Contribution of New Information Technology to the Growth of the Japanese Economy for 1974 – 85 — An Application of Input-Output Model and Productivity Analysis[1] Part 1

By
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Abstract

The development of new information technology for production and other activities (i.e., informatization) has been a major source of the growth of the Japanese economy since 1970s. The present work is an attempt to measure the contribution of informatization. We develop an input-output method to decompose the value of produced goods and the capital stock into two components: the part attributable to the development of new information technology and the remaining part. We apply this method to time series of the Japanese economy for the period 1974-85. By using the factor-productivity analysis to the decomposed time series, we find that ten to twenty percent of the annual growth of the Japanese economy during this period was explained by the development of new information technology and that, without such technology, per capita national income of Japan in 1985 would have been lower than its actual level by approximately twelve percent. The paper is the first part of the work, which is composed of two parts.

1. Introduction

The present work is an attempt to measure the contribution of new information technology to the recent growth of the Japanese economy. We first develop an 'accounting method' to decompose the value of produced goods and the capital stock into two components: the part attributable to the development of new information technology and the remaining part. An input-output analysis is used for this. We apply this accounting method to time series of the Japanese economy for the period 1974-85. Second, by using the factor-productivity analysis to the decomposed time series, we find that ten to twenty percent of the annual growth of the Japanese economy during this period was explained by the development of new information technology and that, without such technology, the per capita national income of Japan in 1985 would have been lower than its actual level by approximately twelve percent. This work comprises two parts: Part 1 deals with 'accounting' and Part 2 with 'productivity analysis.' The first part of the paper contains an explanation of the background of the work, an overall exposition of the method used, and a mathematical description of the model. The second part presents empirical results.

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The development of new information technology in Japan started in the early 1970s. It was led by the invention of IC and LSI in U.S. Manufacturing of IC and LSI in Japan began by the middle of the 1970s; they were subsequently used for building NC-machines and robots. In the 1980s, new information technology spread to offices and homes in the form of personal computers, word processors, facsimiles, and new communication equipment, not to mention mainframe computers. There is no doubt that such changes increased the efficiency of the functioning of the Japanese society in general, and the aggregate productivity of the nation in particular, thereby contributing to the growth of the Japanese economy.

The objective of this work is to measure this contribution numerically. In other words, it intends to estimate the level of the national income at the present time which would have been realized if there had been no development in information technology during the period in question.

The following is a rough sketch of the work. First, an input-output model of the Japanese economy is constructed with two sectors, the new information sector (to be called the H-sector) and the other sector (the Z-sector). By using the 'price-value-added version' of the input-output model, the value of the output of each sector is divided into H-and Z-components.

Second, a time series of the real H-capital and the real Z-capital is constructed by using H-and Z-price deflators, respectively. An economic characteristic of new information technology lies in the rapid increase in the capability of the information device and the rapid decrease in its price; our calculation shows that the real H-capital during the period in question increased 100-to 150-fold, contributing significantly to the growth of the Japanese economy. These are reported in Part 1.

Finally, the annual growth rate of the Japanese economy is divided into H-and Z-components to obtain the contribution of the H-sector (i.e., the new information sector). The theory of macroeconomic production function with productivity measurement (i.e., growth accounting) is used for this. This portion of the work is reported in Part 2.

The following is an outline of this paper. In Section 2, an informal explanation of the work is given. Section 3 spells out in terms of mathematical equations the 'accounting' used in this paper. Section 4 explains briefly the source of the data used. Section 5 presents our findings.

2. Outline of the Method

What is meant by the contribution of new information technology to economic growth? This section is devoted to answering this question.

We begin by observing that there are two routes through which new information technology may increase the national income. First, new information technology has brought about the growth of information industries such as the LSI industry, the computer industry, the telecommunications industry, and the like. National income is the sum of the value added generated in all industries of the society. The growth of the information industries was so rapid that the relative weight of the value added produced in the information industries increased significantly during the 1970s and 1980s; the growth of national income owes much to the development of new information technology in this sense.

Thus, we may define 'the contribution of new information technology to the growth of GNP' to be the increase in the rate of growth of value added generated in the information industries. This definition, however, is not satisfactory for the reason that it neglects the benefits of new information technology to industries other than information industries.

To explain the point, suppose that, contrary to the reality, there was no information industry in Japan and all informational products and services were imported from abroad. The national income of Japan would be composed of the value added of which no portion was generated by the information industries; the contribution of new information technology would be zero. Yet, the economy would have benefited greatly from imported informational goods and services. In fact, such is the reality today in the Japanese database industry; a dominant part of the database services used in Japan is 'imported' from the U.S.

It is clear from this consideration that there exist two ways through which the benefits of new information technology are materialized: (1) supply-side effects, i.e., the increase in the national income due to the increase in the value added generated in the information industries; (2) user effects, i.e., the benefits of informational products and services enjoyed by the industries and the other sectors of the society. The user effects may be divided into two categories: measurable user effects and external user effects.

The measurable user effects are the benefits of new information technology which directly materialize into a reduction in the cost of goods or an improvement of the quality of goods. The external user effects are the benefits of new information technology which are realized through an overall improvement in social and economic systems. Roughly speaking, the measurable effects come from the fact that new information technology contributes to improving the quality of goods and services at the point where they are produced. On the other hand, the external user effects arise from the fact that they improve the performance of social and economic systems as a whole.[2]

In the present work, we concentrate on the measurable user effects. It does not mean that the external effects are unimportant; on the contrary, they are important factors in explaining the effects of new information technology on economic growth. We limit our attention to the measurable user effects for reason of analytical convenience.[3]

To explain the measurable user effects, let us consider the case of automobile production. New information technology affects automobile production through multiple routes, as is pointed out below (See Figure 1). First, the motor of an automobile is controlled by LSI, a product of new information technology; the operation of the motor is more efficient with LSI than without. Second, robots, controlled by LSI and other devices, are used in assembling automobiles; they are more accurate and cheaper than humans in doing mechanical and repetitive tasks, thereby contributing to the improvement of the quality of assembled cars and the reduction of assembly costs.

Third, when a new automobile is to be designed, engineers use workstations driven by softwares;[4] their work is easier and more effective when they use workstations. Fourth, a new car has to be tested repeatedly before it is put into mass production. Testing is done by experimentation and by simulation; for this, equipment controlled by IC, LSI, and general purpose computers are used.

Fifth, new information technology contributes to the operation of the firm selling automobiles through office automation (OA) and value-added networks (VANs). Orders from customers are transmitted to shipment centers and eventually to factories producing automobiles. Without

[2]The external user effects may further be divided into two subcategories: *external economic effects and external noneconomic effects.* The external economic effects come from efficiency improvements in economic systems such as productive firms and markets and in the government from new information technology. Examples of the external economic effects are introduction of electronic fund transfer and shopping by means of bulletin board systems (BBS). The external noneconomic effects reflect improvements in public service systems, political systems, and other social systems brought about by new information technology.

[3]The authors performed a preliminary estimation of the supply-side effects of new information technology (The work was published in Japanese. See [4] and [5].).

[4]They are called CAD (computer-aided design) or CAM (computer-aided manufacturing).

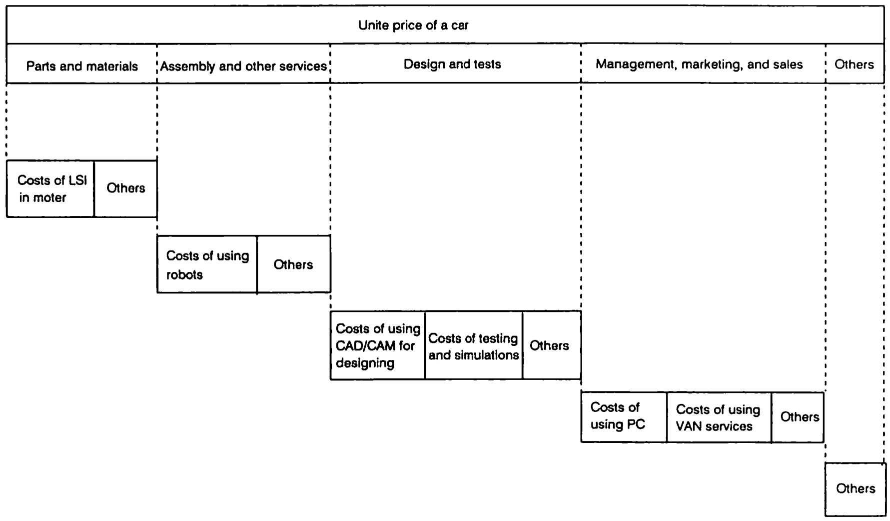

Figure 1 Division of the Unit Price of a Passenger Car into Information and Other Components

electronic devices, orders would have to be processed by humans with written instructions and telephone calls, thereby causing costly delays and errors. Sixth, computers may be used for demand forecasting, marketing, and sales promotion; the management and operation of a firm is greatly improved by new information technology. Finally, one can point out that new information technology is also useful in training workers and managers.

Thus, new information technology contributes to the production and the distribution of automobiles at different levels and in different ways. LSI in the motor of a car improves its performance and adds to its value. Robots used for automobile assembly reduce the cost by substituting for expensive human labor. These are typical examples of the measurable user effects. On the other hand, new information technology used to facilitate the functioning of automobile markets provides benefits to both producers and users of automobiles. This is a case of the external economic effects, as the benefit of improved markets cannot be traced in the form of cost reduction or quality improvement of individual automobiles. The objective of this paper is to aggregate the measurable user effects of new information technology into a small number of indicators so that we may conceptualize about the magnitude of the effects. This objective is pursued by utilizing input-output relations and 'real' economic variables.

In order to isolate the contribution of new information technology, we will divide the value of goods and services, the value of capital stock, and the wage payment into two components, one corresponding to new information technology, and the other corresponding to technology other than new information technology. In reality, however, the two components may not be distinguished physically. For example, an automobile has LSIs attached to its motor. A motor is composed of iron and other materials, of which the production relies directly or indirectly on new information technology. Furthermore, the effects of new information technology are not always visible; frequently, it is hidden in the cost and the quality of a car in the sense that the cost is lower and the quality higher with the help of new information technology.

From this observation, we are led to the following strategy to measure the contribution of new information technology. Whether visible or invisible, tangible or intangible, we express the effects of new information technology by looking at the composition of the value of a commodity. We

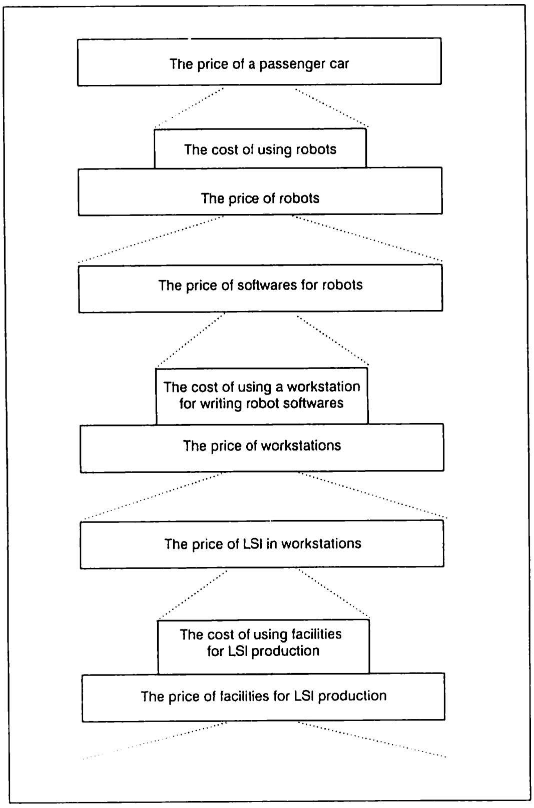

Figure 2 Information Components in the Price of a Passenger Car Traced Backward

do this for the reason that the cost, i.e., the money element, is the only attribute transferable from one commodity to another; the cost factor is the only 'carrier' of the effects of new information technology (See Figure 2).

Thus, the present paper concentrates on tracing the effects of new information technology by computing the cost of a commodity. We divide the nominal value of a commodity into two parts, to be called H-and Z-components, respectively, and treat each of them distinctly.[5] The nominal value spent on the H-component of a commodity is affected by a rapid improvement in its quality and a rapid decrease in its price; the 'real' outcome from a nominal amount of money spent on the H-component is increased because of new information technology. In the present work, we use a single price-quality index for the H-(or Z-) component, rather than a price index and a quality index constructed separately; our index expresses the amount of money needed to purchase a unit able to find a way out other than by using certain simplifying procedures in obtaining suitable data. In the future, however, when data with quality specifications are available, we may be able to use a more accurate estimation procedure than the one presented in this work.

[5]As presented more formally in the following section, there will be two types of goods, the H-good and the Z-good. Likewise, there will be two types of capital stock, the H-capital and the Z-capital. We also consider two types of labor, the H-labor and the Z-labor. The H-component of labor is that part of the productive factor which has the skill of working with the H-capital, and the Z-component is that part which does not have such skill. As this assumption on labor decomposition may be problematic, we will present three models each with different ways of decomposing the labor.

3. The Model

This section explains the model which we will use for the 'accounting.' As outlined in the preceding section, we start with a presumption that the whole economy is divided into two productive sectors, *the new information sector* (the H-sector) and *the other sector* (the Z-sector). The output produced in the H-(or Z-) sector is called *commodity* H (or Z). It is possible to formulate a general model with n sectors; the two-sectoral framework is used here because of the limitation of available data.

First, we present the notation. We use the letters H or Z to identify the component contained in a commodity or in a factor of production, as well as to identify a sector of the economy. We consider three factors: the real capital stock, the labor force, and the 'research and development expenditure' expressed by the variables K,L, and R, respectively. Each of the two commodities and each of the three factors contain both H- and Z-components.

In summary, define

j: index of a sector (j = H,Z); (1)
i: index of output (i = H,Z), or
index of a productive factor (i = K,L,R);
m: index of a component of output or of a factor (m = H,Z).

These variables will be used, for example, in input coefficients, a(i,j), of commodity i at sector j(i = H, Z;j = H,Z). Note that there are four coefficients a(i,j). We postulate that the values of a commodity are divided into H-and Z-components according to the way in which the values of the factors are divided into H- and Z-components (see equation (13) below). Further, we assume that, when a commodity from one sector is used for investment, the H- and Z-components in the invested good are distributed proportionally to the value of the good invested in the H- and Z-sectors (see equation (16) below).

The following is a list of variables to be used in this paper:

t: time period (t = 0,1,2, ...,T) (2)

(i) exogenous data (t = 1, ..., T; i = H, Z or i = K, L, R; j = H, Z; m = H, Z):

$a(i,j,t)$: nominal input coefficient of commodity i in sector j;
$v(i,j,t)$: nominal value-added coefficient of factor i in sector j;
$h(i,t)$: nominal investment of commodity i;
$b(i,j,t)$: the proportion of the investment distributed from sector i to sector j to the total investment produced at sector i (the investment coefficient);[6]
$q(m,t)$: price of the m-component of investment (the deflator of the m-investment);
$d(m,t)$: the rate of depreciation of the m-capital stock;
$l(j,m,t)$: the m-labor force in sector j;
$w(m,t)$: the wage rate of the m-labor force;
$x(K,t)$: the aggregate nominal income distributed to the owners of capital stock (aggregate profit);

(ii) the initial condition (t = 0 only):

[6]Note that the investment coefficient used in this work is different from the capital coefficient used in dynamic Leontief models; the latter is a capital — output ratio, whereas the former indicates a proportion of investment.

$k(j,m,0)$: the initial m-capital stock;
$q(m,0)$: the initial price of the m-capital stock;

(iii) data to be estimated ($t=1,.....,T$):

$r(t)$: the average rate of return;
$e(i,m,t)$: the proportion of m-component in the unit price of commodity i;
$hh(j,m,t)$: nominal gross m-investment in sector j;
$kk(j,m,t)$: real gross m-investment in sector j;
$k(j,m,t)$: real m-capital stock in sector j;
$p(m,t)$: price of the m-capital service (the rental of the m-capital stock);
$pk(j,m,t)$: the proportion of m-component in the value added originated in sector j and was distributed to capital;
$wl(j,m,t)$: the proportion of m-component in the value added originated in sector j and was distributed to labor;
$vv(i,m,t)$: nominal value-added coefficient of m-component in factor i;
$v(i,j,m,t)$: nominal value-added coefficient of m-component in factor i in sector j.

To evaluate the H- and Z-components of output and investment, we consider the price of investment good $q(m,t)$ and the price of capital service $p(m,t)$. In order to take into account quality improvement in the investment good, we define itys price $q(m,t)$ as the amount of money to be paid for a unit of *productive capacity* of the m-investment good, rather than a *physical* unit. As a consequence of the advancement of information technology, the price of the H-investment good, $q(H,t)$, decreased significantly during the period in question. This is a consequence of two factors: a rapid decrease in the price of information commodities and a rapid improvement in the quality of information commodities.

In order to obtain the price of capital services, $p(m,t)$, we use the following equation (Jorgenson and Griliches [7]):

$$p(m, t)=q(m, t)\{r(t)+d(m, t)\}-\{q(m, t)-q(m, t-1)\}, \tag{3}$$
$$x(K, t)=\sum_j \sum_m \{(q(m, t)(r(t)+d(m))-(q(m, t)-q(m, t-1)))\, k(j, m, t)\}.$$

The first equation of (3) indicates a subjective equilibrium condition of an agent who acquires a unit of m-capital stock and rents it to the user. The left side is the cost of purchasing a unit of the m-capital stock. The first term on the right side is equal to the interest cost and the depreciation allowance, whereas the second term is equal to the capital loss (i.e., the negative of the increase in the price of capital stock). The equality between the left and right sides implies that the marginal net revenue from purchasing and renting a unit of the m-capital stock is equal to zero, a necessary condition for equilibrium. The average rate of return, $r(t)$, is calculated by solving the second equation for r, which states that the return to the owner of the entire capital stock is equal to the total profits.

To decompose the output price into two, we first calculate the proportion of each component in the value added of sector j distributed to capital and labor:

$$wl(j, m, t)=w(m, t)\, l(j, m, t)/\sum_n w(n, t)\, l(j, n, t), \tag{4}$$

$$pk\ (j,\ m,\ t) = p\ (m,\ t)\ k\ (j,\ m,\ t) / \sum_n p\ (n,\ t)\ k\ (j,\ n,\ t).^7 \tag{5}$$

Further, we need to decompose the value-added coefficients. As indicated in the following equations, (6) and (7), we calculate the value added coefficients $v(i,j,m,t)$ by dividing the coefficients $v(L,j,t)$ and $v(K,j,t)$, using the results from equations (4) and (5).

$$v\ (L,\ j,\ m,\ t) = wl\ (j,\ m,\ t)\ v\ (L,\ j,\ t), \tag{6}$$
$$v\ (K,\ j,\ m,\ t) = pk\ (j,\ m,\ t)\ v\ (K,\ j,\ t),$$
$$v\ (R,\ H,\ H,\ t) = v\ (R,\ H,\ t), \tag{7}$$
$$v\ (R,\ H,\ Z,\ t) = 0,$$
$$v\ (R,\ Z,\ H,\ t) = 0,$$
$$v\ (R,\ Z,\ Z,\ t) = v\ (R,\ Z,\ t).$$

Equation (6) is used to decompose, e.g., the wage coefficient of the j-sector, $v(L,j,t)$, into $v(L,j,H,t)$ and $v(L,j,Z,t)$, $j = \mathrm{H,Z}$.[8] As is seen from equation (7), we make a special assumption regarding the value-added coefficients for the research and development expenditure. We assume that the entire research and development value added in the H-sector is composed of the H-component, whereas the one in the Z-sector is composed of the Z-component.[9]

We next proceed to calculate the proportion of H- and Z-components in the unit price of the commodity produced in each sector. To do this, we use the value-added price version of the Leontief input-output model with the input coefficients $a(i,j,t)$ and the value-added coefficients $v(i,j,t)$ and $v(i,j,m,t)$, all defined in nominal terms. Furthermore, we define the unit of each commodity to be that quantity of the commodity which can be purchased for a unit amount of money; accordingly, the price of each commodity is equal to one.

To explain, we start with the following equation:

$$\sum_i a\ (i,\ j,\ t) + \sum_i \sum_m v\ (i,\ j,\ m,\ t) = 1, \tag{8}$$

which states that the total cost of producing a unit amount of commodity i is equal to its price. The first term on the left side is the cost arising from intermediate inputs, whereas the second term is the total value added. The right side of this equation is simply the price of this commodity, as stated above. It is noted that the first term contains two input coefficients, whereas the second term has six value-added coefficients. Let us next define new value-added coefficients by

$$vv\ (j,\ m,\ t) = \sum_i v\ (i,\ j,\ m,\ t). \tag{9}$$

[7]Note that $wl\ (j,\ H,\ t) + wl\ (j,\ Z,\ t) = 1$ and $pk\ (j,\ H,\ t) + pk\ (j,\ Z,\ t) = 1$. Also note that the variables $k\ (j,\ m,\ t)$ and $l\ (j,\ m,\ t)$ stand forproductive factors in which quality changes are taken into consideration. Take the labor force, for example. When the number of workers and length of the workweek are unchanged but the quality of the labor service is improved, the labor input 1, $(j,\ m,\ t)$, is increased. In other words, an improvement in the quality of labor service is considered to be equivalent to an increase in the number of workers, or to an increase in length ofthe workweek, without a quality change.

[8]Observerve that, equations (4), (5), and (6) are a device to calculate $v\ (L,\ j,\ m)$ and $v\ (K,\ j,\ m)$ without having nominal value consistent with price and stock data.

[9]In fact, equation (7) 'defines' the two sectors H and Z; the H-sector is defined to be the collection of productive activities with the research and development expenditure devoted solely to the production of the H-component, and the Z-sector is simply the collection of the rest of the economy.

By using (9), equation (8) reads

$$\sum_i a\ (i,\ j,\ t) + \sum_m vv\ (j,\ m,\ t) = 1. \tag{10}$$

We manipulate equation (10), obtaining

$$\sum_i e\ (i,\ t)\ [\mathrm{D}\ (i,\ j) - a\ (i,\ j,\ t)] = \sum_m vv\ (j,\ m,\ t), \tag{11}$$

$$e\ (j,\ t) = \sum_n (\sum_m vv\ (n,\ m,\ t))\ aa\ (n,\ j,\ t), \tag{12}$$

where $aa(n,j,t)$ is the (n,j)-element of the inverse of matrix (I-A), A is a 2×2 matrix of which the typical element is $a(i,j,t)$, $e(i,t)=1(i=\mathrm{H,Z})$, and $\mathrm{D}(i,j)$ is the Kronecker delta, so that $\mathrm{D}(i,i)=1$, $\mathrm{D}(i,j)=0(i\neq j)$.

The variable $e(j,m,t)$ stands for the proportion of the m-component in the unit price of commodity j. We define this by the following equation:

$$e\ (j,\ m,\ t) = \sum_n vv\ (n,\ m,\ t)\ aa\ (n,\ j,\ t), \tag{13}$$

where

$$\sum_m e\ (j,\ m,\ t) = e\ (j,\ t) = 1, \tag{14}$$

as is derived from equations (12) and (13). Equation (12) states that the price of the commodity, which is equal to unity as assumed above, may be obtained from the value-added coefficient $vv(j,m,t)$ by adding up the direct and indirect cost elements. Observe that the additive operations performed on the right side of equation (12) can be divided into two steps, of which the first is used in equation (13) to define the price composition coefficient, $e(j,m,t)$.

The next step is to calculate the real investment and the real capital stock of each component in each sector. Note that the investment coefficient $b(i,j,t)$ stands for the proportion of the nominal investment of output i directed to the capital accumulation in sector j to the total production of nominal investment in sector i; accordingly,

$$\sum_j b\ (i,\ j,\ t) = 1. \tag{15}$$

The gross nominal m-investment, $hh(j,m,t)$, is computed from the nominal investment of commodity $i, h(i,t)$, by using the coefficients $e(m,i,t)$ and $b(i,j,t)$:

$$hh\ (j,\ m,\ t) = \sum_i b\ (i,\ j,\ t)\ e\ (i,\ m,\ t)\ h\ (i,\ t). \tag{16}$$

The real gross investment, $kk(j,m,t)$, is obtained by applying the deflator $p(m,t)$:

$$kk\ (j,\ m,\ t) = hh\ (j,\ m,\ t)/p\ (m,\ t). \tag{17}$$

Now, the real capital stock at the beginning of the following period, $k(j,m,t1)$, may be obtained by

$$k\ (j,\ m,\ t+1) = (1.0 - d\ (m,\ t))\ k\ (j,\ m,\ t) + kk\ (j,\ m,\ t), \tag{18}$$
$$(j=\mathrm{H,\ Z};\ m=\mathrm{H,\ Z};\ t=1,\ \ldots.,\ \mathrm{T}).$$

All of the steps explained above are designed in such a way that, starting from the real capital stock at the beginning of period $t, k(j,m,t)$, we perform a number of operations to end up with the real capital stock at the beginning of the following period, $k(j,m,t+1)$. Therefore, if we are given data for the exogenous variables, the initial capital stock, $k(j,m,0)$, and the initial price of investment good, $q(m,0)$(i.e., the variables in (i) and (ii) as defined above), then we shall be able to compute all variables in (iii).

The objective of the computation explained in this section is to obtain a time series of the real capital stock for sectors H and Z and for components H and Z; i.e., to obtain four series of the real capital stock. To do this, we used the Leontief price model for calculating the cost of each commodity to obtain H- and Z-components, and derived the nominal investment for each of the two components distributed into each of the two sectors, H and Z. We then obtained the real capital stock from the real investment data. We call this procedure the 'H-capital accounting.'

4. Description of the Data

This section gives a brief description of the exogenous data which were used to generate time series of the H- and Z-components of the produced good, the capital stock, and the labor input. A detailed explanation of the source of the data and the way we handled them are given in an appendix to be published separately. Definitions of the exogenous data were stated in (2) of the preceding section. Below, to explain the source of the exogenous data, we follow the order in which the variables are listed in (2).

4.1. Time Period

We used annual data for the Japanese economy from 1973 to 1985. The year 1973 was taken to be the initial period ($t=0$), so that we have a sample period of 12 years, from 1974 to 1985. The development of new information technology was accelerated after 1985; its contribution to the growth of the Japanese economy should be much higher after 1985 than during the sample period. Lack of input-output tables after 1985 precluded us from considering a period beyond the year 1985.

4.2. Sectors

As is explained in the preceding section, we used a two-sectoral framework of the aggregate Japanese economy to estimate the contribution of new information technology. The first sector, the H-sector, is defined to be a collection of industries which are heavily driven by such technology. From the industries in the endogenous sector of the Japanese input-output tables, we selected the computer industry, the semi-conductor industry, the telecommunications industry, the information service industry, and other related industries, to form the H-sector. All of the remaining industries in the endogenous sector, except the research and development industry, are aggregated into the Z-sector. It is noted that our definition of the H-sector is one of the narrowest of this kind; for instance, we excluded from the H-sector the machinery industry, which produces NC-machines and robots.

4.3. Input-Output and Value-added Coefficients

Input-output coefficients ($a(i,j,t)$) and value-added coefficients ($v(i,j,t)$) are obtained by aggregating input-output tables of the Japanese economy.[10] Observe that the input-output matrix

[10]See Applied Research Institute [1] and Ministry of International Trade and Industry [8].

is $2\times 2(i=\mathrm{H,Z}; j=\mathrm{H,Z})$, whereas the value-added matrix is 4×2 ($i=\mathrm{K,L,R}$, and the other primary inputs; $j=\mathrm{H,Z}$). It is noted that a fourth factor (the other primary inputs) appears in addition to the three primary factors mentioned in the preceding section ($i=\mathrm{K,L,R}$). The additional input is composed of non-household consumption (producers' consumption spending not related to their production activities) and indirect taxes minus subsidies. The data for the research and development expenditures are obtained by transferring the research and development industry from the jendogenous sector to the exogenous sector.

4.4. Nominal Investment and Investment Coefficients

Nominal investment of commodity $i(h(i,t))(i=\mathrm{H,Z})$, a component of final demand, is obtained from the input-output tables. Further, the investment coefficients ($b(i,j,t)$) is estimated by the authors from capital stock data.

4.5. Price Indexes and the Rate of Depreciation

As is explained in the preceding section, our strategy is to divide the nominal cost of a produced good into H- and Z-components and to obtain the 'real' value of each component by deflating the nominal value by using a price index. To do this, we need a price index for each of the H- and Z-components. We use the imputed deflator of the gross national product as the price index of the Z-component ($q(\mathrm{Z},t)$). On the other hand, the price index of the H-component ($q(\mathrm{H},t)$) was constructed from a conventional price index and certain quality indicators, as is explained below.

The price index of a manufactured good does not consider improvement in the quality of the good. The wholesale price index of, say, electronic devices is obtained by aggregating the nominal price in each year of those products classified as electronic devices (i.e., the basket). Consider TV sets, for example. The quality of TV sets was constantly improved during recent years. However, as long as TV sets are classified as an item of electronic devices, i.e., as long as TV sets remain as an item in the basket of electronic devices, the current nominal price of TV sets is used to produce the price index of the electronic products without considering the improvement in the quality of TV sets. Therefore, improvement in the quality of TV sets is not represented by the price index of electronic devices. (This would be avoided if we could revise the commodity classification so that TV sets of high quality were distinguished from TV sets of low quality, but this was impossible because of the lack of data.)

Thus, during the perriod 1982 to 1986, the nominal price of a TV set in Japan decreased by 13%, according to the report on the wholesale price index published by the Bank of Japan.[11] In fact, however, tremendous quality improvements were achieved during this period; intuitively, the impact of these quality changes far exceeded that of the decrease in the nominal price. In short, the price index reported in official statistics does not consider quality improvements and, for our purpose, is not of much value.

For this reason, we estimated our own price index of the H-component from the price of computers; we did this by adjusting the nominal price of mainframe computers by means of a hedonic-index method. In particular, we regressed the nominal price of newly leased mainframe computers on two quality indicators, the speed of CPU and the memory size, as well as a time trend:

$$\log(\mathrm{P}) = 13.635 + \underset{(239.3)}{0.5813} \log(\mathrm{MIPS}) + 0.4187 \log(\mathrm{KB}) - \underset{(668.6)}{0.1913}\, t, \tag{19}$$

$$R^2 = 0.92,\ \mathrm{SE} = 0.56,$$

[11]See Bank of Japan [2].

where P stands for the nominal price of new computers, MIPS (million instructions per second) for the speed of CPU, KB (kilobytes) for the size of memory, t for the time period, and log(.) for the natural logarithmic function. T-values of estimates are shown in parentheses.[12] It is seen that the price of new computers with quality held constant decreased at an annual rate of 19%. We set the price $q(\mathrm{H},t)$ by

$$q\,(\mathrm{H},\ t) = \mathrm{Q}_0 e^{-0.1913t}, \tag{20}$$

where Q_0 denotes the base-year price.

The price index of the H- and Z-components is included in Table 1 and Figure 3. It is immediately seen that, whereas the Z-price increased steadily during this period (the average annual rate of change being 3.5%), the H-price decreased tremendously. The ratio of the 1973 to the 1985 H-price is as high as 30. In other words, an amount of 1000 yen spent on the H-product in 1985 is, in effect, 30 times greater than the same amount of money spent on the H-product in 1973. We consider this to be a major source of economic growth due to the advancement of new information technology.

4.6. The Rate of Capital Depreciation

The difference in technological progress and that in price reduction between the H- and Z-components is related to the rate of depreciation of each type of capital stock, as is demonstrated by equation (3). Since no systematic data for depreciation of each component is available (data available from financial reports are useless because they are based on taxation rules, not economic or engineering facts), we assumed that, on average, the length of time for a product to depreciate to 10% of the original value is 12 years for the Z-component and 6 years for the H-component. The corresponding rate of depreciation is equal to 7% and 15% per year, respectively, for the Z- and H-components. The reason that the H-product depreciates much faster than the Z-product is that, because of rapid technological progress and competition, the H-product becomes obsolete a few years after it is purchased, even though it is still usable.

4.7. Labor Input and the Wage Rate

The most difficult problem in preparing data for our work arises when a definition of H- and Z-components of the labor input is to be chosen. It is intuitively clear that, at each step of production (e.g., automobile assembly), a part of labor service (that for operating and maintaining assembly robots) is combined with H-type capital equipment (robots) to produce an output with H-component (automobiles assembled with robots, as distinct from automobiles assembled manually). During the process in which new information technology is adopted, the quality of the labor service is improved through education, training, and learning; the H-component of labor input is increased accordingly. It is not straightforward, however, to give a definition in which labor input may be classified into one of the H- and Z-components. Since the "production of human capital" is not included in the input-output relation of this model, the labor input cannot be divided in the same way as is the capital stock. We need to use some proxy to represent the H- and the Z-components of the labor input. In fact, there are several ways of defining H- and Z-components of labor, and the final results depend significantly on the choice made.

For this reason, we consider three alternative definitions of H- and Z-components of the labor

[12]Equation (19) was estimated with the assumption of linear homogenity; the coefficient of log (KB) is the difference of 1.0 and the coefficient of log (MIPS).

input, and these correspond to three models, called Models A, B, and C.

In Model A, we assume that all labor input is composed of the Z-component only; we assume away the H-component entirely from the labor input. This means that the research and development is the only source of the H-component and the contribution of new information technology is achieved solely through improving the quality of the capital stock. Thus, this model gives a lower bound to the estimate of the contribution of new information technology.

In Model B, wages and salaries are divided into H- and Z-components according to the job content of workers; wages paid to system engineers, programmers, machine operators, and keypunchers are classified as being composed of the H-component only. This presumes that computer operation requires new skills to be obtained from education and training. In this model, we assume, in effect, that the labor input of H-type workers is indispensable for the H-capital to be productive. The cost of the H-capital and the H-labor becomes, in parallel, a part of the H-component of the price of the commodity.

Model C is the same as Model B except that the range of the H-type worker is taken to be much greater than in Model B. In Model B, the H-type worker is a computer specialist. In Model C, a part of nonspecialist labor is also included in the H-component. We consider the hours of office workers devoted to handling informational devices as the H-component of labor input. For this, we used data collected by the Japan Office Automation Association.[13] This study reports data on the hours that clerical and office workers spent in handling general purpose computers, office computers, personal computers, wordprocessors, and on-line terminal equipment. We may state that the effects of office automation is taken into consideration in this model.

5. Findings

In this section, we briefly present the results we obtained from the model explained in section 3 and the data explained in section 4. Because of the limitation of space, we will not show here all the results we calculated; we have selected time series which are useful for us to understand the relative magnitudes of the two sectors, and the differences in the rate of growth of the two components, during the period 1974-85.

First of all, the price of the capital service of each component, $p(m,t)$, is calculated from the price of the investment good, i.e., the price of the newly produced good, q(m,t). The price data are shown in Table 1 and are depicted in Figure 3. It is seen that the price of the Z-component increased slowly during the period 1973-85 at the rate of 2% each year. On the other hand, the price of the H-component decreased at the rate of 32% each year, which means that the price became approximately one-thirtieth at the end of the 12-year period. In other words, because of the progress in new information technology in Japan during this period, the efficiency of the H-component in 1985 is 32-times greater than that in 1973.

Next, by using the price of capital services, we divide the value-added generated by the capital stock into H- and Z-components for each year of this period, as shown in equation (4). The value-added generated by labor is divided into the two components by means of equation (5). As explained in the preceding section, however, we considered three alternative definitions to do this and, hence, we obtained three alternative results in decomposing the produced good and the capital stock.

Tables 2A, 2B, and 2C show the decomposition of a produced good in the H- and Z-sectors into the two components for Models A, B, and C, respectively. In Model A, where the contribution

[13]See Japan Office Automation Association [6].

Table 1 Price Index of H- and Z-Components (1980 = 1.00)

	Price (H)	Price (Z)
1973	3.2877	0.9044
1974	3.3487	0.8204
1975	1.5839	0.8212
1976	1.6605	0.8848
1977	1.9037	0.9317
1978	1.0954	1.0222
1979	1.5105	1.0188
1980	1.0000	1.0000
1981	0.3627	1.0204
1982	0.2081	1.0294
1983	0.2689	1.0391
1984	0.2214	1.0896
1985	0.1176	1.1496

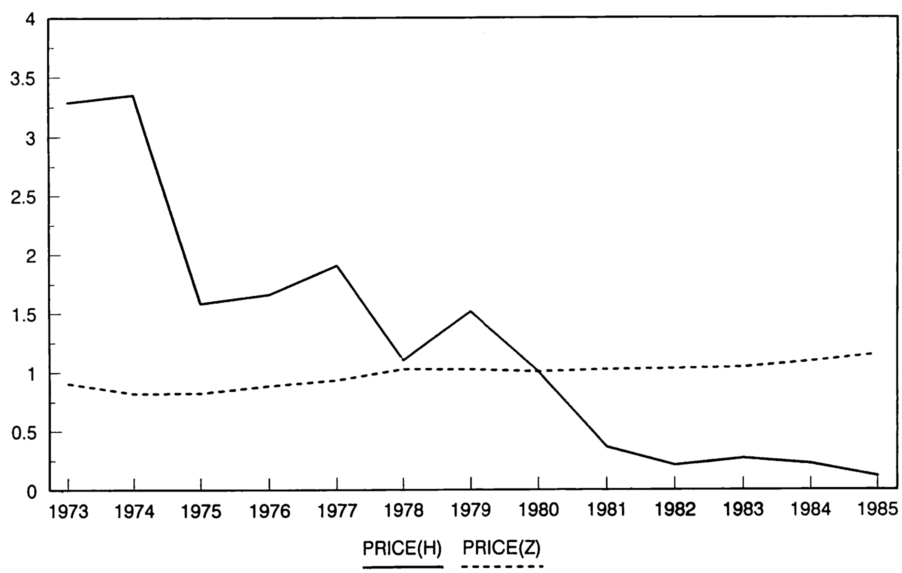

Figure 3 Price Index of H- and Z-Components (1980 = 1.00)

of the H-type labor is defined to be minimal (i.e., zero), most of the cost of the produced good in the H- and Z-sectors is composed of the Z-component. On average, the H-component occupies 2.9% in the H-good, and only 0.2% in the Z-good, as seen from Table 2A.

Table 2B summarizes the results obtained for Model B, in which the contribution of the H-type labor is considered from those who are professionals in computers and communications. The weight of the H-component for this case is calculated, on average during the period 1973-85, to be 7.4% in the H-good and 1.2% in the Z-good.

The results obtained for Model C, in which the contribution of the H-type labor comes not only from information professionals but also from nonprofessionals in information during the period they work with the H-type equipment like personal computers and wordprocessors, are shown in Table 2C. For this model, the H-component is calculated, on average, to be 8.2% of the H-good and 2.5% of the Z-good.

Table 2A Composition of a Unit Price of a Commodity (Model A)

	E(H, H)	E(Z, H)	E(H, Z)	E(Z, Z)
1973	0.0230	0.9770	0.0009	0.9991
1974	0.0251	0.9749	0.0014	0.9986
1975	0.0292	0.9708	0.0016	0.9984
1976	0.0259	0.9741	0.0018	0.9982
1977	0.0275	0.9725	0.0020	0.9980
1978	0.0280	0.9720	0.0018	0.9982
1979	0.0293	0.9707	0.0023	0.9977
1980	0.0316	0.9684	0.0025	0.9975
1981	0.0314	0.9686	0.0022	0.9978
1982	0.0312	0.9688	0.0023	0.9977
1983	0.0318	0.9682	0.0030	0.9970
1984	0.0320	0.9647	0.0032	0.9900
1985	0.0314	0.9618	0.0029	0.9833
AVR	0.0290	0.9702	0.0021	0.9963

[E(m, j) = the proportion of m-component in good j]

Table 2B Composition of a Unit Price of a Commodity (Model B)

	E(H, H)	E(Z, H)	E(H, Z)	E(Z, Z)
1973	0.0517	0.9483	0.0053	0.9947
1974	0.0619	0.9381	0.0077	0.9923
1975	0.0708	0.9292	0.0085	0.9915
1976	0.0706	0.9294	0.0097	0.9903
1977	0.0725	0.9275	0.0111	0.9889
1978	0.0739	0.9261	0.0104	0.9896
1979	0.0754	0.9246	0.0130	0.9870
1980	0.0754	0.9246	0.0139	0.9861
1981	0.0765	0.9235	0.0126	0.9874
1982	0.0781	0.9219	0.0126	0.9874
1983	0.0828	0.9172	0.0151	0.9849
1984	0.0851	0.9116	0.0159	0.9774
1985	0.0846	0.9086	0.0144	0.9718
AVR	0.0738	0.9254	0.0116	0.9869

[E(m, j) = the proportion of m-component in good j]

Table 2C Composition of a Unit Price of a Commodity (Model C)

	E(H, H)	E(Z, H)	E(H, Z)	E(Z, Z)
1973	0.0517	0.9483	0.0053	0.9947
1974	0.0626	0.9374	0.0092	0.9908
1975	0.0725	0.9275	0.0124	0.9876
1976	0.0734	0.9266	0.0159	0.9841
1977	0.0774	0.9226	0.0200	0.9800
1978	0.0798	0.9203	0.0211	0.9789
1979	0.0844	0.9156	0.0274	0.9726
1980	0.0873	0.9127	0.0315	0.9685
1981	0.0886	0.9114	0.0312	0.9688
1982	0.0907	0.9093	0.0329	0.9671
1983	0.0989	0.9011	0.0399	0.9602
1984	0.1020	0.8947	0.0418	0.9514
1985	0.0992	0.8940	0.0381	0.9481
AVR	0.0822	0.9170	0.0251	0.9733

[E(m, j) = the proportion of m-component in good j]

The annual investment in nominal terms from the two sectors, $h(i,t)$, is rearranged into the gross nominal m-investment $hh(j,n,t)$, by using equation (16). The real gross investment $kk(j,m,t)$ is then calculated from equation (17).

The real capital stock divided into H- and Z-components for each of the H- and Z-sectors is obtained by equation (18). The results are given in Tables 3A, 3B, and 3C, corresponding to Models A, B, and C, respectively. Graphs for the capital stock are given in Figures 4A, 4B, and 4C.

It is seen that, for the three Models, A, B, and C, the Z-component of the capital stock in 1980 yen increased approximately 70% during the period 1973-85. The Z-component of the capital stock is less for Model B than for Model A, and it is also less for Model C than for Models A and B, but only slightly. The H-component of the capital stock in 1973 is almost zero because we assumed that the initial value of this capital stock at the end of the year 1972 is zero. The rate of growth of these data for the period 1973-85 differ greatly between Models A, B, and C, because, in Model A, the source of the H-component is limited to the research and development expenditures in the H-sector, whereas in Models B and C, the H-component is generated not only

Table 3A Capital Stock (H, Z) in Trillion Yen (Model A)

	Capital (H)	Capital (Z)
1973	0.05	243.32
1974	0.14	259.37
1975	0.22	271.79
1976	0.29	284.21
1977	0.44	298.75
1978	0.59	317.02
1979	1.03	337.47
1980	2.22	354.35
1981	3.64	371.24
1982	4.81	385.87
1983	6.80	396.54
1984	9.81	407.01
1985	11.61	417.80

Table 3B Capital Stock (H, Z) in Trillion Yen (Model B)

	Capital (H)	Capital (Z)
1973	0.23	243.03
1974	0.60	258.75
1975	0.92	270.86
1976	1.28	282.96
1977	1.99	297.12
1978	2.66	315.03
1979	4.73	334.99
1980	9.82	351.38
1981	15.46	367.87
1982	19.85	382.13
1983	27.41	392.35
1984	38.80	402.37
1985	45.68	412.80

Table 3C Capital Stock (H, Z) in Trillion Yen (Model C)

	Capital (H)	Capital (Z)
1973	0.23	243.03
1974	0.67	258.68
1975	1.14	270.62
1976	1.78	282.45
1977	3.07	296.21
1978	4.47	313.63
1979	8.66	332.88
1980	19.24	348.48
1981	31.57	364.18
1982	41.69	377.65
1983	58.90	386.97
1984	84.31	396.08
1985	98.86	405.83

by the research and development expenditure but also by the H-type labor. In Model A, the H-component of the capital stock at the end of 1985 is less than 1/40 of the Z-component, while in Model C, it is close to 1/4 of the Z-component.

It is seen that the H-capital stock rose significantly in constant prices relative to that in current prices. As is stated previously, this indicates the rapid progress in new information technology expressed by quantitative increases in the capital stock measured in constant prices. One can say that the model is used to convert the progress of new information technology, a qualitative phenomenon, into the increase in the H-capital stock, a quantitative indicator.

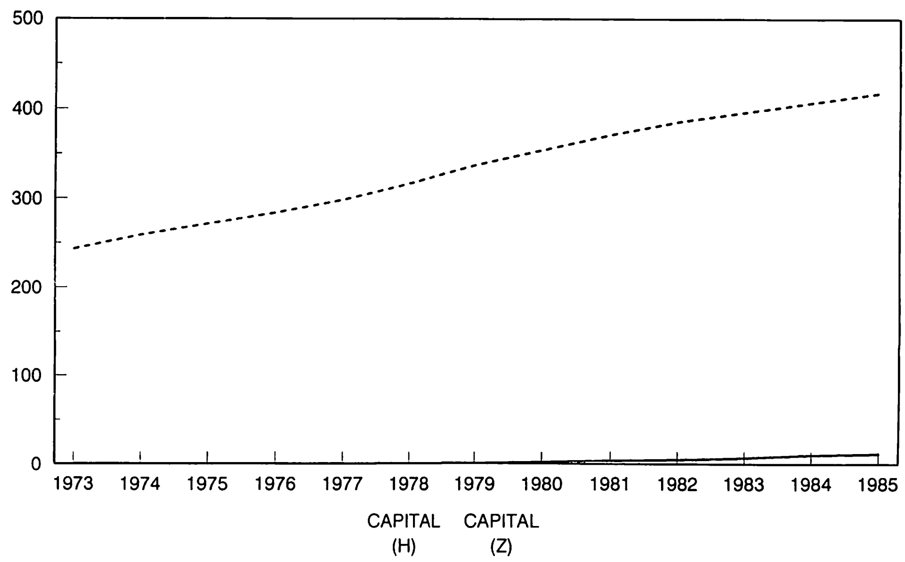

Figure 4A Capital Stock (H, Z) in Trillion Yen (Model A)

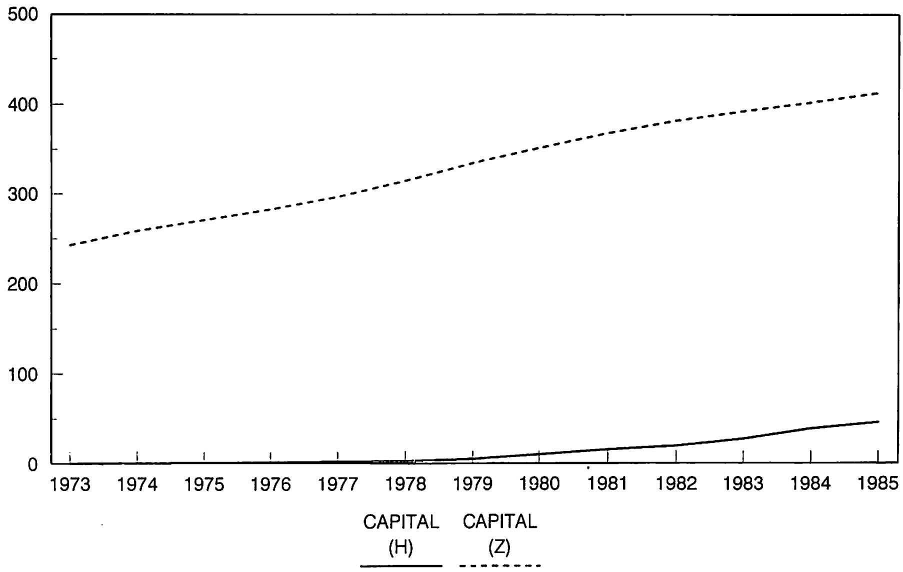

Figure 4B Capital Stock (H, Z) in Trillion Yen (Model B)

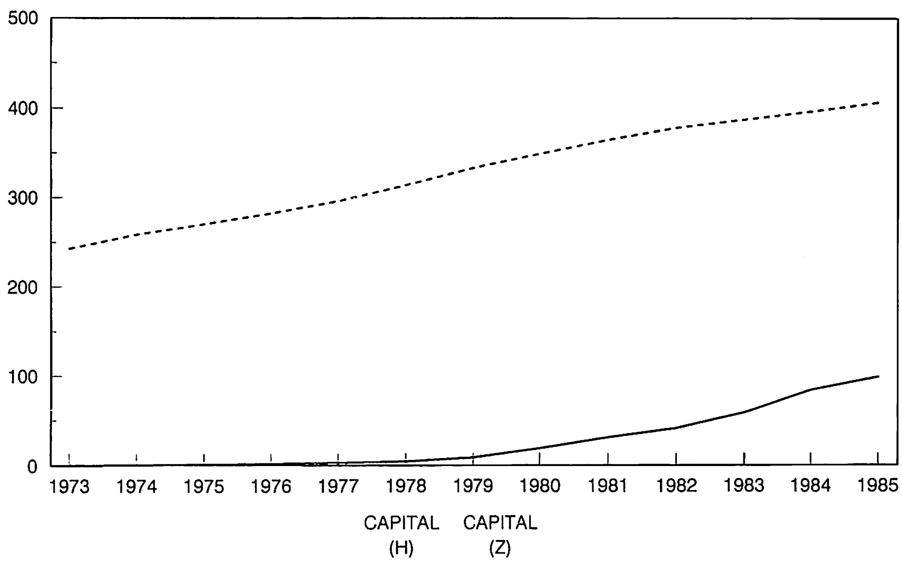

Figure 4C Capital Stock (H, Z) in Trillion Yen (Model C)

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