and the expressions (6.1) and (6.2) approach

$$K = K_1^* + K_2^* \frac{\theta_1}{\theta_2}, \qquad \overline{K} = \frac{K_1^*}{\theta_1} + \frac{K_2^*}{\theta_2} . \tag{6.6}$$

This simple way of correcting for different lifetimes is permissible when one is of the opinion that the interest rate factor ρ which is utilized in the investment calculations is very low. It is also worth noticing that the effect of such corrections will be insignificant even if the lifetimes included are rather different, provided they are all fairly high.

In our opinion it seems clear that it will be advantageous to use such a correction as the one outlined above when one is dealing with tangible assets with different durability which serve the same kind of function in production.

29. In econometric studies on production functions the "flow of capital services" has often been utilized as a factor in the production function in addition to labor input and other current inputs. The concept "capital services" has, however, been defined and measured in rather different ways and thus does not always correspond to the idea outlined above.

If we are only confronted with the problem of aggregating one such group of assets, it will be immaterial what one chooses as "standard lifetime." If this group again is to be aggregated together with other types of assets, it is probably most reasonable to use the average lifetime as the "standard lifetime", or to employ a standard lifetime of one year, which is equivalent to invoking the concept of capital services.

If one has first accepted this, it is natural to ask if one also should not carry out a similar correction when one has assets of various types which serve *different* functions in production. The answer probably depends on the possibilities of substitution between the various types of capital. We hope to have the opportunity to discuss this further at a later occasion.

7. *Capital in a Vintage Model*

In the previous sections our primary aim was to arrive at concepts enabling us to characterize the capital stock by *one* figure which would measure the effect on production or production possibilities of the capital stock concerned. As noted several times capital can be specified according to sector and type, but our primary aim has throughout been to aggregate the different vintages of capital. As we have seen some of the types of "corrections" which we wish to undertake in such connections will, however, demand separate information about each of the capital vintages. If one first compiles statistics on such a basis, one is close to having a statistical base for utilizing a long-term model where the various capital vintages play separate roles and are not only included in the total volume figures. We have in mind a type of model which was presented in an article in Econometrica 1959.[30])

In the first place this model assumes what we have previously called "embodied technical progress." If one has, on an independent basis, acquired knowledge of the speed of this form of technical progress, this property does not in itself prevent us from aggregating capital of different vintages (cf. formula (5.1)). For econometric studies where one will attempt to estimate this technical progress, it is, however, necessary to have the size of the different vintages of capital. One can obtain this from the gross investment figures if one knows the survival curve $l_1, \ldots, l_\theta$.

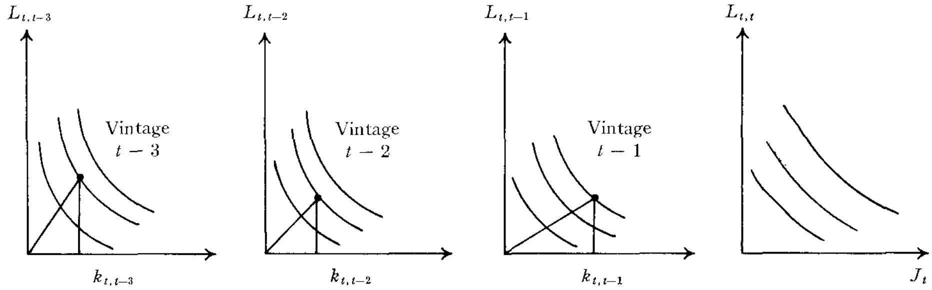
Secondly, the model referred to is based on a special assumption about substitution possibilities. As noted the reasoning in the previous sections holds true generally irrespective of whether we regard a model with fixed production coefficients or a model where total capital stock and total employment appear as substitution factors in a production function. The 1959 model mentioned above is, however, a kind of synthesis of these two types of models since one assumes that substitution possibilities only exist in connection with the gross investment which takes place at any given time, while production equipment which is already installed is "rigid" in the sense that, when it is used, it must be combined with the quantity of manpower for which it was planned at the

30. See Leif Johansen: "Substitution versus Fixed Production Coefficients in the Theory of Economic Growth: A synthesis," *Econometrica*, April 1959.

time when it was installed. We can say that we have substitution possibilities ex-ante and fixed coefficients ex-post, the terms ex-ante and ex-post now referring to the point of time when the capital equipment is being installed. We have, in other words, possibilities of choice regarding the factor combination before we install the equipment, but at the moment it is installed, these choices no longer exist in connection with this equipment.

A model of this type is, of course, also somewhat extreme since in practice certain possibilities will often exist for utilizing installed production equipment more or less intensively by combining it with more or less of current inputs. It is just as obvious, however, that the possibilities of varying the factor proportions which are available after the equipment has been installed are far less than those which were available at the stage of investment planning. As a first step in the direction of a more realistic treatment than that which results from the traditional models with either full substitution possibility both ex-ante and ex-post or completely fixed coefficients both ex-ante and ex-post, there can be grounds for attempting to consider this "synthesis model."

If one wants to attempt this, however, one must abandon the aggregation of all capital vintages into a common total stock. In addition one must probably attempt to coordinate the statistics for employment with vintage statistics for the capital. The situation in a certain year can be illustrated by the diagram below.



As before $k_{t,\tau}$ signifies the quantity of capital which was created in period τ and which is serviceable in period t. J_t is the gross investment in period t. Furthermore, $L_{t,\tau}$ represents the manpower which in period t is employed in connection with capital created in period τ. $L_{t,t}$ is particularly the manpower for which the capital equipment installed in period t is designed. $L_{t,t}$ will partly consist of new manpower in this period, and partly manpower which is released from older capital equipment which is either scrapped or temporarily taken out of use.

The situation at the beginning of year t is then that we have a series of earlier vintages $t-1$, $t-2$, $t-3$ . . . with a certain quantity of capital in each of these vintages. When these quantities of capital were installed, many choices were available regarding the combination of labor and capital as indicated by the isoquants in the above diagrams. One has, however, chosen the relative combinations which correspond to the straight lines through the origin in these diagrams. That will mean that the possibilities of choice in connection with these vintages now consist only of the choice concerning how large a part of these various vintages one will utilize. One can as a maximum use the quantity of capital which corresponds to the terminus of the factor ray in the diagram for a vintage, since the abscissa of this point indicates the quantity of capital of the vintage concerned which is still serviceable in period t. If one chooses to use less than the maximal quantity, employment in connection with this vintage is reduced correspondingly so that one obtains a retraction along the factor ray. Labor is thereby released which can possibly be used in connection with the new capital which is to be installed in the period we are about to enter. Here we still have possibilities of choice since we, in principle, can choose any point in this factor diagram which does not demand more investment or labor than is available.

In the development we have suggested with the diagrams above, the tendency has been in the direction of more capital per worker as new vintages of capital have been installed.

When we move further into the future, the choice we now make regarding the last diagram above will be fixed, and at the same time the points in the diagrams for the earlier vintages will contract towards the origin if we have a survival curve l which declines gradually. In the transition to a new year the oldest vintage will be scrapped if the tangible assets have a technically given lifetime. It can also be the case that assets which from a physical point of view could be used will be scrapped because they become unprofitable. This will be determined by the product price compared to current input costs, the latter depending on the factor proportions characterizing the vintage.

It appears from the above that in order to use a model of this type in practice it would be highly desirable to have the figures for employment coordinated with vintage figures for capital. Only in that way can one empirically establish the factor rays which indicate the possibilities of choice in the diagrams for the older vintages. However, many difficulties arise in connection with the use of such a model. The greatest difficulty is, of course, that it is difficult to identify the different vintages of capital, because an establishment will usually be composed of many different vintages of capital equipment which are operated side by side. However, it would perhaps be possible for many establishments to identify something which can be said to represent the basic equipment and which determines the type of production processes in that establishment, while the remaining is more supplementary equipment. Then the figures for vintage should relate to this "basic equipment."

In addition to such a coordination of figures for employment and capital vintage, this model would make particular demands on investment statistics. It would be very advantageous if one could distinguish between investment which "creates new jobs" and investment which is more supplementary or reparatory. It is not certain that this distinction should follow the traditional distinction between repairs and maintenance on the one hand, and other investment on the other.

Through a concrete review of the different sectors of production one would perhaps arrive at the result that a model of the type which is described here will be suitable in certain sectors, while other types of models mentioned above will be better suited to other sectors.

On peut concevoir la planification économique comme composée de deux phases: d'abord une description de toutes les voies de développement possibles, ensuite un choix de la meilleure de ces possibilités. L'objet du prèsent article est de mesurer le capital réel en rapport avec les besoins de la première de ces deux phases. La section 2 de l'article soutient que la mesure du capital la plus conforme à cet objectif est la valeur brute du stock de capital existant, c'est-à-dire la valeur totale sans calcul de depréciation. La section 3 analyse diverses procédures d'estimation du stock de capital brut. Les sections 4, 5 et 6 discutent une façon de corriger les mesures du capital en fonction des changements d'efficacité dus à l'âge, du progrès technique incorporé ("embodied technical progress"), des différentes durées. La dernière correction conduit à des concepts qui reviennent à mesurer les services du capital comme un facteur de production. Le traitement de l'entretien et des réparations est important pour interprèter certaines de ces corrections. La section finale de l'article propose un modèle qui exige des données sur les années d'origine ("vintages") du capital.