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Abstract

Concerns over the rise in the vintage of capital in the Japanese economy have focused attention on the technological progress embodied in capital. In this paper, we derive the theoretical relationship between the rate of technological progress embodied in capital, the obsolescence rate of capital, and the average vintage of capital, then we estimate these rates by using firm-level panel data from the Ministry of Economy, Trade and Industry (METI) Basic Survey of Japanese Business Structure and Activities in the period between 1997 and 2002.

To measure the obsolescence rate of capital by estimating the production function, it is necessary to construct a capital stock series that takes only physical depreciation into account for each vintage capital held by each firm. To do that, we prepared industry-specific patterns of the physical depreciation ratio of capital goods, based on the pattern of the physical depreciation ratio of each type of capital goods by obtaining information from the U.S. Bureau of Labor Statistics (BLS), and the Japan Industrial Productivity Database (JIP) 2006's investment matrices cross-classified by types of capital goods and industries. We applied these industry-specific patterns of the physical depreciation ratio of capital goods to the individual firms' investment series, constructing a capital stock series in each firm.

We measured the obsolescence rate by estimating the production function, which is similar to the one employed in Sakellaris and Wilson (2004). We added several control variables to their equations. The estimated obsolescence rate of machinery and equipment is found to be between 8 and 22 percent per annum, which is very close to the estimated ratios in other previous research using the production function. This estimation result implies that the average rate of technological progress embodied in machinery and equipment is between 0.2 and 0.4 percent in Japan. The average vintage of capital in the manufacturing industry in the 1990s was estimated to increase by almost two years, because of weak investment during that decade, and it has the effect of lowering the rate of productivity growth in the industry by 0.4 to 0.8 percentage points.

Keywords: Quality of capital, Vintage, Productivity, Panel data
JEL Classification: C33, D24, O33

1 Introduction

The idea that most technological progress is embodied in new capital equipment, and that the benefit of new technology is not realized without introducing new capital equipment, has attracted the interest of researchers as a practical way of treating capital since it was proposed by Johansen (1959) and Solow (1960). More recently, as information technology (IT) capital has drawn increasing attention, this idea has often been revisited. This is partly because the majority of benefits arising from IT are realized only by employing the latest machinery. Taking personal computers (PCs) as an example, while new PCs produced in 2007 certainly perform much better than those produced in 2000, regardless of the type of PC, there is no way of enjoying the technological benefits they bring without buying and using a new one.

This idea may be of great importance, especially for the Japanese economy. As a result of weak investment during the so-called "lost decade" of the 1990s, the replacement of old capital equipment with new equipment has not progressed far enough; not only in terms of IT capital, but also in terms of other types of capital. This explains why some are concerned about the rise in the average vintage of capital.[1] We find such concerns in the "New Strategy for Economic Growth" report issued by the Industrial Structure Council of the Japanese government. In this report, the Council points out the necessity for changing the tax treatment of capital depreciation in accordance with up-to-date technologies. To evaluate the importance of this issue, it is important to measure the potential magnitude of the technological progress embodied in capital in the Japanese economy, and to clarify the relationship between the technological progress actually realized and the amount of new investment.

In addition to such policy-oriented issues, this research is relevant to the measurement of capital and total factor productivity (TFP). In estimating capital stock, it is very important to set a value for the economic depreciation rate, which is the sum of the physical deterioration rate and the obsolescence rate. Most researchers use the value of the economic depreciation ratio, estimated using price information from the second-hand market for equipment and machinery.[2] One way of checking the accuracy of this estimated rate is to use a different estimation method.

As described in section 2, the rate of technological progress embodied in capital is closely related to the obsolescence rate of capital. Therefore, when this rate of capital is not sufficiently reflected in the measurement of capital stock, the rise in the measure of TFP includes the effect of technological progress embodied in capital.

In addition, as explained in detail in section 2, while the extent to which embodied

[1] Miyagawa and Hamagata (2006) and Gittleman, et al. (2006) are recent papers based on this point of view.
[2] Kuninori (1988) surveyed topics related to economic depreciation and measured the economic depreciation rate of construction equipment using price data from the second-hand market.

technological progress is realized may be thought to be the mere result of exogenous technological progress, it is endogenous in the sense that it depends on the volume of new investment. In this case, if one tries to observe the relationship between R&D investment and productivity, the effect of R&D depends on how much or how often new investment in equipment and machinery is carried out, because the new technology obtained through R&D is often embodied in new equipment and machinery.

In most of the previous literature, two methods have been proposed to measure the rate of embodied technological progress. One of these methods focuses on the difference between two types of capital goods price index, namely, that formulated by Gordon (1990), which takes improvement in the quality of capital goods into account, and the traditional price indexes. Research based on this method includes Hulten (1992), Hornstein and Krusell (1996), Greenwood, Hercowitz, and Krusell (1997), and Cummins and Violante (2002).

The second method measures the rate by estimating the production function. Bahk and Gort (1993) and Sakellaris and Wilson (2004) are recent examples of this method. This paper adopts the production function method, and is based on the ideas of Sakellaris and Wilson (2004). In the estimation, we have added firm characteristic variables such as firm age, brand stock constructed with past advertising expenditure, knowledge stock estimated with past R&D expenditure, and dummies of the investment spike period, in addition to the variables used in Sakellaris and Wilson (2004). Firm age and brand stock are used to control for the intangible capital accumulated in each firm. The investment spike is the variable used to capture the effect of large-scale investment in each firm. This reflects the idea that discontinuous technological progress takes place when large-scale investment is made.

The rest of this paper is organized as follows. In section 2, the relationship among the technological progress embodied in capital, capital stock in efficiency unit, and the average vintage of capital are elucidated, and the relationship between the extent to which the technological progress embodied in capital is realized and changes in the average vintage of capital is explained. Section 3 explains how to measure the physical deterioration rate of capital and the average vintage of capital. A description of the data construction of other variables is found in the appendix. Section 4 describes the estimation methods used in this paper and the results obtained. Section 5 concludes the paper.

2 Relationship between Embodied Technological Progress and Average Vintage of Capital

This section explains that when technological progress is embodied in capital it is necessary to measure the capital stock in efficiency unit in which improvement in the quality of capital is reflected.[3] This section also explains the relationship between the rate of technological progress

[3] Both Johansen (1959) and Solow (1960) adopted the idea that technological progress is embodied in capital. Nevertheless, while Johansen (1959) assumed that the capital-labor ratio does not change once capital has been installed, Solow (1960) assumed that the capital-labor ratio can be freely

embodied in capital, the improvement rate in the quality of capital, the obsolescence rate of capital, and the average vintage of capital.

Since old capital reflects a technological level different from that of new capital when technological advances are embodied in the new capital, it is necessary to distinguish between existing capital equipment according to the date (vintage) on which it was installed.

$K_{t,t\text{-}s}$ denotes the quantity of capital stock installed in year t-s that is in service in year t. Gross investment made in year t-s is denoted by $I_{t\text{-}s,}$, is assumed to be deteriorated physically and only part of the investment per unit, D_s, is left in year t. Capital goods are assumed to have a lifespan of T, after which they are taken out of service and discarded. On the basis of these assumptions, the amount of capital of vintage s surviving in year t is written as in equation (1).

$$K_{t,t-s} = I_{t-s} D_s \qquad s=1,\ldots,T. \tag{1}$$

As the first step, the problem of how much labor should be allocated to each vintage of capital is solved. For this purpose, let us consider the firm's profit maximization problem broken down into the production function for each vintage of capital. The amount of labor placed into production with capital $K_{t,t\text{-}s}$ is written as $L_{t,t\text{-}s}$, and the amount of output from these inputs is denoted by $Q_{t,t\text{-}s}$. This relationship is assumed to be a Cobb-Douglas production function with homogeneity of degree 1 as in equation (2),

$$Q_{t,t-s} = B_t (1+\lambda)^{t-s-t_0} L_{t,t-s}^{1-\alpha} K_{t,t-s}^{\alpha} \tag{2}$$

where α is the revenue share of capital, λ denotes the rate of technological progress embodied in the capital, and t_0 is the base year used for measuring embodied technological progress. B_t denotes the technological level that is "not" embodied in the capital, which means the TFP level.[4]

For the sake of simplicity in this discussion, the production function used here takes only labor and capital as input factors. However, the following equations can be derived in the same way using more input factors, such as intermediate inputs.

The outputs and inputs can respectively be aggregated as follows.

$$Q_t = \sum_{s=1}^{T} Q_{t,t-s} \tag{3}$$

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changed during the lifespan of the capital. This paper follows Solow's model.

4 This functional specification does not take the quality of labor into account.

$$L_t = \sum_{s=1}^{T} L_{t,t-s} \tag{4}$$

The firm matches labor input with each vintage of capital input by maximizing the profit that equalizes the real wage rate w_t with the marginal productivity of labor, such that

$$w_t = \frac{\partial Q_{t,t-s}}{\partial L_{t,t-s}} = (1-\alpha)B_t(1+\lambda)^{t-s-t_0} L_{t,t-s}^{-\alpha} K_{t,t-s}^{\alpha} \,. \tag{5}$$

Using equations (1) and (5), one can derive the volume of labor to be allocated to each vintage of capital, which can be aggregated using equation (4) into the labor input for the whole firm, as in equation (6).

$$L_t = h_t \sum_{s=1}^{T} I_{t-s} D_s \left(1+\lambda\right)^{\frac{-s}{\alpha}} \tag{6}$$

Combining the profit maximization condition (6) with equations (1) and (2), one can derive the amount of output from each vintage of capital, which can be aggregated using equation (3) to derive aggregated output, as in equation (7).

$$Q_t = B_t \left(1+\lambda\right)^{t-t_0} h_t^{1-\alpha} \sum_{s=1}^{T} I_{t-s} D_s \left(1+\lambda\right)^{\frac{-s}{\alpha}} \tag{7}$$

where $h_t = \left(\left(1-\alpha\right)B_t\right)^{\frac{1}{\alpha}} w_t^{\frac{-1}{\alpha}} \left(1+\lambda\right)^{\frac{t-t_0}{\alpha}}$.

Equation (7) above can be rewritten as the following equations (8) and (9).

$$Q_t = B_t L_t^{1-\alpha} J_t^{\alpha} \tag{8}$$

$$J_t = \sum_{s=1}^{T} I_{t-s} D_s (1+\lambda)^{\frac{t-s-t_0}{\alpha}} = \sum_{s=1}^{T} I_{t-s} D_s (1+\gamma)^{t-s-t_0} \tag{9}$$

where the second term on the right-hand side of equation (9) is rewritten as $\left(1+\lambda\right)^{\frac{1}{\alpha}} = \left(1+\gamma\right)$.

γ can be interpreted as a rate of quality improvement of capital, and J_t in equation (9) is the sum of the products of the surviving amount of each vintage of capital and the efficiency coefficient, which reflects the quality of capital.[5] Therefore, the term J_t is merely the capital stock in efficiency unit.

Thus, even assuming that technological progress is embodied in capital, if one can measure the capital stock in efficiency unit that reflects the quality improvement in each vintage of capital correctly, then the normal production function can be defined as in equation (8).

When the base year is set to the present year (the last observed year) rather than the earliest year, the efficiency coefficient in equation (9), $(1+\gamma)^{t\text{-}s\text{-}t0}$, is the coefficient that reflects the obsolescence of the existing capital relative to the newest capital with the latest technology, which means that γ can be reinterpreted as the obsolescence rate of old capital. Therefore, if one can measure the economic depreciation rate that reflects both the obsolescence rate and the deterioration rate of capital, the capital stock in efficiency unit defined in equation (9) is directly measurable in efficiency units.

In the capital stock measurement of the Japan Industrial Productivity Database (JIP) 2006[6], the capital stock in efficiency unit is directly measured using the economic depreciation rate used in the U.S. Bureau of Economic Analysis (BEA). In contrast, this paper tries to separate the rate of improvement in capital quality (γ) from economic depreciation, and evaluate the magnitude of technological progress λ. This relation is approximated as $\lambda = \alpha\gamma$, which means that the approximate value of the rate of technological progress embodied in capital can be obtained as a product of the obsolescence rate of capital and its revenue share.

We now turn to the derivation of the relationship between the capital stock in efficiency unit defined in equation (9) and the average vintage of capital.[7] The average vintage of capital defined as V_t in equation (10) is one of the frequently used indicators of average capital quality,

$$V_t = \sum_{s=1}^{T} \frac{sI_{t-s}D_s}{K_t} \qquad (10)$$

where K_t is the simple sum of the remaining physical capital, and is defined in equation (11) below. V_t is therefore the weighted average age of capital, calculated as the ratio of the amount of each vintage of capital to the entire capital stock physically remaining at the present time t.

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[5] Suppose that the rate of improvement in capital quality is denoted by γ, and that capital service from 1 unit of the capital installed in the base year (t_0) is calculated as 1. Capital service from 1 unit of the capital installed $t\text{-}s\text{-}t_0$ years later is therefore calculated as $(1+\gamma)^{t\text{-}s\text{-}t0}$.

[6] Detailed explanation of JIP database 2006 is found in Fukao and Miyagawa (2008).

[7] This relationship is used in Sakellaris and Wilson (2004), but had its origins long before in Nelson (1964). However, in Nelson (1964), quality improvement in capital is not taken into account, and the physical deterioration rate is assumed to be small for the approximation.

$$K_t = \sum_{s=1}^{T} I_{t-s} D_s \tag{11}$$

Where the rate of quality improvement of capital is low, J_t, V_t and K_t have the relationship shown in equation (12) using the approximation equation $(1+\gamma)^{-s} \approx 1-s\gamma$,

$$J_t \approx G(1+\gamma)^t K_t (1-\gamma V_t) \tag{12}$$

where $G = (1+\gamma)^{-t_0}$.

Whether and to what extent the technological progress embodied in capital is realized now depends on whether new investment is actually made in capital equipment that embodies new technology. The rate of realized technological progress embodied in capital can now be measured using equation (12). The rate of technological progress embodied in capital that is realized between t-1 and t, μ, is approximated as in (13).[8]

$$\mu = \alpha\gamma - \alpha\gamma (V_t - V_{t-1}) \tag{13}$$

When the average vintage of capital does not change between the previous year and the current year (i.e., $V_t - V_{t-1} = 0$), it is clear from the equation that the rate of realized technological progress embodied in capital is $\alpha\gamma$, which is the same as the "potential" rate of technological progress explained earlier. If no investment has been made between the previous year and the current year, then the average vintage of capital increases by just 1 year (namely $V_t - V_{t-1} = 1$), which means that the realized rate of technological progress is zero, as is obvious from equation (13).

3 Physical Deterioration and Average Vintage of Capital

For the analysis of this paper, we have constructed panel data of Japanese manufacturing firms based on the Basic Survey of Japanese Business Structure and Activities. The data used in this study are for the period between 1997 through 2002 because data on investments in mechanical apparatus

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8 By taking the logarithms of equation (12) and assuming that γ and γV_t are both small enough, one can approximate the equation as follows: $\log J_t = const. + \log K_t + \gamma t - \gamma V_t$. Since we can define the rate of technological progress realized from the potential progress as "revenue share of capital × (rate of change in J_t – rate of change in K_t)," its rate of change becomes $\alpha\gamma - \alpha\gamma \dot{V}_t$, which is written as equation (13) in a discrete form.

is available only from 1997. This section explains the construction of data of the physical depreciation pattern and average vintage of capital. An explanation of the construction of the other data can be found in the data appendix.

3.1 Physical deterioration pattern of capital

The loss of value in capital equipment that has survived for many years can be divided into the loss of value due to obsolescence in the light of technological progress and physical wastage. Usually, when estimating capital stock using a perpetual inventory method, the economic depreciation rate that simultaneously reflects both physical wear and tear and obsolescence is used. However, for the purposes of this paper, it is necessary to create a capital stock series that takes only physical depreciation into account to allow us to extract the obsolescence rate of capital, or the rate of technological progress embodied in capital, from a production function.[9]

Here, it is assumed that that the physical wear and tear pattern of capital goods is caught by the beta-decay function in equation (14), following Mohr and Gilbert (1996)[10],

$$\Phi_s(k) = \frac{T_k - s}{T_k - \beta s}, \qquad 0 \le s \le T_k \tag{14}$$

where $\Phi_s(k)$ is the survival rate of type k capital goods s-years after their installation. T_k is their average service life, for which value the U.S. BEA estimation for each type of capital goods is applied.[11] β is a curvature parameter, for which the value of 0.75 is adopted.[12] Using equation (14), the pattern of the survival ratio for each type of capital goods is calculated.[13]

Although the survival pattern for each type of capital goods can be created as outlined above, in our firm-level panel data, the composition for every detailed type is not available. However, for

[9] Changes in value due to technological progress are also reflected in the capital (or investment goods) deflator. For this reason, the consumer price index is used in preference to the investment goods price index for the deflation of investment series.

[10] Mohr and Gilbert (1996) distinguish "economic depreciation" from "economic decay." The former term is used to reflect the loss of value in capital goods, whereas the latter term reflects not only the discard but also the decline in production capacity. A beta-decay function is used to capture the "economic decay." In this paper, the terms "physical deterioration" and "physical wear and tear" are used similar to the meaning of "economic decay" of Mohr and Gilbert (1996). For further discussion of deterioration patterns and beta-decay functions, see Nomura (2004).

[11] The values are available in Mohr and Gilbert (1996).

[12] Even in BLS in the U.S., different values are adopted for β, depending on the department concerned. The value for equipment, for example, is either 0.75 or 0.5, depending on the department concerned.

[13] Mohr and Gilbert (1996) and Sakellaris and Wilson (2004) assume that the service life of capital goods is random variables due to such incidents as disasters, accidents, and poor asset construction. This paper applies average service life to each type of capital goods, without taking into account these random events.

industry-level data, the JIP Database 2006 provides us with the composition for 33 types of capital goods in 52 industries[14]. Therefore, we make the assumption that the composition of capital goods types is the same among all firms in the same industry.

First, from the fixed capital formation matrix for each industry taken from the JIP Database 2006, the composition of capital goods types invested in each industry is calculated. Combining this with the survival pattern of each type of capital goods in elapsed years, the survival pattern of total capital in elapsed years is then created for each industry and every investment year. This pattern is then applied to each firm on the assumption that it is common to all firms in the same industry.

The survival pattern classified by elapsed years for each industry is calculated using the following procedure. First, the nominal investment series is deflated by the Consumer Price Index, and this provides us the real investment series cross-classified by the JIP 2006 industry classification and capital goods classification for the period from 1970 through 2002. After applying the survival pattern of each type of capital goods to the real investment series calculated above, the survival pattern of total capital for each industry can be derived by calculating the sum of the survival amount of each type of capital goods for each industry. Let the amount of investment in type k capital goods at time t in the i-th industry be $I_{it}(k)$. After s years of its installment, the survival rate of the investment in the i-th industry carried out at year t is obtained as in equation (15),

$$\frac{\sum_{k=1}^{m} \Phi_s(k) I_{it}(k)}{\sum_{k=1}^{m} I_{it}(k)} \qquad (15)$$

where m is the number of types of capital goods.

Since the composition of types of capital goods invested varies from year to year, the survival pattern calculated above for each industry also changes according to the year in which the investment is made. In this manner, the survival patterns of capital goods in each industry and in each year are calculated from 1970 to 2002.

We now compare the physical depreciation patterns calculated above with that calculated from the fixed rate of economic depreciation used in Hulten and Wykoff (1981). Figure 1 compares the two patterns, which are the arithmetic average of the depreciation patterns for all manufacturing industries.[15]

14 The Japan Industrial Productivity (JIP) Database is provided on the RIETI Web site (http://www.rieti.go.jp/en/database/d05.html). This project is lead by Professor Fukao (Hitotsubashi University) and the authors of this paper are members of the project.

15 The physical survival ratio is calculated on the basis of the composition of capital goods

Since the physical depreciation patterns of capital goods do not reflect the reduction in the value of capital arising from obsolescence, the line indicating physical depreciation patterns is higher than that representing the economic depreciation patterns. Figure 1 shows that it takes approximately 5 years until 50 percent of the value of the capital good is lost when the economic depreciation rate reflecting the obsolescence is used, whereas it takes 12 years if physical depreciation is used instead.

3.2 Average vintage of capital

The average vintage of machinery used in each firm is calculated as in equation (16). The weight used for the average vintage is the physical survival amount of value of each vintage of capital

$$V_t = \frac{\left(V_{t0} + t - t_0 + 1\right) \cdot K_{t0}^b + \left(t - t_0 + 1\right) \cdot I_{t0} D_{t-t0} + \cdots 3 \cdot I_{t-2} D_2 + 2 \cdot I_{t-1} D_1 + 1 \cdot I_t D_0}{K_{t0}^b + I_{t0} D_{t-t0} + \cdots + I_{t-2} D_2 + I_{t-1} D_1 + I_t D_0} \quad (16)$$

in which t_0 is the base year. Multiplying I_t, the investment made at time t, by the survival ratio, Ds, gives the amount of capital that has physically survived amount value for each vintage.
K^b_{t0} is the amount of capital that has physically survived in the base year t_0, and is obtained by multiplying the book value of net capital in the base year by the market to book value ratio of net capital.[16] V_{t0} is the vintage year of the capital stock in the base year t_0.

The main data set used in this paper is from the Basic Survey of Japanese Business Structure and Activities. Given that it is only since 1997 that investment in machinery has been surveyed as a separate category from the total amount of capital as a whole, the issue of how the average vintage of capital in the base year is estimated for firms established before 1996 is a problem. As a solution to this problem, the data series of the average vintage of capital for each industry are calculated using the information from JIP 2006, which are applied to each firm according to the industry in which it is classified and its foundation year.

As we have the real investment series cross-classified by industries and types of capital goods since 1970, from JIP 2006, the industrial average survival values for each vintage of capital can be obtained starting from any year between 1970 and 1996 by applying the investment patterns and the composition of capital goods types in each industry. For firms founded between 1970 and 1996, we use this information to construct each firm's vintage of capital in the base year t_0 allowing for its foundation year and its industry classification. Although this method cannot be applied to firms founded before 1970, for the sake of simplicity it is assumed that firms founded before 1970 have

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investments made in 1990.

16 More detailed explanation of the estimation of the amount of capital stock is in the Appendix.

the same base year vintage of capital as firms founded in 1970.[17] For example, for a company founded in 1975 for which data is available only from 1997, the average vintage value for 1996, which is estimated using industry data from 1975 onward, is applied as the average vintage of capital at the beginning of 1997.

Figure 2 shows the distribution of the average vintage of capital of firms classified in the steel industry, electronic parts industry, and manufacturing sector as a whole. It can be seen that the average vintage of capital in the electronic parts industry is generally distributed around a lower year than in the manufacturing sector as a whole, and that the average vintage of capital in the steel industry is distributed around a higher year. In addition, there are variations in the average vintage year of capital among firms within the same industry.

4 Estimation Method and Results

4.1 Estimation method

Capital goods (tangible fixed assets other than land) are divided into two categories: machinery, and buildings and structures. It is assumed that technological progress is embodied only in machinery, and not in buildings and structures. The estimation equation used in this paper is based on that of Sakekkaris and Wilson (2004), with the additional explanatory variables as control variables. We estimated three types of different equations.

We assume gross product Cobb-Douglas production function, where labor (l_{it} in logarithmic value), intermediate inputs (m_{it} in logarithmic value), the capital stock of buildings and structures (S_{it}), and the capital stock of machinery in efficiency unit (J'_{it}) are used as input factors and the gross product (y_{it} in logarithmic value) is the output, which in turn is rewritten in logarithmic form as in equation (17),

$$y_{it} = \beta_0 + \beta_t \cdot t + \beta_l \cdot l_{it} + \beta_m \cdot m_{it} + \beta_s \cdot \log\left(S_{it}\right) + \beta_j \cdot \log\left(J'_{it}\right) + \beta_X \cdot X_{it} + \varepsilon_{it}, \quad (17)$$

where $J'_{it} = \sum_{s=1}^{T} I_{i,t-s} D_{i,t-s,s} \left(1+\gamma\right)^{t-s-t0}$.

The subscript i and t express firm and year, respectively. γ is the rate of improvement in the quality of capital and $D_{i,t-s,s}$ is the physical deterioration survival ratio. The capital stock of buildings and structures, S_{it}, is calculated by deducting the value of machinery assets from the value of tangible

[17] Our estimation starts from 1997, almost 30 years after the year 1970. This reflects the idea that the possible bias arising from using the same vintage for firms founded before 1970 as that used for firms founded in 1970 is small.

fixed assets without that of land.

Here, since the value of the rate of improvement in capital quality is unknown, the first step is to construct a series of the physically surviving amount of each vintage of machine, $I_{i,t\text{-}s}D_{i,t\text{-}s,s}$, for each firm by applying the physical survival ratio pattern to each firm. The next step is to estimate the nonlinear equation in (17) using the physical survival series obtained in the first step to estimate the rate of improvement in the quality of capital, γ.[18]

Time variable (t) is added as an explanatory variable to take into account the Hicks neutral technological progress in the Cobb-Douglas production function. In addition to these explanatory variables, several control variables are added, which are expressed by the vector notation X_{it} in equation (10). To control for the effect of the intangible capital accumulated in each firm, variables such as firm age, its square, knowledge stock (constructed from firm's past R&D expenditures, in logarithmic value), and brand stock (constructed from firm's past advertising expenditures, in logarithmic value) are added. Furthermore, to control for discontinuous technological progress accompanying large-scale investment, the so-called investment spike, dummy variables which capture the elapsed year after the investment spike are added.[19]

The more commonly used method for taking embodied technological progress into account in production function estimation is to use the average vintage of capital as an additional explanatory variable. As explained in section 2, capital stock in efficiency unit can be approximately decomposed into the gross capital stock (which neglects the change in its value due to obsolescence) and its average vintage. Applying this approximation to equation (17), we can have the following equation (18).[20]

$$\begin{aligned} y_{it} &= \beta_o' + \beta_t' \cdot t + \beta_l \cdot l_{it} + \beta_m \cdot m_{it} + \beta_s \cdot \log\left(S_{it}\right) + \beta_j \cdot \log\left(K_{it}'\right) \\ &\quad + \beta_j \cdot \log\left(1 + \gamma(V_{i0} - V_{it})\right) + \beta_X \cdot X_{it} + \varepsilon_{it} \end{aligned} \tag{18}$$

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[18] If the value of the rate of improvement in capital quality, γ, is known in advance and data on the capital stock per efficiency unit of mechanical apparatus can be created in advance using this value, equation (17) turns into an estimation of a simple Cobb-Douglas production function.

[19] However, this estimation does not take the capital utilization ratio into consideration.

[20] Unlike equation (12) derived in section 2, the approximation of equation (18) follows Nelson (1964) and is derived as follows:

$$\begin{aligned} J_t &= \sum_{s=1}^{T} I_{t-s} D_s (1+\gamma)^{t-s-t_0} = (1+\gamma)^{-t_0-V_0} (1+\gamma)^t \sum_{s=1}^{T} I_{t-s} D_s (1+\gamma)^{-s+V_0} \\ &\approx G'(1+\gamma)^t K_t \left[1 + \gamma(V_0 - V_t)\right] \end{aligned}$$

where $G' = (1+\gamma)^{-t_0-V_0}$ and $(1+\gamma)^{-s+V_0} \approx 1 - s\gamma + V_0\gamma$.

V_{it} is the average vintage of the machine capital of firm i at time t. V_{i0} is the average vintage of the machine capital of firm i at time 0. The average vintage for each firm is calculated using the method explained in the previous section. K'_{it} is the capital stock of the machinery reflecting only physical deterioration, and is the simple sum of the physically surviving amount of value for each vintage.

Since a constant term and a time variable (t) are added in the process of approximating the capital stock of machine capital in efficiency unit, equations (17) and (18) differ in terms of the values and their implication of constant terms and the coefficient of time variables. The coefficient of time variable means only the rate of Hicks neutral technological progress in equation (17), whereas in equation (18) it includes the rate of improvement in capital quality (γ) in addition to the rate of Hicks neutral technological progress, that is, $\beta_t' = \beta_t + \gamma$.

In the estimation of equation (18), since one of the coefficients to be estimated, γ, the rate of improvement in capital quality, is contained in the logarithm, a nonlinear estimation is required. However, if the value of $\gamma(V_{i0}-V_{it})$ is small enough, this part can be further approximated in linear form as the following equation (19). Since equation (19) is linear, in addition to conducting an OLS estimation, a Levinsohn and Petrin (2003) type regression is performed, which is intended to control for the possible endogeneity problem of inputs in the production function estimation.

$$\begin{aligned} y_{it} = \beta_0' + \beta_t' \cdot t + \beta_l \cdot l_{it} + \beta_m \cdot m_{it} + \beta_s \cdot \log(S_{it}) + \beta_j \cdot \log(K_{it}') \\ + \beta_j \gamma \cdot (V_{i0} - V_{it}) + \beta_X \cdot X_{it} + \varepsilon_{it} \end{aligned} \qquad (19)$$

4.2 Estimation results

Table 1 shows the results of the nonlinear estimation of equation (17), and shows the estimated rate of improvement in capital quality (γ). Estimations are performed for two data sets, one of which is the data that R&D expenditures and advertising expenditures are available (for the estimation controlling these variables), and the other data set consists of whole available firms including firms that R&D and advertising expenditures are not available (for the estimation without controlling these variables).

In addition, we compare the two cases whether or not the elapsed year after absolute investment spikes is taken into account as a control variable.

The estimated coefficients of two kinds of capital stock, labor input, and intermediate inputs should represent the factor income share of these inputs.

The estimated results show that the factor income share of intermediate inputs is generally stable at around 80 percent, and the remaining share of approximately 20 percent represents value-added share. Of the value added, 75 or 80 percent is the labor income share, and the remaining of the value added is divided in half, with half for machine capital income and the other half for buildings and structures capital income. Therefore, the factor income share of machine capital to the value of gross output is approximately 2 percent. These estimated factor income shares are generally consistent with the results of previous studies on the production function.

The results show that a 1 percent increase in knowledge stock (R&D stock) increases the TFP level by 1 percent, and that a 1 percent increase in brand stock resulting from advertising expenditure results in a 0.5 percent increase in TFP. However, it should be noted that the number of firms for which R&D and advertising data are available is approximately 23,000 out of the entire sample of 48,000 firms, leaving the possibility that the sample and the results are biased toward high-performing firms. Moreover, the coefficient of the dummy after an investment spike was estimated to result in enhancement of the TFP level by 1 to 2 percent every year until 4 years after the investment.

The rate of improvement in machine capital quality is 9 to 13 percent when the effect of an investment spike is taken into account and 17 to 22 percent when such an effect is not taken into account. If this value is converted to the rate of embodied technological progress, with the result that the estimated revenue share of machine to gross output is 2 percent, it translates into a value in the range of between 0.18 and 0.44 percent.

Table 2 reports the results of nonlinear estimation based on equation (18). The results hardly differ from those obtained using equation (17). The rate of improvement in machine capital quality is 8 to 10 percent when the effect of an investment spike is taken into account and 12 to 14 percent when such an effect is not taken into account. The rates of improvements are a little lower than the previous results in Table 1.

Table 3 reports the results of OLS estimation based on equation (19). Since this estimates the product of the rate of improvement in machinery and its revenue share as a coefficient of the average vintage of machine capital, the former value is obtained by dividing the estimated coefficient by its revenue share, and is reported in the first row of Table 3. The rate of improvement in machine capital quality, which is between 10 to 13 percent when investment spikes are taken into consideration, or between 14 to 17 percent when investment spikes are not taken into consideration, is almost the same as that reported in Table 1. Other estimated numbers of coefficients also have similar values.

Moreover, in addition to using OLS, the estimation is also carried out using the method advocated by Levinsohn and Petrin (2003), which takes into consideration the endogeneity problem of inputs in production function estimation, in order to check the robustness of our results. We obtain results (see Table 4) consistent with the other estimation method used in this paper.

Let us compare our results with those of Sakellaris and Wilson (2004). Their estimation result of the rate of improvement in capital quality is 8 to 17 percent, using U.S. factory-level data for the period from 1972 to 1996, which indicates no significant difference from our corresponding value of

8 to 22 percent. The value obtained by Bahk and Gort (1993) using data from U.S. companies for the period 1973 to 1986, is 15 to 21 percent, which also shows no substantial difference from our estimated number. Therefore our estimated number of the rate of improvement in capital quality is generally consistent with other previous results using a production function approach.

If one accepts the result that the rate of improvement in machine quality (or the obsolescence rate) is quite large ranging over 8 to 22 percent annually, this fact is important for the following two points. The first point concerns the choice of depreciation rate when the capital stock is constructed and productivity measure such as TFP is calculated. The other point is the relation between new investment and the realized technological change.

Firstly, the economic depreciation of machine capital in the manufacturing industry in 2002 is calculated to be 12.7 percent in JIP Database 2006, which follows the approach adopted by Hulten and Wykoff (1981). Alternatively, although the range of values calculated for the obsolescence rate of capital is wide, if one takes the mid-value of the obsolescence rate referred to above, 15 percent, and takes 2.8 percent as the physical deterioration rate[21], the economic depreciation rate becomes 17.8 percent, which is quite larger than that calculated following Hulten and Wykoff (1981). Supposing that the results of this paper provide a more accurate rate of economic depreciation, then the estimated capital stock based on the depreciation rate calculated by Hulten and Wykoff (1981) may be too large and the estimated TFP may be too low.

Secondly, although Hayashi and Prescott (2002)[22] prescribe the downturn in economic growth in Japan in the 1990s for the decline in the TFP growth rate, if one accepts the rate of improvement in capital quality to be between 9 and 20 percent on an annualized basis, it can be inferred that the decrease in the introduction of embodied technological progress caused by the downturn in new investment contributed greatly to the 1990s downturn in economic growth in Japan, which may be mis-measured as the low TFP growth rate. Our results show that if the vintage of machine capital rises by exactly one year, the rate of embodied technological progress is expected to fall between 0.2 and 0.4 percent.

5 Conclusion

Recognizing that measuring the degree of technological progress embodied in capital in the Japanese economy is important, we have attempted to perform estimations using data in a way as

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[21] Since the depreciation method adopted in this paper is not the constant percentage method, the constant depreciation rate is not defined. In this trial calculation, the rate used is the average annual rate of depreciation from the introduction of the asset concerned until five years after its introduction. The 10-year average of these rates is 5.2%.

[22] They used the Capital Stock data taken from the Japanese National Accounts in their study. The amount of capital stock in the National Accounts is estimated by applying the depreciation rates obtained from the information about average service lives of the capital goods. The information is from the Japanese National Wealth Survey conducted in 1970.

consistent as possible with the theoretical model. In analyzing the data, it is necessary to measure the amount of survival capital value for each vintage that reflects only physical deterioration and does not include the effect of obsolescence for each firm in order to extract accurate information on the rate of improvement in capital quality (which is the same as the obsolescence rate) by estimating production function of the firm.

Although the estimated rates of improvement in capital quality differ somewhat depending on the estimation model and method used, the annual rate of 8 to 22 percent calculated in this study is generally consistent with the results of previous studies. The rate of improvement in capital quality means the obsolescence rate of capital. The economic depreciation rate, which is the sum of the obsolescence rate and the rate of physical deterioration, is estimated to have a greater value than the depreciation rate provided by Hulten and Wykoff (1981).

As explained in section 2, the value calculated as the product of the rate of improvement in capital quality and the capital income share is the rate of technological progress embodied in capital, and is estimated to be 0.2 and 0.4 percent on an annual basis in this paper.

However, the potential for capital-embodied technological progress is realized only when new investment is made to allow the vintage to be maintained at a fixed level. If new investment goes down and the average vintage of capital begins to go up, the rate of embodied technological progress will slow. Table 5 shows the change in the average vintage of machinery in Japanese industries from 1985 to 2002, which are calculated by applying the physical survival pattern according to the types of capital goods explained in Section 3 to the JIP 2006 investment series classified by industry from 1970 onwards, obtaining the amount of survival stock for every vintage.[23] The rise in the average vintage of capital every five years from 1985 to 2000 is shown on the right-hand side of the table. The shaded parts of the table show the industries in which the average vintage increased by one year or more during the five-year period concerned.

Compared with the second half of the 1980s, what stands out from the first half of the 1990s is the rise in the vintage of machinery in most of the electronic machinery industries, which plays a major role as export industries in Japan until the 1980s, as well as a number of industries in which the average vintage of machinery rise greatly, even doubling in some industries. In the late-1990s, although the upward trend in the average vintage of capital in the communications equipment industry and the electronic equipment and electronic measuring instruments industry came to a halt, the upward trend in the vintage of capital in other electronic machinery industries continue, especially in the electrical generating, transmission, distribution and industrial apparatus industry, the household electrical appliances industry, and the electronic parts industry, in which the trend is remarkable. In such industries, since the average vintage of capital is estimated to have risen by

[23] As described in section 3, these 1996 values are used as the initial values for the average vintage of capital for each firm.

approximately two years, it is inferred that the increase in vintage reduced the growth rate of productivity by 0.4 to 0.8 percent. Moreover, production in those industries that use the products of such industries as intermediate inputs were also affected, and the rise in the age of capital in those industries is considered to have had significant effect on the stagnation of growth seen in the Japanese economy.

Under current economic conditions in Japan, where the TFP growth rate is not particularly high, it is important not to miss the opportunity for the potential productivity gain brought approximately by technological progress embodied in capital from this point forward. From this perspective, as the Industrial Structure Council points out, policy that encourages the renewal of capital equipment, such as a change in the tax treatment of capital depreciation, will be needed as part of the "new economic growth strategy."

Appendix: Data Construction

Section 3 describes our calculations for the survival ratio resulting from the physical deterioration of capital by industry and the average vintage of capital by firm. This data appendix briefly explains how we constructed other data used for the estimations.

The firm level data set used in this paper is part of the panel data from the "Basic Survey of Japanese Business Structure and Activities (BSJBSA)" conducted by METI, of which the data for firms in the manufacturing industry for the period between the year ending in March 1995 and the year ending in March 2003 are used. Since each firm is classified according to its reported composition of sales in each year, the industries in which firms are classified in the original data change in some cases during the sample period. In this paper, each firm is reclassified to the industry in which the firm is initially classified in the data set, and is treated as though not subsequently changed. Samples with a value of zero or a negative value for gross sales, number of staff employed, value of tangible fixed assets, wage costs, or intermediate inputs are removed as outliers.

1. Output, intermediate inputs, and labor input

As a measure of gross output, sales figures from BSJBSA are used, and are deflated to derive a real value. The deflator used is the output deflator from the JIP 2006. The nominal value of intermediate inputs is calculated from BSJBSA cost information as

The nominal value of intermediate input = cost of sales + selling, general and administrative expenses - (total wages + depreciation expenses)

The real value of intermediate inputs is obtained by deflating this figure by the intermediate input deflator from JIP 2006. Labor input is the product of the number of employees and the industry average labor hours from JIP 2006.

2. Real capital stock

BSJBSA investigates the book value of stock and investment to total tangible fixed assets and machinery from 1997 onwards.

For the estimations, it is necessary to divide capital stock and investment into categories of land, machinery, and buildings and structures. For this purpose, it is first necessary to remove land from total tangible fixed assets. As a first step, we calculate the average land ratio divided by total tangible fixed assets by industry using the information about land and total tangible fixed assets gathered by BSJBSA in its surveys for the 1995 and 1996 fiscal years.[24] The estimated value of land is

[24] BSJBSA surveyed the book value of land as a separate category of tangible fixed assets in the fiscal years ending March 1996 and 1997, but removed land as a separate category of the survey in subsequent years.

subtracted from the tangible fixed assets of each firm using this value. The book value of machinery is then deducted from tangible fixed assets (book value) excluding land (based on the estimated value of land) to obtain the book value of buildings and structures.

The real capital stock (1995 price) of buildings and structures is estimated as the product of their book value and the market to book value ratio of capital, which is estimated using data from the "Financial Statements Statistics of Corporations by Industry (FSSCI)" survey conducted by the Ministry of Finance and the deflators used in JIP 2006.

For machinery, the initial real value of machinery stock is estimated using the same market to book value ratio. The series of real values of investment in machinery is added to the initial value of physically deteriorated stock as described in section 3 to derive the amount of physically surviving stock for each vintage.

3. R&D stock and brand stock

R&D stock and brand stock are built through a company's expenditure on R&D and advertising. The deflators used to calculate the real value of such expenditure are the research and development deflator from the *White Paper on Science and Technology* and the Service Price Index for Companies of the Bank of Japan, respectively.

The depreciation rate used for R&D stock is taken from JIP 2002 data on the depreciation rates used for R&D stock in various industries. The depreciation rate for brand stock is assumed to be 30 percent.

4. Elapsed years after an investment spike

In a study focusing on new large-scale investments, Power et. al. (1998) consider the time at which a large-scale investment is made to be an investment spike, and analyzed the effect of such an investment on productivity in subsequent years. They assume that new technology is introduced only with large-scale investment and the effect of introducing new technology on productivity is realized in years subsequent to an investment spike. They apply three kinds of investment spike (a relative investment spike, an absolute investment spike, and an investment spike lasting two years or more). We also test these three kinds of different investment spike dummies, but we report only the estimation results obtained using the absolute investment spike (cases in which the investment exceeds 20 percent of the value of stock in the previous period), since we find that any type of investment spike concerned does not make a significant difference in the estimation results.

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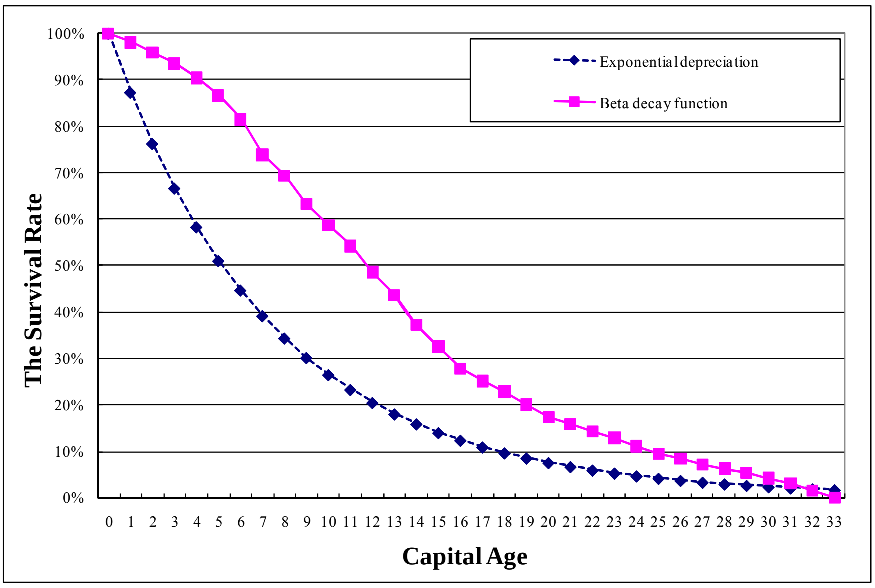
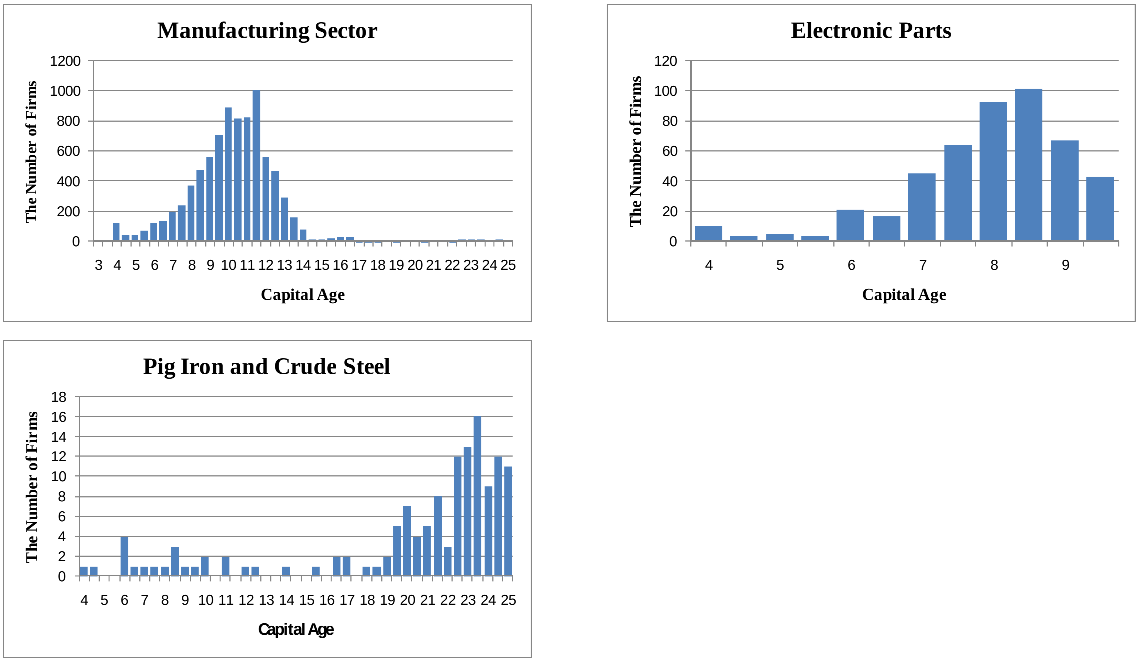
Figure 1 Depreciation Pattern of Capital Goods in the Manufacturing Industry



Source: Authors' calculation with BSJBSA and JIP 2006

Figure 2 Distribution of Average Vintage by Industry (2000)



Source: Authors' calculation with BSJBSA and JIP 2006

Table 1 Rate of Quality Improvement of Capital

	NL1	NL2	NL3	NL4
Time trend	-1.0.E-04 ***	-1.8.E-04 ***	-1.2.E-04 ***	-2.3.E-04 ***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Rate of quality improvement of capital	0.169 ***	0.223 ***	0.090 ***	0.126 ***
	(0.0147)	(0.0230)	(0.0157)	(0.0230)
Capital - Machinery equipment	0.021 ***	0.020 ***	0.020 ***	0.019 ***
	(0.0005)	(0.0007)	(0.0005)	(0.0007)
Capital - Building and structure	0.017 ***	0.020 ***	0.017 ***	0.021 ***
	(0.0006)	(0.0008)	(0.0006)	(0.0008)
Labor	0.188 ***	0.150 ***	0.188 ***	0.150 ***
	(0.0012)	(0.0017)	(0.0012)	(0.0017)
Intermediate input	0.786 ***	0.802 ***	0.786 ***	0.802 ***
	(0.0009)	(0.0013)	(0.0009)	(0.0013)
R&D stock		0.009 ***		0.009 ***
		(0.0005)		(0.0005)
Brand stock		0.005 ***		0.005 ***
		(0.0005)		(0.0005)
Firm age	-0.001 ***	-0.001 ***	-0.002 ***	-0.001 ***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)
Firm age^2	1.2.E-05 ***	6.0.E-06 ***	1.3.E-05 ***	6.6.E-06 ***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Absolute investment spike			0.013 ***	0.016 ***
			(0.0016)	(0.0021)
1 year after AIS			0.010 ***	0.011 ***
			(0.0018)	(0.0022)
2 year after AIS			0.014 ***	0.016 ***
			(0.0020)	(0.0027)
3 year after AIS			0.014 ***	0.013 ***
			(0.0024)	(0.0034)
4 year after AIS			0.017 ***	0.016 ***
			(0.0034)	(0.0047)
R-squared	0.992	0.995	0.992	0.995
Observation	47,729	22,875	47,729	22,875

1. Nonlinear estimation based on equation (17)
2. Dummy variables for industry and year are included but not reported here.
3. Because of the dummy variables, the constant term is excluded.
4. *, **, and *** denotes significant at 10%, 5%, and 1%, respectively.
5. Numbers in parentheses are standard errors.

Table 2　Rate of Quality Improvement of Capital using Average Vintage (NL)

	NL1	NL2	NL3	NL4
Time trend	0.001	0.004	-0.005	-0.001
	(0.0029)	(0.0038)	(0.0029)	(0.0038)
Rate of quality improvement of capital	0.124 ***	0.137 ***	0.079 ***	0.095 ***
	(0.0084)	(0.0098)	(0.0137)	(0.0178)
Capital - Machinery equipment	0.019 ***	0.018 ***	0.020 ***	0.019 ***
	(0.0005)	(0.0006)	(0.0005)	(0.0006)
Capital - Building and structure	0.017 ***	0.020 ***	0.017 ***	0.020 ***
	(0.0005)	(0.0008)	(0.0005)	(0.0008)
Labor	0.191 ***	0.154 ***	0.190 ***	0.152 ***
	(0.0011)	(0.0016)	(0.0011)	(0.0016)
Intermediate input	0.787 ***	0.803 ***	0.786 ***	0.802 ***
	(0.0008)	(0.0012)	(0.0008)	(0.0012)
R&D stock		0.009 ***		0.009 ***
		(0.0005)		(0.0005)
Brand stock		0.005 ***		0.005 ***
		(0.0005)		(0.0005)
Firm age	-0.002 ***	-0.002 ***	-0.002 ***	-0.001 ***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)
Firm age^2	1.6E-05 ***	1.0E-05 ***	1.6E-05 ***	9.5E-06 ***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Absolute investment spike			0.023 ***	0.025 ***
			(0.0015)	(0.0018)
1 year after AIS			0.017 ***	0.017 ***
			(0.0016)	(0.0021)
2 year after AIS			0.016 ***	0.016 ***
			(0.0019)	(0.0026)
3 year after AIS			0.016 ***	0.013 ***
			(0.0023)	(0.0032)
4 year after AIS			0.019 ***	0.017 ***
			(0.0033)	(0.0045)
Constant term	-2.929	-8.659	8.772	1.269
	(5.7101)	(7.5657)	(5.7730)	(7.6851)
R-squared	0.992	0.995	0.992	0.995
Observation	47,667	22,845	47,667	22,845

1. Nonlinear estimation based on equation (18)
2. Dummy variables for industry and year are included but not reported here.
3. *, **, and *** denotes significant at 10%, 5%, and 1%, respectively.
4. Numbers in parentheses are standard errors.

Table 3 Rate of Quality Improvement of Capital using Average Vintage (OLS)

	OLS1		OLS2		OLS3		OLS4	
Time trend	-0.003		0.000		-0.006	**	-0.002	
	(0.0028)		(0.0040)		(0.0028)		(0.0041)	
Rate of quality improvement of capital	*0.139*		*0.168*		*0.106*		*0.126*	
Rate of quality improvement of capital × distribution share of capital	0.003	***	0.003	***	0.002	***	0.002	***
	(0.0004)		(0.0005)		(0.0004)		(0.0005)	
Capital - Machinery equipment	0.020	***	0.020	***	0.019	***	0.019	***
	(0.0006)		(0.0008)		(0.0006)		(0.0008)	
Capital - Building and structure	0.017	***	0.020	***	0.018	***	0.021	***
	(0.0007)		(0.0009)		(0.0007)		(0.0009)	
Labor	0.190	***	0.152	***	0.189	***	0.151	***
	(0.0021)		(0.0022)		(0.0021)		(0.0022)	
Intermediate input	0.787	***	0.802	***	0.787	***	0.802	***
	(0.0020)		(0.0022)		(0.0020)		(0.0021)	
R&D stock			0.009	***			0.009	***
			(0.0005)				(0.0005)	
Brand stock			0.005	***			0.005	***
			(0.0006)				(0.0005)	
Firm age	-0.002	***	-0.002	***	-0.002	***	-0.001	***
	(0.0001)		(0.0002)		(0.0001)		(0.0002)	
Firm age^2	1.6E-05	***	9.8E-06	***	1.6.E-05	***	9.6.E-06	***
	(0.0000)		(0.0000)		(0.0000)		(0.0000)	
Absolute investment spike					0.016	***	0.019	***
					(0.0015)		(0.0019)	
1 year after AIS					0.011	***	0.011	***
					(0.0017)		(0.0021)	
2 year after AIS					0.010	***	0.011	***
					(0.0020)		(0.0027)	
3 year after AIS					0.009	***	0.008	**
					(0.0023)		(0.0034)	
4 year after AIS					0.013	***	0.012	**
					(0.0033)		(0.0046)	
Constant term	5.088		-0.218		10.920	*	4.272	
	(5.5215)		(8.0399)		(5.6136)		(8.1318)	
R-squared	0.992		0.995		0.992		0.995	
Observation	47,667		22,845		47,667		22,845	

1. OLS estimation based on equation (19)
2. In this estimation, the estimated coefficient of average vintage corresponds to the rate of quality improvement of capital × distribution share of capital. By dividing this with the distribution share of capital, *the rate of quality improvement of capital* is obtained.
3. Dummy variables for industry and year are included but not reported here.
4. *, **, and *** denotes significant at 10%, 5%, and 1%, respectively.
5. Numbers in parentheses are standard errors.

Table 4 Rate of Quality Improvement of Capital using Average Vintage (Levinsohn and Petrin)

	LP1		LP2		LP3		LP4	
Time trend	-0.205		-0.246		-0.215		-0.259	
	(0.4947)		(1.0799)		(0.3162)		(0.4047)	
Rate of quality improvement of capital	*0.158*		*0.112*		*0.183*		*0.109*	
Rate of quality improvement of capital × distribution share of capital	0.009	***	0.008	***	0.007	***	0.006	*
	(0.0022)		(0.0031)		(0.0020)		(0.0031)	
Capital - Machinery equipment	0.056	***	0.075	***	0.037	***	0.051	***
	(0.0064)		(0.0087)		(0.0055)		(0.0093)	
Capital - Building and structure	0.057	***	0.062	***	0.058	***	0.063	***
	(0.0028)		(0.0055)		(0.0038)		(0.0049)	
Labor	0.655	***	0.622	***	0.654	***	0.622	***
	(0.0096)		(0.0112)		(0.0086)		(0.0115)	
R&D stock			0.035	***			0.036	***
			(0.0025)				(0.0027)	
Firm age	-0.002	*	-0.002	*	-0.002		-0.002	
	(0.0008)		(0.0010)		(0.0010)		(0.0011)	
Firm age^2	1.0E-05		1.5E-06		1.1E-05		1.2E-06	
	(0.0000)		(0.0000)		(0.0000)		(0.0000)	
Absolute investment spike					0.049	***	0.061	***
					(0.0045)		(0.0074)	
1 year after AIS					0.033	***	0.038	***
					(0.0050)		(0.0078)	
2 year after AIS					0.023	***	0.022	***
					(0.0063)		(0.0078)	
3 year after AIS					0.021	***	0.014	
					(0.0071)		(0.0104)	
4 year after AIS					0.041	***	0.048	***
					(0.0092)		(0.0146)	
Observation	47,260		25,061		47,260		25,061	

1. Levinsohn and Petrin (2002) type estimation based on equation (19)
2. In this estimation, the estimated coefficient of average vintage corresponds to the rate of quality improvement of capital × distribution share of capital. By dividing this with the distribution share of capital, *the rate of quality improvement of capital* is obtained.
3. Dummy variables for industry and year are included but not reported here.
4. *, **, and *** denotes significant at 10%, 5%, and 1%, respectively.
5. Numbers in parentheses are standard errors.

Table 5 Average Vintage of Capital by Industry (annual rate average, %)

JIP2006	Industry Name	1985	1990	1995	2000	2002	1985-1990	1990-1995	1995-2000
8	Livestock products	8.2	8.4	7.8	8.4	8.6	0.2	-0.6	0.6
9	Seafood products	8.2	8.0	7.4	8.4	8.9	-0.2	-0.6	1.0
10	Flour and grain mill products	7.3	8.9	8.7	9.0	8.7	1.6	-0.2	0.3
11	Miscellaneous foods and related products	8.1	8.5	8.0	8.9	9.1	0.4	-0.5	0.9
12	Prepared animal foods and organic fertilizers	8.6	7.8	6.5	7.3	7.8	-0.8	-1.3	0.8
13	Beverages	8.3	7.1	6.8	7.1	7.6	-1.2	-0.3	0.3
14	Tobacco	7.6	10.0	10.5	10.2	9.5	2.3	0.5	-0.3
15	Textile products	9.0	7.0	7.4	8.3	8.5	-1.9	0.3	1.0
16	Lumber and wood products	6.6	5.6	6.3	6.9	7.0	-1.0	0.6	0.7
17	Furniture and fixtures	6.1	6.2	6.6	7.3	7.4	0.1	0.4	0.6
18	Pulp, paper, and coated and glazed paper	9.1	8.9	10.0	10.4	10.5	-0.2	1.0	0.5
19	Paper products	8.7	7.9	8.4	9.4	9.6	-0.8	0.5	1.0
20	Printing, plate making for printing and	6.2	5.3	6.1	6.6	6.6	-0.8	0.8	0.4
21	Leather and leather products	4.6	5.2	7.2	8.2	8.4	0.6	2.0	1.0
22	Rubber products	7.3	6.0	6.9	7.6	7.7	-1.2	0.9	0.6
23	Chemical fertilizers	7.9	8.8	10.8	11.5	11.3	0.9	2.0	0.7
24	Basic inorganic chemicals	7.8	7.5	8.5	8.9	8.9	-0.2	1.0	0.4
25	Basic organic chemicals	8.4	9.3	9.9	8.6	7.7	0.9	0.6	-1.3
26	Organic chemicals	8.8	8.8	9.2	9.6	9.6	0.0	0.4	0.4
27	Chemical fibers	9.3	9.9	11.5	12.9	13.2	0.6	1.6	1.4
28	Miscellaneous chemical products	8.4	8.3	8.7	9.5	9.8	-0.1	0.4	0.8
29	Pharmaceutical products	7.7	6.9	6.3	7.0	7.4	-0.8	-0.6	0.7
30	Petroleum products	11.4	13.4	9.5	9.6	10.2	2.0	-3.9	0.2
31	Coal products	11.4	14.2	14.5	16.0	16.9	2.8	0.3	1.5
32	Glass and its products	6.1	6.4	7.9	8.9	9.0	0.3	1.5	1.1
33	Cement and its products	7.2	7.9	8.3	8.4	8.9	0.7	0.4	0.1
34	Pottery	5.9	6.5	8.1	9.5	10.0	0.6	1.6	1.4
35	Miscellaneous ceramic, stone and clay products	6.8	7.9	9.4	7.3	6.1	1.0	1.6	-2.1
36	Pig iron and crude steel	13.5	18.2	21.5	18.1	15.7	4.7	3.4	-3.5
37	Miscellaneous iron and steel	7.7	10.3	12.2	13.6	13.8	2.6	1.9	1.4
38	Smelting and refining of non-ferrous metals	10.2	11.4	11.0	10.1	10.2	1.1	-0.4	-0.9
39	Non-ferrous metal products	7.5	8.7	10.2	11.2	11.8	1.3	1.5	1.0
40	Fabricated constructional and architectural metal products	8.2	8.9	8.6	9.7	10.2	0.7	-0.3	1.0
41	Miscellaneous fabricated metal products	8.2	7.1	7.5	9.0	9.6	-1.1	0.4	1.5
42	General industry machinery	6.9	7.4	8.1	9.3	9.9	0.5	0.7	1.2
43	Special industry machinery	6.9	8.1	8.9	9.9	10.5	1.2	0.8	1.0
44	Miscellaneous machinery	8.0	8.5	8.8	9.4	9.8	0.6	0.2	0.6
45	Office and service industry machines	6.9	8.3	8.8	9.6	10.1	1.3	0.6	0.8
46	Electrical generating, transmission, distribution and industrial apparatus	4.1	4.6	6.8	9.0	10.0	0.5	2.2	2.3
47	Household electric appliances	4.9	4.9	6.0	7.3	7.9	-0.1	1.1	1.3
48	Electronic data processing machines, digital and analog computer equipment and accessories	4.5	5.3	7.0	7.8	8.2	0.8	1.8	0.7
49	Communication equipment	5.3	7.5	10.1	9.8	9.5	2.2	2.6	-0.3
50	Electronic equipment and electric measuring instruments	5.1	5.7	8.1	7.9	7.5	0.6	2.4	-0.2
51	Semiconductor devices and integrated circuits	3.3	4.0	5.3	5.7	6.0	0.7	1.3	0.4
52	Electronic parts	4.6	3.9	5.4	6.5	7.2	-0.7	1.5	1.1
53	Miscellaneous electrical machinery equipment	6.4	4.8	5.9	7.4	8.2	-1.6	1.1	1.5
54	Motor vehicles	6.9	7.6	8.7	9.0	8.9	0.6	1.1	0.3
55	Motor vehicle parts and accessories	6.1	6.3	7.0	7.6	7.8	0.2	0.8	0.6
56	Other transportation equipment	8.8	9.0	9.2	9.6	9.4	0.2	0.1	0.4
57	Precision machinery & equipment	4.9	5.3	6.5	6.5	6.7	0.4	1.2	0.1
58	Plastic products	6.3	6.0	7.6	8.3	8.1	-0.3	1.6	0.6
59	Miscellaneous manufacturing industries	5.8	5.8	7.7	8.0	7.8	0.0	1.9	0.3

Note: The average vintage of capital by industry is obtained by applying the physical survival rate to the series of investment of machinery equipment by industry in and after 1970, and by aggregating the amount of survival stocks of each vintage. The values in 1996 were used as initial values of the average vintage of each firm by industry.