A VINTAGE MODEL OF SWEDISH ECONOMIC GROWTH FROM 1870 TO 1975

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I. INTRODUCTION

Econometric analysis of macroeconomic production functions has long been the standard method used in empirical studies of the casual factors behind the process of economic growth. The scientific literature is crowded with articles and books reporting different attempts to use such analysis for historical growth studies.[1] These attempts have, no doubt, made important contributions to our understanding of the growth process. There are, however, some weak points inherent in the production-function approach. A number of important features of the growth process cannot be analyzed because of the high level of aggregation. In addition, it is extremely difficult, not to say impossible, to construct reliable estimates of the capital-stock development, which is of fundamental importance for the analysis.

During the last twenty years, much attention has been paid to the vintage theory of capital, originally formulated and developed by Leif Johansen, Robert Solow and Edmund Phelps.[2] The essence of this theory is the assumption that capital of different ages is not fully malleable. This assumption implies, of course, that it is necessary

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[1] Surveys of a number of different studies have been given by Centrum voor Economishe Studien [1974], Brown [1967] and Kennedy and Thirlwall [1973], amongst others.

[2] Johansen [1959], Solow [1960] and Phelps [1963].

to distinguish between amounts of capital that have been created at different points of time. By the introduction of this disaggregated way of looking at things, growth theory was enriched in several respects. In contrast to what is possible in an ordinary production-function model, a vintage model allows us to

(a) Make a distinction between embodied and disembodied, technological progress.

(b) Make a distinction between "ex ante substitutability" and "ex post substitutability" between labour and capital

(c) Treat capital scrapping as an endogenous variable, and

(d) Treat the time structure of investment as one of the determinants of the volume of production.

As an instrument of empirical analysis, the vintage approach has the very important advantage over the traditional production-function approach that it does not require capital-stock data. It is sufficient to have information about yearly investments. In those cases in which capital-stock data are not available, this advantage is, of course, decisive as regards the choice of approach.

In recent years, a number of studies have been made in which the vintage approach has been used for empirical analysis.[1] In most of these studies, the estimation of the rate of growth of technological progress has constituted the central point and in this respect some remarkable results have emerged. The models of the clay-clay type show, in general, a fairly high rate of growth of technological progress.[2] In contrast, the putty-clay models show a very low rate

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1 Bliss [1965], Attiyeh [1967], Baum, Görzig and Kirner [1971], Isard [1973], de Vries [1973/74], Benassy, Fouquet and Malgrange [1975], Görzig [1976], den Hartog and Tjang [1976], Kuipers and Bosch [1976], Sutton [1976] and Sandee [1976].

2 Cf, for instance, den Hartog and Tjang [1976] and Benassy, Fouquet and Malgrange [1975].

of growth of such progress.[1] Furthermore, in those models which include not only embodied but also disembodied, technological – progress factors, the rate of growth of the embodied factor has turned out to be zero or very close to zero.[2]

Most of the empirical vintage studies that have been made so far have been attempts to find out the possibilities of using the vintage approach, in a fruitful way, for empirical analysis. As all these studies have been designed differently and for different purposes, it is difficult to give a general judgment as to whether the outcomes are to be regarded as positive or not. Some puzzling results have emerged and it is extremely difficult to make a fair appraisal of the realism of the models under consideration. It seems to be urgent to get more experience in this field of research.

The purpose of this paper is to report some additional experience of empirical analysis based on vintage models. For this purpose, I shall present a vintage model which I have constructed for the analysis of the economic development in Sweden from the beginning of the industrial revolution up to the 1970s. The general problem underlying the construction of this model can be formulated like this. Is it possible to construct a simple, one-sector, vintage model that is capable of simulating Swedish economic development during the period 1870-1975 and of giving non-trivial explanations for some of the characteristic features of the growth process during that period?

My model is, indeed, very simple. It includes only one sector – the whole Swedish economy, except public administration. Throughout the entire period under consideration, the economy is assumed to have been characterized by perfect competition and permanent equilibrium. In contrast to most other vintage models used for empirical analysis,

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[1] Cf Bliss [1965] and Görzig [1976].

[2] Cf Bliss [1965], Isard [1973] and de Vries [1973/74].

it includes only one technological-progress factor, a labour-augmenting one. Other specific features are the assumptions that production within existing vintages decreases at a constant yearly rate and that the quantity of labour in existing vintages varies in inverse proportion to the labour-augmenting factor. The rate of interest plays a strategic rôle as a determinant of the life length of capital. Capital is scrapped for economic reasons only and at the point of time when labour costs tend to exceed the value of production. In new vintages, the volume of production is determined by a Cobb-Douglas function and there the labour share is constant. This implies that the capital-output ratio in new vintages is variable.

This procedure of parameter estimation differs radically from those used in earlier studies. The numerical specification of the model is given by using only information concerning the Swedish economy at the very beginning of the 1870s. Consequently, no information is used from the time-series which are to be explained.

The following presentation of my model is divided into four sections. The first one gives an account of how I have estimated the structure of the Swedish economy at the beginning of the period under consideration, i e in 1870. The second section gives a description of the model of the Swedish economy after 1870. The third section shows the results of the estimation of the development of the technological progress factor and, in addition, a simulation of the development of production and income distribution from 1870 to 1975. The fourth section, at last, gives some examples of concrete conclusions that can be drawn from a vintage model of the type presented in this paper.

II. THE ECONOMIC STRUCTURE OF SWEDEN AT THE BEGINNING OF THE 1870s

A necessary condition for the possibilities of using a vintage model for empirical analysis of the growth of an economy is that some basic facts are known concerning the structure of the economy in question at the beginning of the period under consideration. As my study covers the period from 1870 up to the present, the use of a vintage model for the analysis necessitated an attempt to estimate some characteristics of the Swedish economic structure at the very beginning of the 1870s. This attempt was made as follows.

The start of the industrial revolution in Sweden is commonly dated to the first few years of the 1870s. All empirical evidence shows that economic growth after the end of the 1860s became more rapid than it had been before. We do not know the growth rate at the beginning and the middle of the nineteenth century, since the Swedish national-income estimates do not go further back than 1860. However, the available figures of production in agriculture and the steel industry during the beginning and the middle of the nineteenth century indicate stationarity rather than growth in production per head. Since the population grew at a rate of 1 per cent per year during the pre-1870 period, I found it natural to assume that before 1870 the Swedish economy was characterized by a steady-state growth of 1 per cent per year.

For the further description of the initial structure, the following three basic assumptions were made:

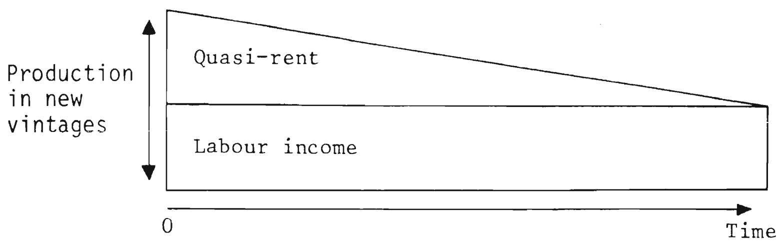
(a) The production volume associated with a certain vintage of capital was reduced - due to depreciation - by 1 per cent per year as time went on,

(b) Only those pieces of capital were used for which the value of production exceeded the labour costs, and

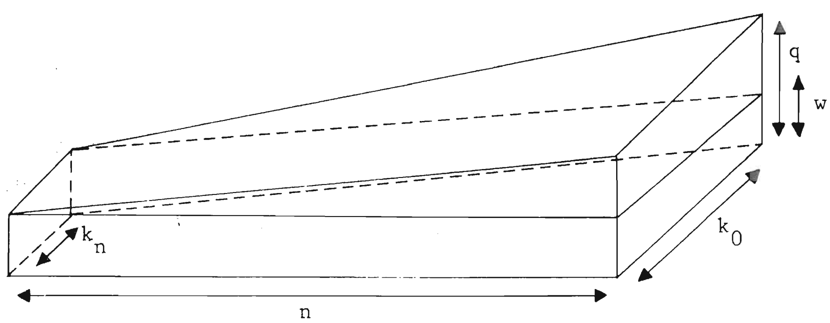
(c) Substitution between labour and capital was possible ex ante but not ex post,

(d) There was no technological progress.

On these assumptions, the development of production, the labour income, and the quasi-rent associated with a given amount of capital in period 0 can be illustrated like this:



Combined with the steady-state assumption made earlier, these three assumptions imply an economic structure that can be illustrated by a "box" of the following kind:



Here n illustrates the life length of capital and k_0 the volume of investment at the end of the period while k_n corresponds to the volume of investment n years earlier. The distance q shows the production per capital unit in a new vintage and the distance w represents the labour income per unit of capital.

In the following pages the following notations will be used:

q_{st} = Volume of production, associated with an s year old vintage in year t,

Q_t = Aggregated volume of production in year t,

ℓ_{st} = Number of employees associated with an s year old vintage in year t,

L_t = Total labour force in year t,

k_{0t} = Volume of investment in year t,

w_t = The real wage level in year t,

$(LW)_t$ = Total real labour income in year t,

n = The number of vintages in use,

α = The labour share of production in new vintages,

β = The rate of yearly decrease of production in existing vintages,

γ = The output-capital ratio in new vintages,

ε = The rate of steady-state growth before 1870,

V_{st} = The present value of the expected future profit stream associated with the s year old vintage in year t,

V_t = The sum of all V_{st} in year t,

r_t = The rate of interest in year t.

In accordance with the assumptions made above, the following equations will hold good

$$\alpha = e^{-n\beta}, \tag{1}$$

$$q_{0t} = \gamma k_{0t}, \tag{2}$$

$$k_{0,t-s} = k_{0t}e^{-\varepsilon s}, \tag{3}$$

$$Q_t = q_{0t} \underbrace{\int_0^n e^{-(\varepsilon+\beta)s} ds}_{N}, \tag{4}$$

$$(LW)_t = \alpha q_{0t} \underbrace{\int_0^n e^{-\varepsilon s} ds}_{M}, \tag{5}$$

where $\varepsilon = 0.01$ and $\beta = 0.01$.

According to the definitions of V_{st} and V_t we can, further, write

$$V_{st} = q_{st} \int_0^{n-s} e^{-(\beta+r)z} dz - 0.53 q_{0,t-s} e^{-s\varepsilon} \int_0^{n-s} e^{-rz} dz \tag{6}$$

and

$$V_t = \int_0^n V_{st} ds. \qquad (7)$$

Using equations (1), (2), (4) and (5) and denoting by M and N the two integrals appearing in (4) and (5), this system can be transformed into

$$\alpha = \frac{(LW)}{Q} \cdot \frac{M}{N}, \qquad (8)$$

$$n = -(\log\alpha):\beta \text{ and} \qquad (9)$$

$$\gamma = [CM]^{-1}, \qquad (10)$$

where C stands for the investment ratio in the entire economy.

Since the "box" is meant to illustrate the Swedish economy at the end of the 1860s, these equations have to be consistent with the corresponding empirical data from that time. What matters in this context is that at the end of the 1860s the labour share of production, (LW):Q was 0.69 and the investment ratio, C, was 0.064. These values, inserted in the equations above, together with $\varepsilon = 0.01$ and $\beta = 0.01$, imply that[1]

$$\alpha = 0.53, \qquad (11)$$

$$n = 63 \text{ and} \qquad (12)$$

$$\gamma = 0.43. \qquad (13)$$

These figures describe the "box" completely.

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[1] Since the integrals M and N - after the numerical description of ε and β, - are functions of n only and the same is true of equation (9), we can solve the equations (8) and (9) for n and α.

The above assumption that the rate of yearly decrease of production within existing vintage amounts to 1.0 per cent is, in fact, not arbitrary. I shall now show that this value, in combination with the above values of n, α and γ, is consistent with the prevailing rate of interest. As shall be explained further in section IV, the rate of interest prevailing around 1870 can be estimated to 7 per cent, approximately.

From equation (6) can be concluded that

$$V_{0t} = 4.9q_{0t}. \tag{14}$$

Further it can easily be verified that

$$V_t = 2.8Q_t \tag{15}$$

or the equivalent value

$$V_t = 101q_{0t}. \tag{16}$$

The value V_{0t} consists of two parts, one corresponding to a net addition of capital amounting to 1 per cent of V_t and the other corresponding to the depreciation of the existing capital stock. Taking into consideration equations (14) and (16), it will easily be seen that these two parts amount to q_0 and $3.9q_0$. Consequently, the depreciation rate is 0.039.

As the Swedish economy before 1870 is assumed to have been stationary, the following relationship should hold good

$$(r+d)V_t = Q_t - (LW)_t,$$

where d is the depreciation rate. For $Q-LW = 0.31Q$ and $d = 0.039$, this equation gives

$r = 0.07$.

Consequently, the parameters calculated above are consistent with the empirical value of the rate of interest. As V_t is an increasing function of n, this condition of consistency will not be satisfied for other values of n.

In this context, it should be observed that V_0 is not identical with k_0. While k_0 is the value of investments in buildings, structures and machinery, V_0 includes in addition to these types of capital, also all other types of capital that are necessary for the production and marketing process, for instance, land growing forests, inventories, liquid assets, licences, etc.[1]

The quantity $V_0 - k_0$ can, in fact, be interpreted in the following way: Suppose that the volume of production is determined by a production function $F(L,K,v)$ where $\underline{v}$ is the <u>volume of land</u>, inventories and other factors of production corresponding to $V_0 - k_0$. Suppose further that the (L,K,v) combination chosen by the firms is determined by some profit maximization procedure. If only such optimal situations are considered the v-variable can be excluded from the production function, which accordingly can be written $H(L,K)$. Consequently, the existence of a difference between V_0 and k_0 is not a contradiction with the existence of an ordinary two-dimensional production function, provided that only optimal situations are considered.

In the following shall be assumed that the quantity $V_0 - k_0$ has the character of fixed costs. Once invested it can never be regained. After the moment of investment the reward going to the factor of production v is therefore an inseparable part of the quasi-rent.

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[1] According to the estimations above, V_0 is about twice as large as k_0. This does not seem to be too unrealistic. Old estimates of Sweden's national wealth indicate that, at the end of the nineteenth century, the value of natural resources and inventories was of the same order of magnitude as the total value of buildings, structures and machinery.

So far nothing has been said about the production functions of new vintages. This was not necessary for the description of the "box". In order to simplify the presentation in the next section, however, some remarks concerning the production function will be made here.

The production function in a new vintage will be assumed to be of the Cobb-Douglas type:

$$q_0 = A\, \ell_0^a\, k_0^b$$

where a+b=1. As the labour requirement is assumed not to change with the age of the vintage and the volume of production in existing vintages is assumed to be reduced by 1 per cent per year, the above description of the production function implies that the production in an s-year-old vintage can be written

$$q_s = A\, \ell_s^a\, h_s^b,$$

where $h_s = k_0 e^{-0.01s:b}$. By depreciating the capital in a proper way, we can, consequently, for all vintages, formulate a Cobb-Douglas production function with the same exponents as those appearing in the production function of the new vintage. This fact has the following implication. Let us suppose that the production function above holds good and let us define three aggregates L, K and Q in the following way:

$$L = \int_0^n \ell_s ds; \quad K = \int_0^n h_s ds \quad \text{and} \quad Q = \int_0^n q_s ds.$$

For given values of n, a and b, it is then possible to write

$$Q = B\, L^a K^b,$$

where B is a constant. This formula can now be used for determining the values of a and b in the following way.

The numerical description of the "box" implies that 1.1 per cent of the total employment and 0.78 per cent of the total production are associated with the oldest vintage. Let us suppose now that this vintage is scrapped. Since the two figures just mentioned can be identified with dL/L and dQ/Q, the following equation should hold good:

$$0.78 = 1.1a + (1-a)dK/K.$$

The total capital stock K is, of course, depending upon the rate of depreciation, which in its turn is determined by the labour elasticity of the production function. Furthermore, dK, i e the capital associated with the oldest vintage, is also determined by this elasticity. Consequently, dK/K, is a function of a only — for a given value of n — and the equation can be solved for a. The only value of a that satisfies the equation is

$$a = 0.6.$$

For the model construction in the next section, I have accepted this value and I have assumed that the production function elasticities remained constant and equal to 0.6 and 0.4 during the whole period up to 1975.

III. THE MODEL OF SWEDISH GROWTH SINCE 1870

The model described in the preceding section refers to a steady-state growth with no technological progress. In the following pages, it will be called the "stationary model". In this section, I shall give an account of the more general model, which I have constructed for the analysis of Sweden's economic growth in modern times, here defined as the period 1870-1975. This model will be called the "growth-model".

In the construction of the growth model, I maintained the stationary model as a skeleton, so that the former can be regarded as a modified version of the latter. The modifications are, however, quite essential A growth-creating, technological-progress factor has been introduced and the following parameters appearing in the stationary model have been made variable: the life length of capital, the capital-output ratio in new vintages, the capital intensity in new vintages and the rate of production depreciation within existing vintages.

The technological-progress factor

Only one single kind of technological-progress factor is introduced in the model, a disembodied, labour-augmenting factor. The motives for choosing this and only this progress factor were briefly the following:

Experiments with different combinations of labour- and capital-related factors and with different combinations of embodied and disembodied factors yielded clear and uniform results. They all indicated that the disembodied, labour-augmenting factor was greatly predominant. When included in the model, the other types of progress factors had only small effects on production and, in addition, they behaved "irrationally", in the sense that they showed unexplainable ups and downs with no systematic trends. This experience is in good accordance with the above-mentioned results of those earlier studies in which both embodied and disembodied progress factors were included.

The predominance of the disembodied, labour-augmenting factor can be explained also by a more general consideration. Looking at the sta-

[1] See, for instance, Bliss [1965], de Vries [1973] and Isard [1973].

tionary model, it is easy to conclude that a wage increase implies one of two alternative types of change, either a decrease in the number of vintages in use or a productive gain in the oldest vintage. The first of these two alternatives cannot, alone, give rise to more than a very modest, long-run, wage growth without leading to an unreasonably large decrease in the number of vintages. The second alternative must imply the existence of disembodied, technological progress, either labour-augmenting or capital-augmenting. However, from a glance at the empirical data of employment, wages and capital formation, it is easy to conclude that the capital-augmenting factor, if present, cannot have been very important. The reason is that the combination of an even rather small, capital-augmenting factor and such a fast-growing, capital formation as occurred in Sweden at the end of the nineteenth century would imply a much higher rate of employment growth than the actual one. The general conclusion to be drawn from these facts is, of course, that the only technological-progress factor that — within the framework of my model — can give a reasonably good explanation of the Swedish wage growth after 1870 is a disembodied, labour-augmenting factor.

Since embodied, technological-progress factors cannot create wage increases in the old vintages, the assumption that all technological progress is of an embodied character cannot be consistent with a rapid wage growth. Such an assumption is, in addition, inconsistent with the available data also in another respect. In my model, the conditions of equilibrium in the new vintages would imply that a long-term increase in embodied, technological progress should result either in a downward trend in the price ratio between capital goods and consumer goods or in an upward trend in the cost of capital. However, the Swedish data do not show such trends.[1]

The way in which a labour-augmenting factor should be introduced into the model was fairly self-evident. Taking the stationary model

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1 I cannot, of course, deny the existence of capital augmenting technological progress. The fact that they are difficult to discern, statistically, is perhaps due to the existence of one or more neutralizing factors, for instance the gradual reduction of capital utilization caused by the shortening of the time of work.

as a point of departure, we can denote by ℓ_{st} the labour quantity associated with an s-year-old vintage in year t. In the growth model this variable was quite simply replaced by the variable $\ell_{st}x_t$, where x_t (x_0 = 1.0) denotes the accumulated value of the technological-progress factor from 1870 (t=0) up to the point of time t. This variable x has, obviously, the character of a labour-efficiency factor and in the following pages, the ratio w_t/w_0x_t, where w_0 is the wage level in 1870, will be called the wage-efficiency factor. It will be denoted by y_t.

After the introduction of the x-factor, the production function in new vintages will be

$$q_{0t} = A(\ell_{0t}x_t)^{0.6}k_{0t}^{0.4}. \qquad (17)$$

Since the x-factor in this equation can be put outside the bracket, it cannot be identified as a labour-augmenting factor. What makes such an identification possible is the assumption that this x-factor affects also the labour requirement of existing vintages. More precisely, it is assumed that the volume of labour associated with an s-year-old vintage in year t is

$$\ell_{st} = \ell_{0,t-s}x_t^{-1}x_{t-s}, \qquad (18)$$

a formula which implies that in existing vintages the labour quantity is gradually reduced at the same rate as the technological-progress factor x is increasing. Consequently, an increase in the x-factor of z per cent implies a decrease of z per cent in the labour input in all existing vintages.

The labour share

In the stationary model, the labour share in new vintages was estimated as 0.53. But how should it be assumed to vary in the growth model? As a basis for my consideration of this question, I took the well-known fact that in most countries the labour share of total production has remained fairly stable. This fact indicates a long-run stability of the labour share in new vintages.[1] So I have made the very simple assumption that the labour share in new vintages remained constant during the whole period 1870-1975. This assumption means that

$$w_t \ell_{st} = 0.53 q_{0,t-s} y_t y_{t-s}^{-1}. \qquad (19)$$

The capital-output ratio

The assumption of a constant labour share has an immediate implication for the capital-output ratio on new vintages. By substituting $0.53q/w$ for ℓ in the production function formula (17) we get, after some manipulations, the following equation:

$$q_{0t}/k_{0t} = B(x_t/w_t)^{1.5},$$

where B is a constant. With the above definition of the variable y, this equation can also be written

$$q_{0t}/k_{0t} = B' y_t^{-1.5}, \qquad (20)$$

which shows that the output-capital ratio is proportional to the 1.5 power of the inverted, wage-efficiency ratio.

The production-depreciation factor

In the stationary model, it was assumed that production within each

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[1] It should be observed that the constancy of the labour share does not follow from the constant elasticity property of the Cobb-Douglas function. The reason is that production decreases as time goes on. In fact, the present value of the expected stream of quasi-rents coming from a new investment project can be written as

$$q_0 \int_0^n e^{-(\beta+r)s} ds - w\ell \int_0^n e^{-rs} ds.$$

By maximizing this expression we get

$$\frac{w\ell}{q} = aI_1 I_2^{-1}$$

where I_1 and I_2 are the two integrals above and a is the labour elasticity parameter in the Cobb-Douglas function.

existing vintage was reduced by 1 per cent per year. A similar depreciation factor is assumed to exist in the growth model, but there it is supposed to be variable. Accordingly, the production in an s-year-old vintage can be written

$$q_{st} = q_{0,t-s}e^{-s\beta_{t-s}} \tag{21}$$

where β_{t-s} is the depreciation factor associated with capital invested in $t-s$.

On the assumption of static expectations, the consistency of the model implies that a decrease of the life length of capital is followed by an increase of the production depreciation rate in the future vintages.[1] With a constant labour share of 0.53, the following equation has to be satisfied:

$$e^{-n_t\beta_t} = 0.53,$$

which implies that

$$\beta_t = 0.63n_t^{-1}, \tag{22}$$

where the index t refers to the period of time when the vintage was "born".

Number of vintages

A central feature of the model is the assumption that only those vintages are used in which the value of production is not less than

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[1] It should be observed that a change in β can occur only simultaneously with a change in the capital intensity in new vintages. On the assumption that there is a relationship between the capital intensity and the costs of repair and maintenance, it is obviously possible to interpret an increase in β as a consequence of an increase in the repair and maintenance expenditures caused by the change in capital intensity. On this assumption, it is, furthermore, possible to imagine a profit-maximization procedure, by which the labour share and the production-depreciation factor β are determined simultaneously.

the labour costs. This assumption implies, of course, that the value of production in the oldest vintage equals labour costs, and that a wage rise is possible only if either the labour-augmenting factor rises or the number of vintages is reduced. In the former case, the wage level can rise in the same proportion as the productivity factor. In the latter case, every year of decrease in the life length of capital gives room for 100 × β per cent increase in the wage-efficiency ratio. Consequently, for all years in which the scrapping refers to vintages in which the production-depreciation rate is 0.01 we can write

$$(63-n_t)0.01 = \frac{w_t}{w_0 x_t} - 1$$

or

$$1 + (63-n_t)0.01 = y_t. \qquad (23)$$

For years in which the scrapping refers to vintages in which the production depreciation factor differs from 0.01 the corresponding equation can be written

$$\beta_{t-n}\Delta n_t = \Delta y_t. \qquad (24)$$

In the analysis below it so happens that all scrapping refers to vintages with a depreciation factor of 0.01 except the scrapping during the 1970s. This means that the equation (23) is valid for all years up to 1970 and the equation (24) refers to the years after 1970 only.

The rate of interest

The assumption of perfect competition implies that the discounted value of the expected income stream of quasi-rents emanating from a new investment project should equal the total investment costs, V_0. Consequently, the following equation should hold good:

$$q_{0t}I_1 - w_t \ell_{0t} I_2 = V_{0t}, \qquad (25)$$

where the I:s are defined as

$$I_1 = \int_0^n e^{-(\beta_t+r_t)z} dz \quad \text{and} \quad I_2 = \int_0^n e^{-r_t z} dz.$$

Since a wage increase proportionate to a corresponding increase in the productivity factor leaves labour income and production value unchanged, such a wage change will not affect the variables in the equation above. The situation is, however, different for a change in the wage-efficiency ratio. If the rate of return of the investment project is not to be worsened by a rise in the wage-efficiency ratio the rate of interest must fall so much that the labour-cost increase is compensated by a decrease in capital costs. Consequently, there must be a relationship between the wage-efficiency ratio and the rate of interest.

In the preceding section, it was shown - equations (13) and (14) - that the stationary model implied that

$$V_{0t} = 4.9q_{0t} \quad \text{and} \quad k_{0t} = q_{0t}/0.43 = 2.3\, q_{0t},$$

which in turn implies that

$$V_{0t} = k_{0t} + 2.6q_{0t}. \qquad (26)$$

This equation is assumed to hold good also for the periods after 1870, an assumption which implies that the value of capital not included in the figures of investment, i e land, inventories, etc, varies in proportion to the volume of production in new vintages.

Inserting the right-hand member of equation (26) in equation (25), we get

$$I_1 - 0.53I_2 = k_{0t}/q_{0t} + 2.6, \qquad (27)$$

an equation which includes four variables, n, β, k_0/q_0 and r.

Since β and k_0/q_0 are uniquely determined by n, according to equations (22), (20) and (23), we can regard (27) as an equation between n and r only. Given r, we can consequently determine n, and vice versa. Therefore, we can formally write equation (27) as

$$F(n_t, r_t) = 0. \quad (28)$$

The mechanism behind this equation obviously means that the rate of interest and the wage-efficiency ratio act as two communicating vessels. If the wage-efficiency ratio is raised, the rate of interest must fall. If not, investment projects will show expected losses and therefore no investment will take place.

The model equations

By bringing together equations (28), (23), (24), (21), (20), (22), (17), (18) and (19), we get the following complete description of the growth model:

$$F(n_t, r_t) = 0, \quad (29)$$

$$y_t = 1 + 0.01(63 - n_t) \text{ for all years before 1870}, \quad (30a)$$

$$\Delta y_t = \beta_{t-n} \Delta n_t \text{ for the 1970s}, \quad (30b)$$

$$\beta_t = 0.63 n_t^{-1}, \quad (31)$$

$$q_{0t} = A(\ell_{0t} x_t)^{0.6} (k_{0t})^{0.4}, \quad (32)$$

$$q_{0t} = B y_{0t}^{-1.5} k_{0t}, \quad (33)$$

$$q_{st} = q_{0,t-s} e^{-\beta_{t-s}}, \quad (34)$$

$$\ell_{st} = \ell_{0,t-s} x_t^{-1} x_{t-s}, \quad (35)$$

$$w_t \ell_{st} = 0.53 q_{0,t-s} y_t y_{t-s}^{-1}. \tag{36}$$

By simple summation, we can, of course, also form the three aggregates

$$Q_t = \int_0^n q_{st}, \quad (LW)_t = \int_0^n (w_t \ell_{st}) \text{ and } L_t = \int_0^n \ell_{st}. \tag{37}$$

Furthermore, by using equation (23) we can determine the labour-augmenting factor like this:

$$x_t = (LW)_t (LW)_0^{-1} L_0 L_t^{-1} [1 + 0.01(63-n_t)]^{-1}. \tag{38}$$

A glance at the above equation system indicates that, given the time-series of the investment volume and the interest rate, equations (29)-(34) make it possible to determine, in turn, the variables n_t, y_t, q_{0t}, β_t, and q_{st}. Consequently, the aggregated production Q_t can also be determined. Furthermore, the values of q_{0t} and y_t can be used to determine $w_t \ell_{st}$ by equation (35) and consequently the aggegated labour income $(LW)_t$ can also be obtained. All this together means that access to empirical data showing the time-series of the volume of investment and the rate of interest enables us to simulate the corresponding time-series of total production and total labour income. Access to data on total employment enables us, in addition, to simulate the development of the labour-augmenting factor x_t. These properties of the model have been used for the simulation procedure that will be described in the next section.

The propelling factor of the "model economy" is assumed to be the labour-augmenting factor x. The time path of this factor is regarded as exogenously given. When it grows, it creates disequilibrium tendencies which put the whole system into motion.

In the very long run, total employment must, reasonably, develop close to the total labour force. Therefore, my model makes no distinction between these two variables. They are assumed to have identical values. However, a conceptual distinction should nevertheless be made, because the total labour force has to be regarded as exogenously given, while the total employment is determined as an endogenous variable in the model. In fact, total employment should be looked upon as a target variable determined - either by a labour-market mechanism or by economic-policy measures - in such a way that it will equal the total labour force.

There are two more variables whose status in the model has not been made clear - the rate of interest and the volume of investment. As regards their character of exogenous or endogenous variables, different interpretations are possible. One alternative is to regard the rate of interest as exogenously given. The consistency of the model requires in this case that the volume of investment is determined - either via a wage policy or via some investment affecting government policy - in such a way that full employment is attained. Another alternative is to regard the volume of investment as exogenously given and to regard the rate of interest as a policy parameter, used as an instrument for attaining full employment. Yet another alternative is to regard the wage-efficiency ratio as given by the labour-market mechanism and to regard the rate of interest and the volume of investment as policy parameters, used for creating equilibrium and full employment.

The fact that the model allows for different interpretations of the casual order does not, of course, mean that one of these alternatives is to be regarded as the right one and the others as wrong. It is, in fact, quite possible to imagine that the different alternatives refer to different periods of time. Furthermore, it should be observed that the simulation results are independent of the choice of alternative.

IV. THE SIMULATION RESULTS

In the preceding section, I showed that access to time-series of the volume of investment and the rate of interest makes possible a simulation of all the relevant variables included in the model. This property of the model has been used for the simulation procedure to be reported in this section, together with the simulation results. This procedure is in fact very simple.

According to the model, the rate of interest determines uniquely the number of vintages and the output-capital ratio in new vintages. This means that, starting from the year 1870, we can gradually estimate (period by period), the total production and the total labour income by the following two equations:

$$Q_{t+1} = \gamma_{t+1} i_{t+1} (1+\beta_{t+1})^{-1/2} - q^{s}_{t+1} - \sum_{s=t_{0,t+1}}^{t} q_{st}(1+\beta_{t-s})^{-1} \text{ and} \qquad (39)$$

$$(LW)_{t+1} = 0.53\, \gamma_{t+s} i_{t+1} - (\ell w)^{s}_{t+s} - [(LW)_{t} - (\ell w)^{s}_{t+1}](1+\beta_{t+1}\Delta n), \qquad (40)$$

where γ denotes the output-capital ratio in new vintages and i the volume of investment. The variables q^s and $(\ell w)^s$ stand for the volume of production and the labour income, respectively, in vintages scrapped during the period. The symbol β_s is the production depreciation factor, referring to the vintage invested in s, Δn is the decrease in the number of vintages under the period and $t_{0,t+1}$ is the period of time to which the oldest vintage refers.

Knowing the development of Q and (LW) up to the point of time t and in addition, the values of i_{t+1} and r_{t+1}, all the terms in the right-hand members of equations (39) and (40) can be determined and, consequently, also the left-hand members.

In order to simplify the calculations, I have used throughout 5-year averages of the investment figures. This means that the value of β in the equations above has to be thought of as being approximately five times as high as its 1-year equivalent. It should be observed that the values of Q and LW, which emerge from the simulations, refer to separate years, not to 5-years averages.

For the simulation procedure and for the comparison between simulated and actual values, the following four time-series were needed:

(1) the volume of production in the private sector of the Swedish economy, (2) the volume of investment in this sector, (3) the labour share of production in this sector and (4) the rate of interest (or, more correctly, the cost of capital). The first two of these time-series could easily be constructed by some minor manipulations with data published elsewhere.[1] For the post-war period, the desired income-distribution figures have been provided by the Swedish Employers' Confederation.[2] For the period before 1950, new data were constructed by making some modifications to the data presented in an earlier study.[3]

The estimation of a time-series showing the development of the rate of interest was a little problematic. For the period before the First World War, the statistical information about different rates of interest is very incomplete. However, it can be concluded that the interest rates of industrial bonds issued by big firms varied between 5 and 6 per cent and that the bank rates were 1 or 2 per cent higher. These rates remained at the same level, approximately, during the 1920s, but at the beginning of the 1930s, there was a sudden fall by a couple of percentage units. With the exception of the war years, this low rate was maintained until the middle of the 1950s, and since then the nominal rates of interest have been higher. However, the real rates - which seem to be the relevant ones in this context - have remained very low, about 3 per cent as an average, for the 1950s and 1960s. Since 1970, the real rate has been approximately zero.

In the study presented in this paper, there seems to be little sense

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[1] Krantz and Nilsson [1975] and National Accounts.

[2] The figures for the after-war period shown in table 1 on p 39 are 3 percentage units lower than the corresponding figures given by the Swedish Employers' Confederation. This is due to the fact that my figures had to be chained to the series for the period before 1950. Consequently my figures are probably 3 percentage units too low.

[3] Jungenfelt [1966].

in using sophisticated methods of determining the year-to-year development of the rate of interest. Instead, an extremely schematic procedure has been chosen. For the simulation, I have quite simply allowed for a constant rate of interest of 7 per cent all the time from 1870 to 1930 and a rate of 5 per cent from 1930 to 1950. For the period 1950 to 1970, I have allowed for 3 per cent and for the first part of the 1970s for 0 per cent.

The growth path in the efficiency factor is estimated by the quantities of labour measured by the number of individuals. From many points of view, it might have been better to proceed not from the number of individuals but rather from the number of working hours. As the data are lacking for earlier periods, it has not been possible to do it in this way without a loss of comparability between periods. Those who want to relate the efficiency factor to working hours instead of individuals can easily do so. It is only necessary to add to the estimated value of growth in the efficiency factor the growth of the ratio of the number of individuals employed to the number of hours worked. From 1950 to 1972 this ratio has grown by 0.15 per cent per year on the average.

The results of the simulation are shown in Tables 1 and 2. They can be summarized like this:

(1) In view of the very long period covered by the simulation and of the fact that the simulation has been performed without using information from the time-series to be explained, the conformity between the hypothetical and the actual values seems to be remarkably good. This good fit justifies a positive answer to the first part of the basic problem raised in the introductory section. There it was asked whether it is possible to construct a simple, one-sector model that is capable of making possible a close-to-reality simulation of Swedish economic development during 100 years. The figures presented in Table 1 confirm this possibility.

(2) The good fit between the simulated and the actual values supports the general hypotheses underlying the model, including the hypothesis that the technological progress has been predominantly disembodied and labour-augmenting.

(3) The simulation indicates that the lifetime of capital was constant during the first 60 years of the period under consideration and that it fell thereafter to 40 years in 1970 and to 30 years in 1975. This fall in the number of vintages is in agreement with the results of some other studies.[1]

(4) According to the simulation, the output-capital ratio decreased from 0.43 during the period 1870-1930 to 0.26 at the beginning of the 1970s. Simultaneously, there was a gradual increase in the ratio of capital depreciation to gross investment. The same type of development has been found in other studies.[1]

(5) It must be admitted that the realism of the assumption made above concerning the relationship between the rate of interest and the number of vintages - equation (28) - is doubtful. Therefore, it may be worth while to investigate the consequence of giving up that assumption. This can be done by estimating the number of vintages, on the assumption that the simulated and the actual values of aggregate production coincide during the whole period. The result of this calculation was as follows:

Year	1870	1890	1910	1930	1950	1955	1960	1965	1970	1975
Number of vintages	63	60	60	64	47	42	39	40	35	31

A comparison with the figures given in Table 1 shows that the series in question are nearly identical except for one single year, 1970. This indicates that the assumed relationship between the rate of interest and the number of vintages is in good agreement

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[1] Cf, for instance, den Hartog & Tjang [1976].

Table 1. Estimations of production, labour income, labour share, output-capital ratio and number of vintages

	1890	1910	1930	1950	1955	1960	1965	1970	1975
Production									
Actual (1870=100)	167	322	602	1014	1107	1307	1669	1949	2157
Simulated	171	326	594	1021	1099	1333	1670	2042	2155
Error margin, %	+2.4	+1.2	-1.3	+0.7	-0.7	+2.0	-0.1	+4.8	0.0
Labour income									
Actual (1870=100)	163	299	549	940	1122	1325	1716	1948	2218
Simulated	163	305	556	1009	1137	1336	1640	1987	2271
Error margin, %	0.0	+2.0	+1.3	+7.3	+1.3	+0.8	-4.6	+2.0	+2.4
Labour share[a]									
Actual (1870=100)	0.67	0.64	0.63	0.64	0.70	0.70	0.71	0.69	0.71
Simulated	0.66	0.65	0.65	0.68	0.71	0.69	0.68	0.67	0.73
Estimated number of vintages	63	63	63	49	40	40	40	40	30
Estimated output-capital ratio	0.43	0.43	0.43	0.34	0.30	0.30	0.30	0.30	0.26

[a] Cf note No. 2 on p. 36.

Table 2. Estimations of yearly growth rates and the yearly growth of technological progress

	1870-1890	1890-1910	1910-1930	1930-1950	1950-1955	1955-1960	1960-1965	1965-1970	1970-1975
Yearly growth rates, %									
Actual	2.6	3.3	3.1	2.6	1.8	3.3	4.9	3.1	2.0
Estimated	2.7	3.2	3.0	2.7	1.5	3.9	4.5	4.0	1.1
Estimated yearly growth of technological progress	1.9	2.5	2.1	1.0	1.6	3.1	5.4	2.7	0.7

with the other assumption of the model.

(6) The error margins presented in Table 1 are in most cases small. There are, however, three exceptions. They refer to labour income in 1950 and 1965 and to production in 1970. It is not very easy to understand why the simulation gives such a bad fit for the labour income of 1950 and 1965. The bad fit for production in 1970 can, however, easily be explained. The capital costs for Swedish industry were, no doubt, lowered during the latter part of the 1960s by a number of economic-political measures aimed at the stimulation of investments; the investment funds were released much more generously than previously and large subsidies were given to firms starting new plants in backward areas. It seems, in fact, that the assumption of a 3 per cent rate of interest during this period is not very realistic. The large margin of error in Table 1 and the figure given for 1970 under paragraph (5) above indicate strongly that there was a decrease in the number of vintages by about 5 during the period 1965-70.

(7) The rate of growth of the labour-augmenting factor has varied around a value slightly above 2 per cent per year, which seems to be a "normal value". That the rate was higher during the period 1890-1910 is not surprising, if we consider the exceptionally good conditions for economic growth that pertained during that period. Nor is it surprising that the rate was exceptionally low during the period 1930-50. The high rate 1965-70 and the low rate 1970-75 can be explained by what was said above, namely, that a part of the estimated decrease in the number of vintages for the period 1970-75 in reality occurred already during the end of the 1960s; the average of the growth rate for the 10-year period 1965-75 was 1.7 per cent. Also for the two periods of the fifties the average was rather normal. The low rate at the beginning of the 1950s and the high rate at the beginning of the 1960s do not, however, fit into the "normal" picture.

(8) The estimated values of the rates of growth of the labour-augmenting factor agree rather well with the estimate made in an earlier

Swedish study using a production-function approach.[1] The disembodied technological factor — divided by the labour elasticity in order to be comparable with a labour-augmenting factor — was estimated to have been 2.2 for the period 1870-1964. The figures in Table 2 are also in a rather good agreement with the results obtained by C E Ferguson and P A David and Th van de Klundert in aggregated production-function studies of the U S economy.[2] Ferguson's analysis yielded a labour-augmenting factor of 1.9 for the period 1948-63, while David's and van de Klundert's investigation, which covered the period 1899-1960, indicated a labour-augmenting factor of 2.3.

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[1] Y Åberg [1969].

[2] C E Ferguson [1965] and P A David and Th van de Klundert [1965]

V. THE EXPLICATORY POWER OF THE MODEL

The scientific value of a model of the above type is, of course, dependent on the possibilities of using it for drawing concrete conclusions concerning reality. In making a general appraisal of the model, it is, consequently, important to get some information about its power to explain actual economic phenomena. The purpose of this section is to give some information of that kind, by presenting some examples of conclusions that can be drawn from the model presented in the preceding section. These examples refer, of course, to Swedish development, but it should be borne in mind that my purpose is not to present an analysis of the Swedish growth process but only to show that a very simple, one-sector, vintage model may allow us to draw some important conclusions.

As will be seen from Table 1, the growth rate of the Swedish economy has varied from one period to another. Most of these variations have been simulated correctly by the model and, in that sense, the simulation can be said to explain the variations in the rate of growth. This is true also for the period of high growth-rate between 1890 and 1910 and the extreme boom period of 1960-65. According to the model, the production increase during these periods was caused by the high investment ratio. Also the slow rate of growth at the beginning of the 1950s is fairly well mirrored by the simulation. The slow growth during these years is explained by the model by the extra scrapping that occurred as a consequence of an increase in the wage-efficiency ratio.

It is certainly true that the extreme boom during the first half of the 1960s does not give rise to "difficulties of explanation" if we look only at the production side of the model. However, if we look at the labour side, such difficulties will arise. The problem is how all the new, invested capital could be manned without pulling more than the "normal" amount of labour from the oldest vintages. According to the model, this was possible because of a sudden jump in the labour-augmenting factor. But why did this jump happen? The model cannot, of course, give an answer to that question, but it has raised the problem.

Within the framework of the model, it is hardly meaningful to disaggregate the growth of production into parts interpreted as separate effects of changes in capital stock, employment and technological progress. However, the model does allow of assessments of the marginal productivity of capital and labour. For labour, such an assessment is trivial. For capital, it is not so. It is, in fact, possible to estimate not only the marginal productivity that is of relevance to the private investor but also the social, marginal productivity, defined as the increment in total production in consequence of an increase in investments at a constant level of employment. Of course, such a change implies a transfer of labour from the oldest to the newest vintages. Estimates of the social, marginal productivity defined in this way indicate that it amounted to 20 per cent during the period 1870-1930. After 1930, it decreased and in 1975 it was no more than 12 per cent.[1]

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[1] On the assumption that the initial situation is characterized by full employment, the production increase per unit of incremental capital can be written

$$dQ/dk_0 = (dq_0 - dq_n) : dk_0,$$

where dq_n stands for the production in the vintage, scrapped because of the necessary transfer of labour to the extra new capital. For the period 1870-1930, the output-capital ratio in new vintages remained constant and equal to 0.43. During that period, the ratio between the labour productivity in the oldest vintage and the productivity in the newest vintage was 0.53. Consequently, the derivate dQ/dk_0 is equal to

$$0.43(1-0.53) = 0.20.$$

In 1975, the output-capital ratio in new vintages was 0.26. This implies that dQ/dk_0 for 1975 was 0.12.

The marginal productivity of capital was defined as the ratio between the increment of production in year t, following from the hypothetical extra investment at the beginning of that year and the volume of this extra investment. However, investments in year t affect production also in the years t+1, t+2, etc. If the entire series of consequential increments to production is known - net after deduction of the corresponding production loss in the oldest vintage - it is, of course, possible to estimate the social rate of return of the extra investment. Such an estimate shows that the internal rate of return, according to the model, amounted to 18 per cent until 1930 and thereafter decreased to less than 10 per cent in 1970.

The long-term development of the Swedish functional distribution of income is characterized by a reduction in the labour share from 1870 to 1930 and by two, sudden, upward jumps of the labour share, one at the beginning of the 1950s and one at the beginning of the 1970s. In "the world of the model", the reduction in the labour share until 1930 is explained by the combination of an unchanged number of vintages and a shift in the centre of gravity of the production structure towards younger vintages, where the labour share is lower than in the older ones. The jumps at the beginning of the 1950s and the 1970s are explained by the decrease in the number of vintages. A decrease in the number of vintages implies a tendency to raise the labour share.

The combination of an acceleration of the investment growth and a non-decreasing number of vintages implies, in the "world of the model", a decrease in the labour share of production.[1] If this mechanism is realistic, it has an important consequence for economies that are at the beginning of the industrialization process and have an abundant labour supply. On the traditional assumption that the saving rate from capital incomes is higher than that from labour incomes,

[1] J Sutton [1976] deals fairly much with this mechanism. He shows that the combination of an investment acceleration and an elastic labour supply results in a lowering of the labour share. He explains the development in Japan by this mechanism.

the income redistribution caused by an investment acceleration creates automatically at least some of the additional saving that is needed for financing the investment growth. In Sweden, this savings-creating mechanism seems to have been very important, especially during the period 1890-1910.

The model indicates that the number of capital vintages was constant during the entire period of 60 years from 1870 to 1930. This constancy implies that the wage rate increased at the same rate as the labour-augmenting factor, which in turn means that the labour costs remained constant. Since the rate of interest did not change very much during this period, there were no incentives to substitute capital for labour — or vice versa — during this period. It was, according to the model, not until the depression during the 1930s that substitution started to take place. The fall in the rate of interest provided incentives to use more capital-intensive methods of production than before.

According to the model, the labour productivity is higher in new vintages than in the older ones. This means that the ratio between total production and total labour force is influenced by the vintage structure; the larger the young vintages, the greater is the aggregated productivity. This property of the model is important as regards the problem of estimating the productivity gains attained by the transfer of labour from agriculture to industry. According to the actual model, a great part of the productivity gap between manufacturing industry and agriculture that existed in Sweden up to the Second World War can be explained quite simply by the difference in the vintage structure between the two sectors. The labour productivity was higher in manufacturing industry than in agriculture, because the mean age of capital was lower in the former sector than in the latter. This does not, of course, imply a difference in marginal productivity between the two sectors.

At the beginning of the 1930s, there was obviously some type of structural shift in the Swedish economy, a shift from a situation characterized by unaltered labour costs (unaltered for augmented labour), lack of substitution between labour and capital and a downward long-term trend in the labour share of production to a situation characterized by increasing labour costs, substitution between labour and capital and an increasing trend in the labour share. In trying to find the explanation of this shift, we immediately encounter the problem touched upon in section III, viz. how to interpret the casual order of the model. There are, in principle, two different alternatives to choose between.

As I stated earlier, one way of looking at the causal order is to regard the rate of interest as an exogenous and casual factor. This implies that the casual order can be thought of as follows. On account of the fall in the rate of interest, the capital costs in new vintages decreased, which created room for an increase of the wage-efficiency ratio in the new vintages. This increase was spread over the entire labour market and forced an extra amount of scrapping of old vintages, which in turn produced a tendency to unemployment. This tendency was, however, never realized, because the lowering of the rate of interest stimulated investments enough to make it possible for the labour freed by the extra scrapping of old capital to be absorbed by the manning of new capital.

The other interpretation alternative is to consider the rise in the wage-efficiency ratio as exogenous and to regard the structural shift as an effect of institutional changes caused, for instance, by a transition from one type of economic policy to another, from one labour-market mechanism to another, etc. One can, for example, imagine an institutional change leading to increased wage pressure, which forces the authorities to lower capital costs in order to compensate for increased labour costs and to avoid the unemployment tendencies arising from the increased scrapping of old capital.

In the Swedish economy, there has been a substantial increase in the ratio of capital depreciation to gross investment. This development is fairly well mirrored by the model. In the "world of the model", the ratio in question increased from a low of less than 40 per cent in 1950 to around 65 per cent at the beginning of the 1970s. The explanation of this development is the increase in the frequency of vintages with high production-depreciation rates.

An increase in the ratio of capital depreciation to gross investment means, of course, a tendency to a lower growth rate, given the volume of investment. Therefore, the development mentioned in the preceding paragraph has meant a lowering of the growth potential of the Swedish economy. Earlier in this section, I argued that this potential was impaired also by another phenomenon, the decline in the output-capital ratio. Consequently, there are at least two factors that create important tendencies to worsen the growth potential of the Swedish economy. The model indicates that these tendencies started to assert themselves in the middle of the 1930s and that they have grown in strength, especially since the middle of the 1960s.

The appearance of the growth-potential-worsening factors mentioned in the preceding paragraph is, in the model, a consequence of the decrease in the number of vintages. This decrease in its turn is a consequence of the high investment level; the manning of all new capital necessitated the pulling of labour from the oldest vintages. If this mechanism has a general validity, it implies that the possibilities of promoting growth in a full-employment society by expanding investments are narrowly limited. The more investments are expanded, the more the growth-counteracting factors will worsen the growth potential. This conclusion is certainly in full agreement with the traditional assumption of the decreasing marginal productivity of capital, but in the model presented above, this marginal-productivity effect is reinforced by others working in the same direction.

It is well known that a traditional production-function model can be used for forecasting future production for given values of the volume of investments, the volume of labour and the productivity factor(s). The same types of forecasts can be made with the aid of a vintage model of the type presented in this paper. My model has, in fact, been used for a number of such estimates. All these estimates have shown that - given a normal 2-per-cent increase of the labour-augmenting factor - an extreme increase in the investment ratio will be necessary, if the Swedish economy is to be able to attain a growth rate of 3 per cent per year or more. This means a much lower growth potential than before. The reasons are, of course, those mentioned above - the decrease in the output-capital ratio, and the higher rate of capital depreciation.

In the introductory section was stated that the general problem underlying the construction of the model presented in this paper was to find out whether it is possible to construct a simple one-sector model that is capable of simulating the Swedish economic development during the last one hundred-year period and of giving non trivial explanations for some of the characteristic features of the growth process during that period. The first part of this problem was answered positively in the preceding section. The discussion in this section has shown that the model has a good capability of explaining specific features of the growth process and that, consequently, also the second part of the above problem can be answered in the affirmative.

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