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# **Capital Accumulation, Vintage and Productivity: The Japanese Experience**

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## **Abstract**

We empirically examine the relationship between capital accumulation and vintage as well as the productivity of industries in Japan from 1980 to 2007. Based on the empirical analyses, we confirmed that vintage exerted a significant influence on the productivity during the period of economic expansion, particularly during the economic upturn that started in 2000, where strong vintage effects were observed in all industries.

The rejuvenation of capital equipment during this period clearly resulted from a strong productivity effect. In contrast, during the bubble period of the late 1980s, vintage exerted no observable effects on productivity despite significant increases in investment. This finding shows that increase of capital stock during this period was not necessarily productive and was likely to produce a merely temporary boom. From this view, we reconfirm that the relationship between vintage and productivity changed in subtle ways in response to the phases of business cycles.

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## 1 Introduction

Productivity is an indispensable factor for understanding the mid-and long-term characteristics of a macroeconomy. A value-added level of the macroeconomy depends on the labor force and capital stock. However, other factors may increase the value added. For example, more value can be added from the same level of input through various types of technological progress, referred to as an increase in productivity. Therefore, examining the factors that influence technological progress, or productivity, is important. We can divide productivity into two categories. The first category is new product development through the progress of science and technology. Imagine a case where new IT products of high value are developed by promoting basic research on semiconductors or a new pharmaceutical is developed from life science research. These exogenous factors, such as basic and applied scientific research, lead to increase in productivity. The second category is new investments endogenously determining productivity. It is highly probable that newly installed equipment include various types of technological progress in production. Depending on the circumstances, strong demand in investments and rejuvenation of equipment can promote innovation in technology and increase productivity. Various factors simultaneously influence the real economy, and productivity is no exception. Therefore, it is well worth investigating the mechanism of productivity growth using Japanese firm-micro data since 1980s.

The remainder of this paper is organized as follows. Section 2 introduces the concept of capital vintage and provides a detailed overview of prior studies regarding capital vintage and productivity growth. Section 3 presents a theoretical model which explicitly considers the relationship between capital vintage and productivity. Section 4 describes the data. Section 5 provides the various estimation results. The final section summarizes conclusions obtained in this analysis.

## 2 Overview

The study of capital accumulation and growth in a country's economy dates back to the research of Harrod and Domar, and scholars still study their findings as critical and fundamental themes in macroeconomics. Capital accumulation and increased investment in equipment generate economic growth through expansion in production capacity while increasing effective demand through a multiplier process. However, the relationship among capital accumulation, technological progress and economic growth

has not been examined explicitly in the discussion of Harrod and Domar.

In contrast, economists such as Solow and Swan (1956) began to actively research growth theories in the 1950. The 'neoclassical growth theory' flourished in this era. These theories, under a full employment economy, explicitly discussed the role of technological progress and the types of technology, but considered these factors exogenous. Neoclassical growth theory developed as the optimal growth theory during and after the 1960s, but in the form of an endogenously assumed savings rate later on. However, this period featured interesting perspectives about the impact of endogenous technological progress on economic growth. Arrow (1962) asserted that the accumulation of experience in economic agents, particularly in firms, induces productivity, that is technological progress. According to Arrow (1962), the introduction of new machinery and equipment, which represents new investment in equipment, provides learning opportunities for laborers involved in production. Higher productivity through their learning manifests as technological progress that accelerates economic growth.

Solow (1960) investigated the role of investment from an aspect different to that of Arrow (1962). He considered new machinery and equipment to include novel technology, and he discussed whether the introduction of unconventional equipment improves productivity more than conventional technology. Arrow emphasized workers' improved adaptability following the introduction of new equipment, whereas Solow focused on new technology as embodied in the new equipment itself., which came to be known as 'the embodiment hypothesis'. Under the embodiment hypothesis, the year in which capital equipment is installed indicates the level of technological standard. Therefore, by calling the age of the equipment its 'vintage', Solow theoretically clarified the relationship among capital accumulation, technological progress and economic growth. Solow (1960) also attempted a quantitative analysis in which he established and estimated a production function with real capital embodying technological progress as the production factor and calculated the rate of embodied technological progress. Nelson (1964), following Solow (1960), improved the quantitative analysis and concluded that the embodiment hypothesis was probably established in the American economy from 1929 to 1960. Phelps (1962) also sought to measure the embodied technological progress.

The study of technological progress embodied in capital have been continuing to undergo extensive analyses in the same direction as that of productivity fluctuations in an actual macroeconomy. Since the 1970s, productivity has been declining in major developed countries such as the United States. In view of this circumstances, Kendrick (1980) and Clark (1979) employed growth accounting analysis to calculate the rate of technological progress embodied in capital. In particular, Clark (1979) noted that of the

1.17% productivity decrease from 1965-1973 to 1973-1978, only 0.1% is accounted for by a decline in the progress of embodied technology.

Analysis of the embodiment hypothesis was pursued vigorously in the 1990s, probably because U.S. productivity rose notably during the late 1990s. In the U.S., the growth rate of equipment investment, centering on IT, accelerated from an average of 3.2% in the 1980s to 5.9% in the 1990s. IT investment collectively refers to investment in various technologies, with personal computers dominating budgets. It also includes communication devices such as mobile phones and the equipment used to develop and manufacture these products. In IT-related investment, new technology is embodied at high speeds, as represented by Moore's Law, suggesting a clear relationship between capital vintage and productivity. Recognizing this possibility, academia revived the embodiment hypothesis. Wolff (1991, 1996) applied Nelson's (1964) method to examine the G7 countries at the industry level. Both analyses demonstrated that technological progress embodied in capital is significant and cannot be ignored. Hulten (1992), Greenwood et al. (1997), Gittleman et al. (2006) and Hobjin (2001) also measured productivity at the industry level. In particular, Hulten (1992) analyzed the embodiment hypothesis within the long-term time series of 1949-1983 using capital goods prices adjusted by quality. According to Hulten, approximately 20% of the growth rate of total factor productivity (TFP) of U.S. manufacturing was embodied in capital during this period. He also concluded that when the sample period is divided into 1949-1973 and 1974-1983, the difference in the rate of contribution of the embodied technological progress between the two periods is negligible. Gittleman et al. (2006) conducted a detailed analysis wherein they recalculated TFP considering the economic obsolescence rate associated with capital vintage and the depreciation rate of capital stock based on data from 1947 to 1997 from U.S. Bureau of Economic Analysis. Their analysis found that the rate of technological progress embodied in capital is approximately 5% of the TFP growth rate. Sakalliaris (2001) utilized Nelson's (1964) framework in analyzing the data of American manufacturing from 1974 to 1988 (three-digit SIC category) and indicated that the rate of technological progress embodied in capital is approximately 10% of the TFP growth rate.

Investigations based on firm-level micro data have recently been pursued vigorously. Bahk and Gort (1993) attempted to estimate the production function with labor, human capital, physical capital and capital vintage as production factors when considering the learning process in production activities. Their investigation used panel data from 2,150 plants. Power's (1998) analysis used micro data from approximately 14,000 U.S. manufacturing plants between 1972 to 1988. He separated capital stock into

facilities and machinery and calculated the vintage of capital goods, concluding that facilities and machinery have different impacts on TFP. Sakalliaris and Wilson (2004) utilized Nelson's (1964) framework in analyzing the micro data of 24,000 U.S. manufacturing plants between 1972 to 1996. Their findings demonstrated that the rate of technological progress embodied in capital accounts for 8-17% of the TFP growth rate.

The embodiment hypothesis has enjoyed long-standing interest in Japan. Using Nelson's (1964) method, Watanabe and Egaitu (1967) quantitatively confirmed that the embodiment hypothesis was established during the Japanese economy's high growth period which is from 1952 to 1962. However, when Japan entered its low growth period during and after the late 1970s, the increasing age of capital, associated with declining capital investment, and resulting stagnation of productivity posed serious issues. The Development Bank of Japan (1979) conducted a pioneering attempt that estimated the vintage series in Japan. This estimate was followed by a more sophisticated vintage calculation by the Development Bank of Japan (1981, 1983, and 1984), Kuninori and Takahashi (1984) and Suzuki and Miyagawa (1986). After the stagnation of 'the lost ten years', productivity and economic growth were discussed actively in Japan in the 2000s. Hayashi and Prescott (2003) initiated the discussion. The studies of Miyagawa and Hamagata (2006) and Tokui, Inui, and Ochiai (2008) are fascinating attempts in this direction that have comprehensively analyzed the relationship among capital accumulation, capital age and productivity in the context of Japan's long-term recession since 1990s.

Miyagawa and Hamagata (2006) captured the qualitative improvement in equipment renewal and capital from the twin aspects of capital age (vintage) and the renewal cycle of equipment (echo effect) to examine the protraction of renewal investment under long-term stagnation. Tokui, Inui, and Ochiai (2008) examined the validity of the embodiment hypothesis in the Japanese economy in the late 1980s from two aspects: the consideration of capital vintage and the introduction of new technology for implementing large-scale equipment investment (investment spike). Their intriguing conclusions are that new technological progress will probably be introduced along with large-scale investment and will be embodied in capital goods of young vintage.

Unlike the quantitative analyses, the Development Bank of Japan (2005) sought detailed data about Japanese equipment investment through a questionnaire survey of individual firms. This survey investigated interesting topics, uniquely allowed for awareness surveys, such as the level of awareness of ageing equipment, the disadvantages of ageing equipment and prospects for future equipment age. Based on this survey, the Development Bank of Japan (2005) indicated that Japanese firms are

inclined to make investments based on maintaining equipment at a certain age level.

This paper study has three major characteristics not found in earlier studies. First, it uses micro data to perform a substitutive calculation of capital stock and to measure the capital vintage series using an approach consistent with the calculation of capital stock. The traditional calculation of capital stock used accounting methods on disposal amounts via the declining balance method and the straight-line method to calculate capital stock. However, this assumption is strictly based on an accounting concept and does not reflect actual physical depreciation. Hence this study calculated gross capital stock on the basis of acquisition cost and successfully measured capital vintage in a manner consistent with this calculation.

The second notable characteristic is that we calculated the firm-level capital vintage and productivity time series which cover more than twenty years. Our research database is the Development Bank of Japan Corporate Finance Data Bank which is the most comprehensive and reliable firm-level accounting data in Japan and we can get more than 3,000 companies' information since 1980 to 2007. With this database, we made a detailed calculation of the capital vintage and TFP which have fruitful information both time series and cross section dimension. Such attempt has been never done in earlier studies.

The third illuminating point is that we succeeded in the examination of the time-varying effects of vintage on productivity. Basically, the older the capital vintage is, the lower the productivity becomes. It is interesting topic that this relationship between vintage and productivity may vary in the state of economic conditions. For example, during the late 1980s, which is so called 'bubble period' in Japan, despite of rapid increase in equipment investment, it is widely known that productivity growth was not necessary dramatic. We can get a deep understanding for the above phenomena with our panel dataset which has relatively long time series.

### 3 Model

In this section, we present the theoretical model which explicitly considers the relationship between capital vintage and productivity<sup>1)</sup>. Firstly, the capital accumulation process is described in detail. Various firms accumulate capital stock in the form of Equation (1).

$$K_t = K_{t-1} + I_t \tag{1}$$

In this situation,  $K_t$  represents real gross capital stock at the end of period  $t$ , and  $I_t$  represents real gross investment during period  $t$ . As Equation (1) is a simplified version, the capital depreciation rate is assumed to be 0. If initial capital stock was assumed to be 0, capital stock derived from Equation (1) would be the sum of the gross business investment of each period, from period 1 to period  $t-1$ , which can be represented in the form of Equation (2).

$$K_{t-1} = \sum_{v=-\infty}^{t-1} I_{tv} \quad (2)$$

Currently (period  $t$ ), firms determine the production level ( $Y_t$ ) on the basis of the labor input level of period  $t$  ( $L_t$ ) and capital stock at the end of  $t-1$  ( $K_{t-1}$ ). In this situation, the production level represented by  $Y_{ts}$  is based on the capital equipment ( $I_{t-1s}$ ) of period  $s$  ( $v = s \leq t - 1$ ). By using the Cobb-Douglas production function structure, the production level can be represented by Equation (3).

$$Y_{ts} = A_{ts} L_{ts}^\alpha I_{t-1s}^{1-\alpha} \quad (3)$$

In this setting,  $L_{ts}$  represents the number of employees during period  $t$  who operate capital equipment installed during period  $s$  ( $s \leq t - 1$ ), and  $A_{ts}$  represents the technology level during period  $t$  of capital equipment installed during period  $s$ .

Equation (4) can be derived from the maximum profits of the firm and with optimal labor input.

$$L_{ts} = \frac{\alpha P_t}{W_t} Y_{ts} \quad (4)$$

Where  $P_t$  the sales is price and  $W_t$  is the nominal wage. Optimal production level is derived as Equation (5) after substituting Equation (4) into Equation (3).

$$Y_t = A_{ts}^{\frac{1}{1-\alpha}} \left( \frac{\alpha P_t}{W_t} \right)^{\frac{\alpha}{1-\alpha}} I_{t-1s} \quad (5)$$

At this point, capital stock at the end of period  $t-1$  is considered and the optimal production level of the current period ( $t$ ) can be edited to be similar to Equation (6), where  $\theta_{ts}$  represents the proportion of investment of period  $s$  at the time of establishment.



$$Y_t = \left( \sum_{s=-\infty}^{t-1} A_{ts}^{\frac{1}{1-\alpha}} \theta_{ts} \right)^{1-\alpha} L_t^\alpha K_{t-1}^{1-\alpha} \quad (6)$$

$$\theta_{ts} = \frac{I_{t-1s}}{K_{t-1}} = \frac{I_{t-1s}}{\sum_{v=-\infty}^{t-1} I_{tv}}$$

Total factor productivity (TFP) can be defined using Equation (7).

$$\ln(TFP_t) = \ln(Y_t) - \alpha \ln(L_t) - (1 - \alpha) \ln(K_{t-1}) \quad (7)$$

Substitution Equation (6) into Equation (7) yields Equation (8)

$$\ln(TFP_t) = (1 - \alpha) \ln \left( \sum_{s=-\infty}^{t-1} A_{ts}^{\frac{1}{1-\alpha}} \theta_{ts} \right) \quad (8)$$

In this model, technological progress is set according to the exponential form as Equation (9).

$$A_{ts} = B \exp(\mu t + \lambda s) \quad (9)$$

$$B > 0, \mu > 0, \lambda > 0$$

If  $s$  is large, that is, if the data of capital establishment is closer, the level of technological progress is larger. Equation (8) is rewritten as Equation (10) by substituting Equation (9).

$$\ln(TFP_t) = \ln(B) + \mu t + (1 - \alpha) \ln \left[ \sum_{s=-\infty}^{t-1} \theta_{ts} \exp \left( \frac{\lambda}{1-\alpha} s \right) \right] \quad (10)$$

At this point, we performed a McLaurin expansion around  $\lambda = 0$  on the third item on the right-hand side of Equation (10) and rearranged terms to obtain Equation (11).

$$\ln(TFP_t) = \ln(B) + \mu t + \lambda \left[ \sum_{s=-\infty}^{t-1} s \theta_{ts} \right] \quad (11)$$

Now we set the vintage index to have the same structure as Equation (12).

$$Vin_t = \sum_{s=-\infty}^{t-1} (t - s) \theta_{ts} \quad (12)$$

Equation (12) implies that the vintage index depends on two elements: the time of equipment installation ( $s$ ) and the proportion ( $\theta_{ts}$ ) of equipment that accounts for capital stock of period  $s$  at the end of period  $t-1$ . Thus, when installation time is recent and  $s$  approaches  $t$ , the vintage index decreases, and this value is more noticeable when the proportion of new equipment increases. Using this vintage index, TFP can be finally expressed as Equation (13) by rewriting Equation (11).

$$\ln(TFP_t) = \ln(B) + (\mu + \lambda)t - \lambda Vin_t \quad (13)$$

Equation (13) shows that TFP can be explained by a constant value, time trend and vintage. For  $\lambda \geq 0$  as shown in Equation (9), the coefficient value of the time trend can be assumed to be positive. In addition, when the vintage index is smaller, that is, when capital equipment is rejuvenated by recent active equipment investment, we can predict that the value of TFP increases.

## 4 Data

### 4.1 Capital stock

There is a demand for calculating capital stock data using the data on production capabilities needed to estimating productivity. In accounting, there are two differences between capital stock in terms of production abilities and of tangible fixed assets. Tangible fixed assets with depreciation subtracted from the balance sheet are accounted for as *net capital stock*, whereas purchasing cost, including accumulated depreciation, carried on the tangible fixed assets is accounted for as *gross capital stock*. Capital stock with production abilities as an index can be measured by the existing amount of equipment. Therefore, it is preferable to consider gross capital stock<sup>2)</sup>. For accounting purposes, fixed tangible assets are a nominal value, but because capital stock as an index of production abilities is represented by the amount of equipment, a real value is needed.

Based on the above consideration, the calculation of real gross capital stock should be calculated. There are two basic methods for measuring real gross capital stock: the benchmark method and the perpetual inventory method. Our study adopted the later method. Firstly, nominal gross capital stock (here after abbreviated as KGN) is obtained from the current volume of previous investment as Equation (14).

$$KGN_t = \sum_{v=-\infty}^t \phi(v, t) IN_v \quad (14)$$

$$0 \leq \phi(v, t) \leq 1, \phi(v, v) = 1, \frac{\partial \phi(v, t)}{\partial t} \leq 0, \text{ for } t > v$$

Where  $\phi(v, t)$  is the proportion of equipment of year  $t$  installed in year  $v$ ,  $IN_v$  is the nominal investment installed in year  $v$ . Secondly, real gross capital stock (here after abbreviated as KGR) can be calculated with the investment goods deflator of the various periods of past investment ( $PI_v$ ) as Equation (15).

$$KGR_t = \sum_{v=-\infty}^t \phi(v, t) IR_v \quad (15)$$

$$IR_v = \frac{IN_v}{PI_v}$$

Where  $IR_v$  is the real investment deflated by the investment goods price of the various periods of past investment ( $PI_v$ )

In this model, estimates of gross capital stock is estimated by assuming ‘one-hoss shay decay’<sup>3)</sup>. Equipment, whose accounting value disappears after depreciation, contributes to production. Although data construction using the age-efficiency profile is desirable for representing capital stock as production capacity, it is not possible because of limited data availability. Therefore, as shown in Equation. (16), we adopt one-hoss shay decay assumption, wherein efficiency is kept constant immediately before physical scrapping.

$$\phi(v, t) = \begin{cases} 1 & v \leq t \leq v + T \\ 0 & v + T < t \end{cases} \quad (16)$$

Data from tangible fixed assets schedule are recorded in the annual report that listed companies are mandated to disclose to the Financial Services Agency. The tangible fixed assets schedule includes items such as increases in current-period tangible fixed assets (IN), decreases in current-period tangible fixed assets (SN), the stock of tangible fixed assets at the end of period (acquired amount base) (KGN), accumulated depreciation of tangible fixed assets (CDEP), current-period depreciation of tangible fixed assets (DEP) (according to balance sheets) and tangible fixed assets (net capital stock: KNN). In these periods, the relationship in Equation (17) and (18) holds.

$$KGN_t = KGN_{t-1} + IN_t - SN_t \quad (17)$$

$$KNN_t = KGN_t - CDEP_t \quad (18)$$

The data in the Development Bank of Japan Corporate Finance Data Bank are categorized as total tangible fixed assets, buildings, structures, machinery, ships, vehicles and transportation equipment, tools, rental fixed assets, other depreciable assets, land and construction-in-process accounts. In addition, the database records increases in current-period tangible fixed assets (IN), decreases in current-period tangible fixed assets (SN), end-of-period stock of tangible fixed assets (acquired amount base)(KGN), accumulated depreciation of tangible fixed assets (CDEP), current-period depreciation of tangible fixed assets (DEP) (according to balance sheets) and tangible fixed assets (net capital stock: KNN). The database, however, does not record amounts for current-period depreciation, total and construction-in-process. In addition, increases in the amount during the current period are small compared with recorded acquisition costs. Consequently, using on the identity related to stocks (end of period stock= previous period stock + increased amount – decreased amount) and calculating the gap = end of period stock – (previous end of period stock + increase amount – decreased amount), consistency holds by adding to the increased amount when the gap is positive and adding the absolute value to the decreased amount when the gap is negative.

Depreciable assets are defined by subtracting non-depreciable assets (such as land and construction-in-process account) from the total amount<sup>4</sup>. Acquisition costs (nominal gross capital stock: KGN) related to depreciable assets are estimated on the basis of the amount of the current-period increase (nominal investment: IN) and the amount of the current-period depreciation (SN) based on the following procedures in Equation (19)-(22). Further, the point in time ( $v_t$ ) at 0 or negative in the beginning is determined from the acquisition cost in the most recent period ( $t = t_1$ ) when data back to the past and subtracted from the amount of the current period increase. This calculation follows from the logic that current capital stock is organized by the latest investment based on the assumption of first-in/first-out. In other words, the following condition holds.

$$\sum_{s=v_{t+1}}^t IN_s < KGN_t \leq \sum_{s=v_t}^t IN_s \quad (19)$$

A portion of the oldest amount of the current-period increase ( $IN_{v_t}$ ) constitutes capital stock at the end of the period t. For a portion of the investment of during period ( $v_t$ ):

$$\omega_t = \frac{KGN_t - \sum_{s=v_{t+1}}^t IN_s}{IN_{v_t}}, \quad 0 < \omega_t \leq 1 \quad (20)$$

and after period  $v_t + 1$ , the summation of investment until the aforementioned point in time comprises acquisition costs at the point in time  $t$  as Equation (21).

$$KGN_t = \omega_t IN_{v_t} + \sum_{s=v_t+1}^t IN_s \quad (21)$$

This approach enables us to determine which investment comprise capital stock I each period and to create an accurate od real gross capital stock. Using even the oldest data, acquisition costs fail to reach zero or become negative at point in time  $v$  (period  $t_d$ ). We proceed with retroactive estimation of the amount of the current-period increase ( $IN_t$ ). If most recent service life is available ( $\theta_{td+1} = t_d + 1 - v_{td+1}$ ), we fix the value and use it, and then the amount of current-period depreciation ( $SN_t$ ) corresponds to the current-period increase amount of  $(t - \theta_{td+1})$

$$IN_{t-\theta_{td+1}} = SN_t, \quad t_0 \leq t \leq t_d \quad (22)$$

From Equation (22), a retroactive business affiliation of the investment can be obtained and by using this data, the procedures in the first stage can be determined. Although this method is the same as the benchmark method, it has the unique characteristic of processing the service life obtained from the recent perpetual inventory method when realizing current-period depreciation.

Firstly, firm data from portions of 1956 to March 2008 (FY2007) was gathered. Among the 74,918 cases in the 1980-2007 data sample, 58,701 cases (78%) of capital stock data were created The service life of 93% of these cases was not fixed, and by using the available data for the current-period increase amounts, we created real gross capital stock data.

## 4.2 Total Factor Productivity (TFP)

TFP, which is defined by Equation (23), is calculated by using the real value of added ( $VR_t$ ), real gross capital stock of the previous end of period ( $KGR_{t-1}$ ), number of employees ( $L_t$ ) and the average capital distribution rate of industries ( $\alpha$ ) based on the Cobb=Douglas production function<sup>5)</sup>.

$$TFP_t = \ln(VR_t) - \alpha \ln(KGR_t) - (1 - \alpha) \ln(L_t) \quad (23)$$

$$VR_t = KY_t + LY_t \quad (24)$$

As Defined in Equation (24), real value added is composed by capital income ( $KY_t$ ) and labor income ( $LY_t$ ). In this study,  $KY_t$ =depreciation + interest and discount expense + rent + ordinary income + taxes, and  $LY_t$ =labor cost+ offices' bonuses + salaries and allowances + provision of allowance for houses + welfare expenses + provision of allowance for employee retirement benefits<sup>6</sup>.  $\alpha$  is obtained from the average value of profit distribution rate of corresponding industry between 1980 and 2007<sup>7</sup>.  $L_t$  is the number of employees in each company at the end of the period<sup>8</sup>.

### 4.3 Capital vintage

Based on the Equation (15), the capital vintage is determined by the average age of existing equipment as Equation (25)<sup>9</sup>.

$$Vin_t = \frac{\sum_{v=-\infty}^t (t-v)\phi(v,t)IR_v}{KGR_t} \quad (25)$$

The slight modification of Equation (24) yields the dynamics of capital vintage as Equation (26).

$$Vin_t = \frac{IR_t}{KGR_t} + (1-d)(1 + Vin_{t-1})\frac{KGR_{t-1}}{KGR_t} \quad (26)$$

Give the initial value of  $Vin_t$ , capital vintage in each period can be recursively calculated in Equation (26).

【 Figure 1 】

Figure 1 summarizes the age-based shares of vintage in the main industries. These figures are categorized into three parts: less than five years, more than five years and less than ten years, and more than ten years. The share of the more than ten-year-old vintage index has increased in almost every industry since the 1980s. This tendency is particularly remarkable in the material industries (such as chemical and primary metal), Electricity, gas and water industries. These heavy industries have large-scale equipment installed. Since the 1980s, called the period of stable economic growth, such renewal

investment grew at a sluggish pace and their share increased gradually. This characteristics were also observed in the machinery industries. However, the share of old vintage in these industries is relatively low. For example, in 2007, the average vintage of more than ten years in the material industries was 54%. In contrast, it was 35 % in machinery industries. In non-manufacturing industries excluding electricity, gas and water, the aged vintage share was lower than in the material sectors, and the average share in 2007 was 34%.

【 Figure 2 】

Figure 2 shows changes in the capital vintage index of the various industries. The subtle differences in trends in different industries can be explained by considering that vintage increased during periods of economic recession and decreased during periods of economic expansion. This is particularly so during the economic bubble of late 1980s and the boom after 2000, where vintage decreased steadily. During economic expansion, capital equipment was rejuvenated because of increase in capital investment, resulting in decrease in vintage. In contrast, during economic recessions, because the installation and renewal of new equipment stagnates and equipment age, the vintage index also increased. This trend can be observed in the Figure 1, thereby confirming that Our measurement of the capital index was correct.

## **5 Empirical Evidence**

### **5.1 Estimation results (1)**

First, we conducted panel estimations for the period 1980-2007. As a preliminary test, we conducted a specification test (Hausman test) to determine whether we could choose a fixed effect model or random effect model by industries. As the results of specification test vary among industries, we examined the estimation results of both models. Table 1-1 reports the summary of results of the random effects model and Table 1-2 reports the results of the fixed effect model.

【 Table 1-1 】

【 Table 1-2 】

We investigated 13 manufacturing industries, eight non-manufacturing industries

and all industries. The estimation equation is based on Equation (13) shown in section 3 and we make a little modification of Equation (13) as an estimation form as follows:

$$LTFP_{it} = \alpha + \beta trend + \gamma Vin_{it} + \varepsilon_{it} \quad (27)$$

Where  $LTFP_{it}$  shows the logarithmic value of total factor productivity and trend represents time trend.  $Vin_{it}$  indicates the capital vintage index derived and measured in section 4. As the dependent variable is the logarithmic value, the coefficient  $\beta$  and  $\gamma$  represent semi-elasticity. Coefficient  $\gamma$  is expected to be negative because the smaller the value of the vintage index, that is, the younger the equipment age of capital stock, the stronger the effects of productivity improvement.

The following discussions and explanations are based largely on the results of random effects model and, where appropriate, we identify differences to the fixed effect model. The vintage coefficient was significant across all industries and recorded a value of 0.01. This outcome indicates that when the average age of capital increases by one year, TFP falls to 1%<sup>10</sup>. By dividing the manufacturing industries into the material industry (pulp and paper, chemicals, coal and petroleum products, stone, clay and glass, primary metal and fabricated metal) and machinery industry (four types of machines), we observe that the effect of the vintage coefficient is stronger in the material industry. This trend is also observed in the fixed effect model. In general, material industry includes heavy industries, where the setup and installation of capital equipment occurs infrequently. This outcome implies that despite the comparative lower frequency of the renewal of capital stock in the material industry, it is highly likely that, during renewal, the new technology introduced is markedly different from the previous technology. For example, in the petroleum refining and chemical industry, the vintage coefficient values are relatively higher, highlighting such characteristics. Even in non-manufacturing industries, slightly different results were obtained in the fixed effect model although the vintage coefficients were significantly negative.

The impact of the trend ( $\beta$ ) differs across industries. In the random effect model, vintage has a significant positive impact on all industries. This result suggests that between 1980 and 2007, certain factors supported the uptrend in TFP on a macro level level in Japan. However, after examining the details closely, we could not identify these characteristics in the material industry, leaving us to postulate that the factor driving the uptrend must have been in the non-manufacturing industries.

Finally, we analyze the impact on the constant term. The constant term ( $\alpha$ ) is different to the factors behind the trend, as demonstrated by Equation (9) in the



theoretical model in section 3. The constant term represents a technology improvement factor. This factor is irrelevant to temporal changes such as business cycle and economic expansions, but is believed to reflect a range of industry-specific management attitudes regarding research and development and new products. This factor is significantly positive across all industries. We confirmed that factors that did not appear to affect uptrend and vintage actually spurred TFP. These effects may differ slightly across industries, but we observed an overall positive effect.

## 5.2 Estimation results (2)

Here, we present estimations by industry. Figure 3 depicts estimations based on Equation (26) and the results of estimation (rolling regression) conducted on 22 industries on a year-by-year basis. During the estimation period of six years, the initial Estimation period was between 1980 and 1984, and the last estimation period was between 2000 and 2007. Upper and lower line in each diagram show the 95% confidence interval. The shaded zone denotes the period determined by the Cabinet Office as the economic recession period.

【 Figure 3 】

During the economic expansion period in the first half of the 1980s, the vintage coefficient was significantly negative in all industries. This result indicates that the increase in new equipment investment backed by economic expansion rejuvenated the age of capital equipment and thereby spurred an improvement in productivity (hereafter called the ‘vintage effect’). This vintage effect was confirmed during the boom period beginning in 2002. The effect was particularly distinct in the primary metal and chemical industries within the materials industry and in the general machinery and transport machinery industries within the machinery industry. This growth period lasted longer than Izamani boom of the 1960s, and it featured brisk investment in equipment across all industries. In particular, high demand for semi-finished products and capital goods in developing countries increased exports of goods from Japan’s material industry, and renewals and installations of new capital equipment soon followed. This investment boom prompted adoption of machinery equipment equipped with the latest technology; thus, the vintage effect was widely evident, even in the material industry.

We now focus on the characteristics of the 1987-1991 expansion. During this period, the capital equipment boom was larger than the boom period after the 2000s, but the

vintage effect was weaker, as the diagrams in Figure 4 shows. Within the material industry in particular, few industries exhibited positive vintage coefficient values. Thus, despite buoyant capital investment during the bubble period, the rejuvenation of the age of capital equipment did not necessarily cause improvement in productivity.

To explore the reasons for this phenomenon, we conducted two complementary investigations. First, the rolling estimated coefficients of vintage in Equation (27) were regressed by the intensity of research and development (R&D intensity) and by the researcher-employee ratio<sup>11</sup>. To investigate that regression, we selected two types of dependent variables: the coefficient of embodied technological progress ( $\hat{\lambda} = -\hat{\gamma}$  in Equation (27)) and the coefficient of disembodied technological progress ( $\hat{\mu}$  in Equation (27))<sup>12</sup>.

【 Table 2 】

Table 2 reports the estimation results. Both R&D intensity and the researcher-employee ratio exert positive significant effects on disembodied technological progress ( $\hat{\mu}$ ). These explanatory variables, however, did not have the correct sign, indicating that The enforcement of R&D stimulates disembodied technological progress and does not necessarily correlate with embodied technological progress. In this complementary estimation, we used industrial level data (16 industries) to investigate the relationship between technological progress and research and development. It is essential that future research examine this issue using data from individual firms.

As a second complementary investigation, we examined changes in the share of non-factory buildings (such as dormitories, employee recreation centers) included in capital stock during various periods. Capital equipment in these facilities did not necessarily feature the latest technology and did not directly spur improvements in productivity.

【 Table 3 】

Table 3 reports the share of buildings, excluding factory facilities, in various industries (recorded as K share). In addition, we recorded the average values of the coefficients during this period, which were measured according to a rolling estimation. Table 3 demonstrates that more than half of the periods that registered the highest K share occurred during the bubble period. During the same period, we also observe that vintage coefficient values were remarkably low compared with other periods. In contrast,

during the economic boom after 2000, K share was comparatively low whereas vintage Coefficient values were high across all industries. Hence, even within the same economic expansion period, the vintage effect does not necessarily present the same situation and relies strongly on the content of capital equipment. It may be possible to measure technological progress using the ratio of buildings in net capital stock at the firm level. This issue remains for future research.

## 6 Conclusions

Using the firm-level financial data in Japan, this study empirically examined the relationship between the vintage of capital and productivity. As the foundation of our empirical analysis, we conducted a detailed measurement of capital stock. We then measured the vintage index and total factor productivity and completed the preliminary work for required for our empirical analysis. Subsequently, we reached the following conclusions based on the estimation results.

First, we confirmed the vintage effect by examining the entire period. The effect was particularly distinct in the materials, general machinery and transport machinery industries. Second, we considered time-varying changes in vintage effects and observed them during periods of economic expansions, particularly during the post-2000 economic upturn, where they were generally observed in all industries. We reconfirmed that the rejuvenation of capital equipment during the same period resulted from a strong productivity effect. In contrast, during the late 1980s, despite significantly increased investment, the vintage effect exerted an observable effect on productivity. This finding shows that investment during such periods is not necessarily productive and is highly likely to produce a merely temporary boom.

We made attempts to deeply analyze the factors that determine productivity. In addition to reconfirming the effect of vintage on productivity, we closely examined the time-varying effects of vintage during different business cycles. Our analysis indicates that sustained economic expansion and recovery requires higher productivity and that capital accumulation is significant, effective and necessary for improving productivity. This message must be a valuable lesson to emerging market economies including East Asian countries.

## Acknowledgement

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## Footnote

- 1) We constructed the embodied technological model originally developed by Nelson (1964).
- 2) OECD (2001) is based on the age-efficiency profile, which recommends estimation of macro-/industrial-level capital stock, but when handling industrial data, it can be used only in the concept of aggregating various types of assets such as buildings, construction, machinery and equipment. Therefore, it states that estimation based on the age-efficiency profile is not advisable.
- 3) The phrase ‘one-hoss-shay decay’ is derived from the expression that one-hoss shay had been running for hundred years and suddenly broke down. This phrase is borrowed from a passage in the poem ‘Deacon’s Masterpiece’ by Oliver Wendell Holmes (1809-1894).
- 4) Creating data at the individual asset level, such as a building or piece of machinery, is possible, but coverage of tangible asset increases at that level is roughly 60% of the balance. Therefore, such a detailed approach has not been adopted.
- 5) In this study, GDP deflator is used as a real-added-value deflator and is calculated by dividing the nominal added value by the amount of real output subtracted from real input value. For example, when we calculate this value in the electric industry (1990=1),

it is 87.9 in 1970, 1.92 in 1980 and 0.53 in 1998, and these values change dramatically. Therefore, the deflator is assumed to be common in all industries and this study uses GDP deflator.

6) The definition of personal expenses follows that given in the personal expenses element of corporate statistics by the Ministry of Finance. In many cases, employee benefit costs and provisions for severance pay allowances are recorded together and cannot be separated. Therefore, provisions for severance pay allowances are recorded and included in personal expenses.

7) It is possible to vary  $\alpha$  by industry. In such a case, however, it is difficult to calculate TFP for different values of  $\alpha$  and compare TFP across industries. In addition, we cannot establish panel dataset.

8) The reason why we use value-added and not aggregate products is that the share of intermediate input differs among industries, indicating that it may be dangerous to assume the same proportion between companies producing intermediate inputs and companies outputting them. For example, in the electric industry, a less than 10% proportion of value-added in sales is about 14%, and a more than 30% proportion is 21%.

9) Technically, building, structures and machinery have their own vintages. In general, buildings and structures may have a longer service life than machines. Therefore, the vintage of these assets affects productivity with a time lag and it seems worthwhile to consider the calculation of a vintage index by assets. Acquisition costs and amounts of increases and decreases in buildings, structures and machinery are recorded in the Detailed Table of Tangible Assets in financial statements. Hence we can calculate each vintage based on this information. However, we cannot use current amounts of decreases by assets, and we can only use current amounts of increases by industry from 1978 based on financial data by Development bank of Japan, which we used in this study. These problems cause difficulty in calculating the vintage index by assets. This modification will be a challenge for the future.

10) By considering a simple average of the vintage index in all industries and measuring absolute change, it is about 0.15 year, implying that the effect of vintage on TFP is nearly 0.15%. Considering the fact that the real growth rate of GDP from 1980 to 2007 was 2.5%, the effect of vintage on TFP is about 6%.

11) R&D intensity and the researcher-employee ratio in 16 industries are collected from the *Report of Survey of Research and Development* (Ministry of Internal Affairs and Communications). The definition of research and development investment was changed from experiment and research expenses to research and development in 1998, and the time series of the data was discontinuous. Thus, research data by industry were used in this study.

12)  $\hat{\mu}$  is calculated by subtracting  $\hat{\lambda}$  from  $\hat{\beta}$ .

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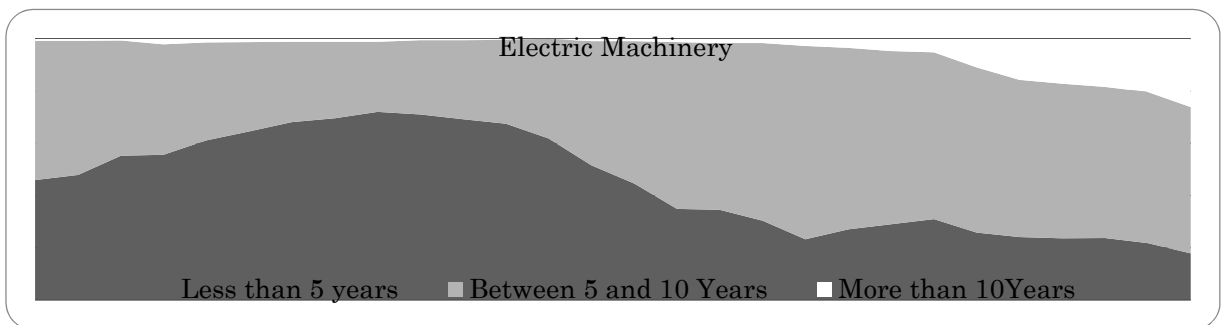
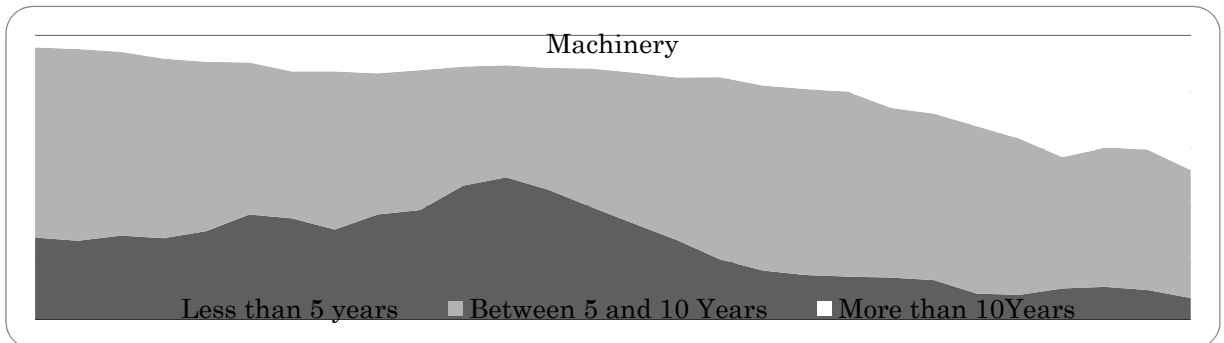
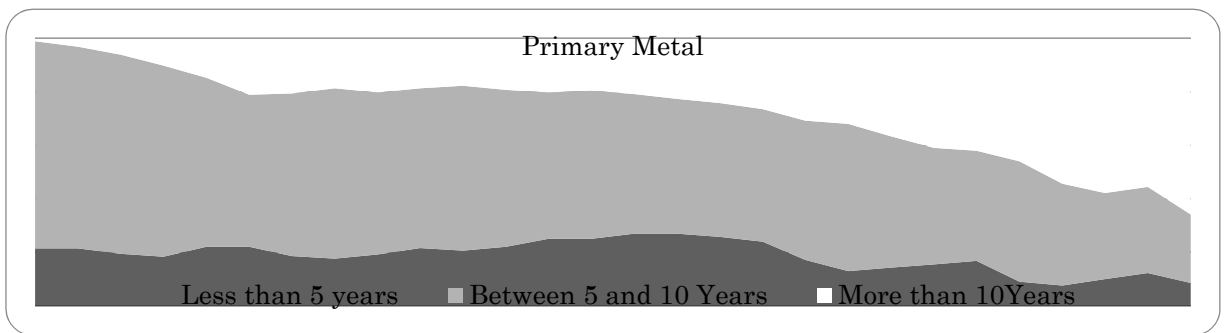
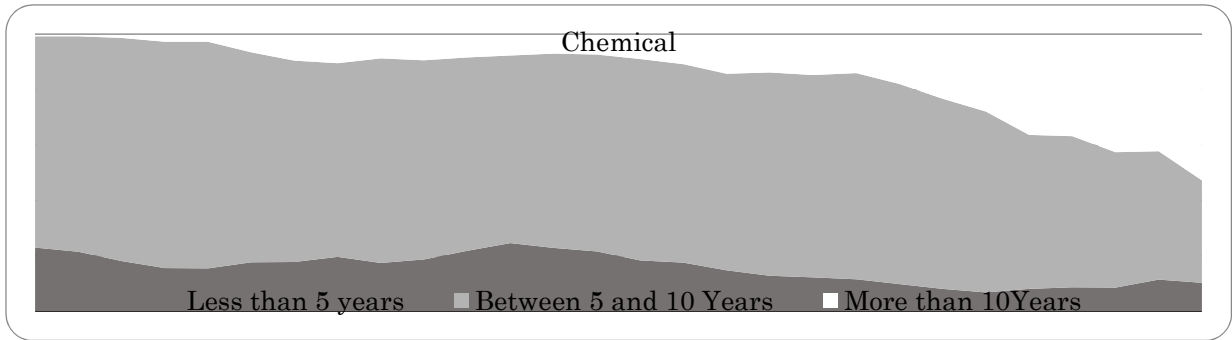
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Figure 1  
Age share of capital vintage 1980-2007



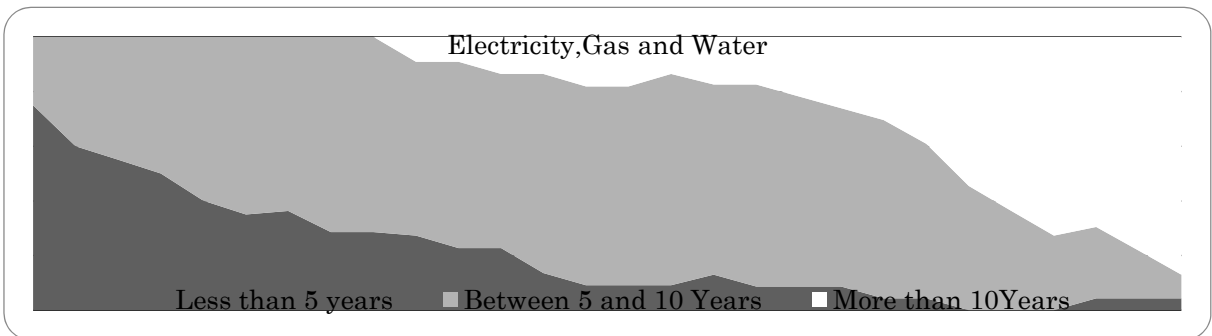
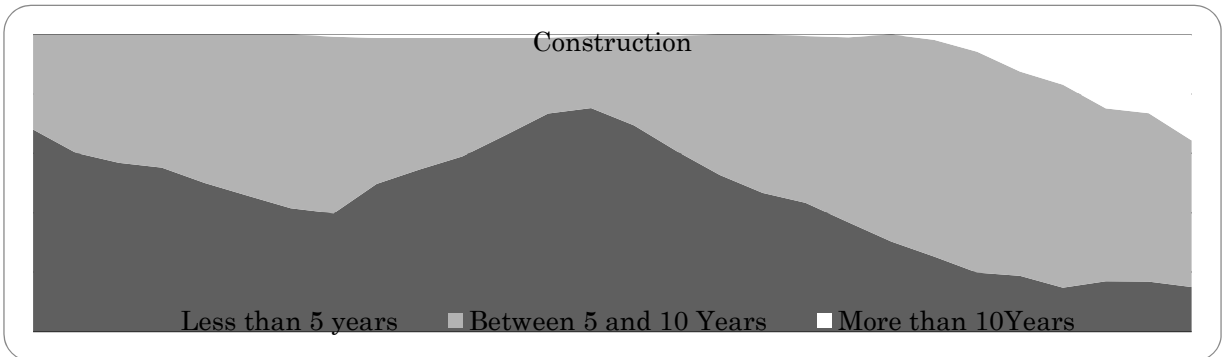
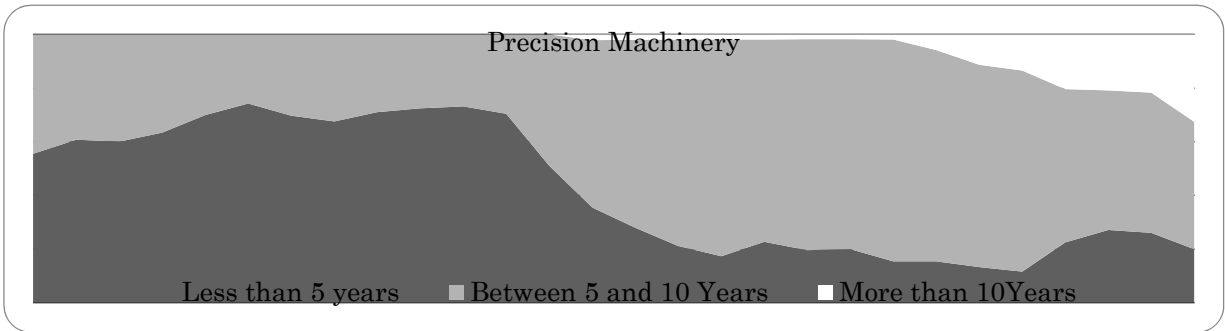
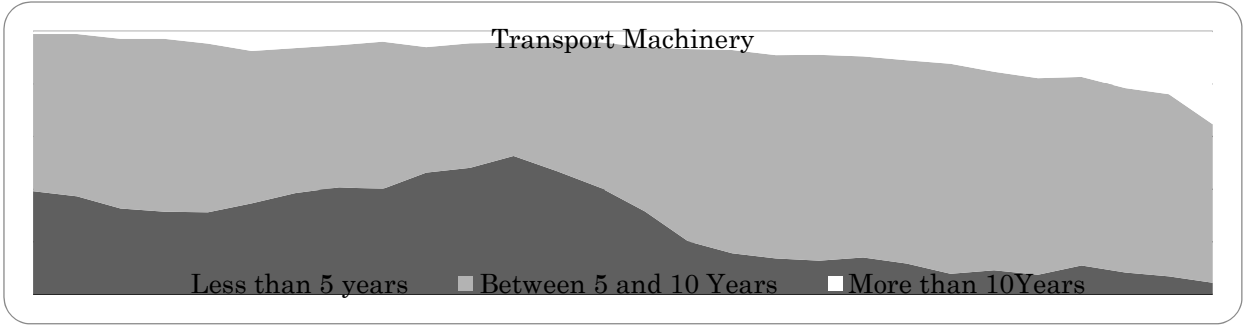


Figure 2  
Vintage Index 1980-2007

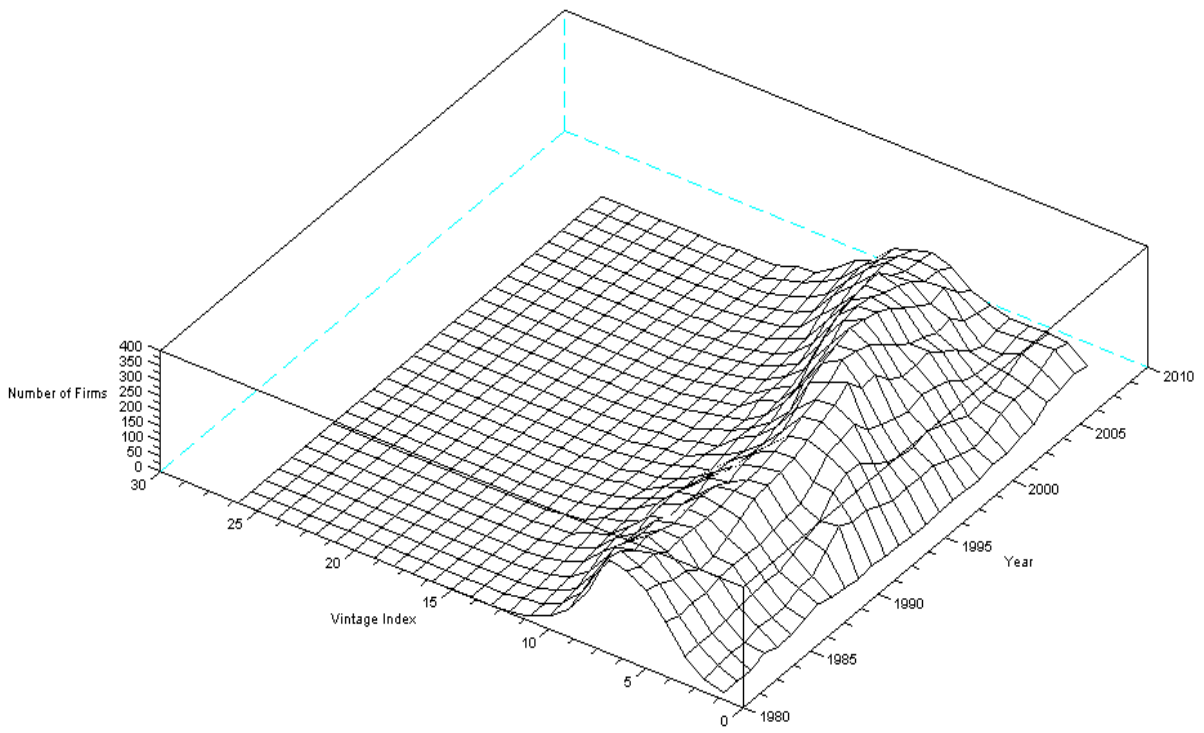
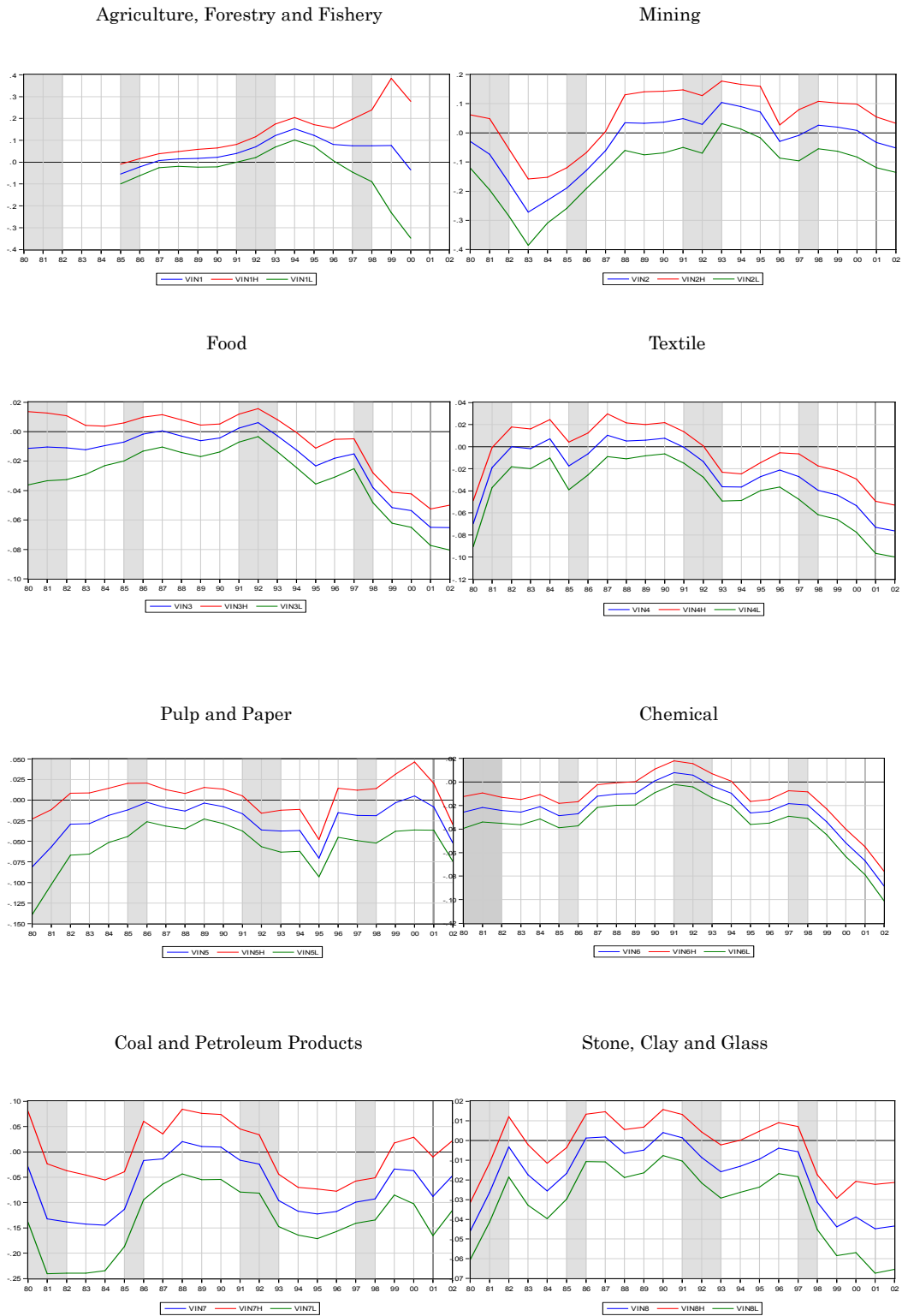
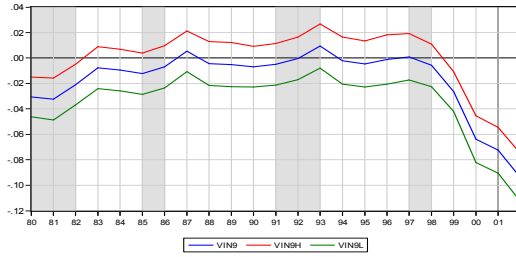


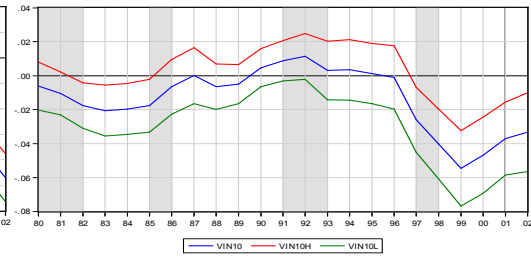
Figure 3  
Estimation Results (2)



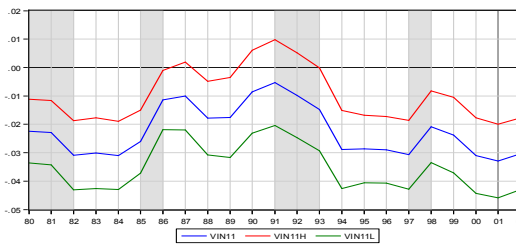
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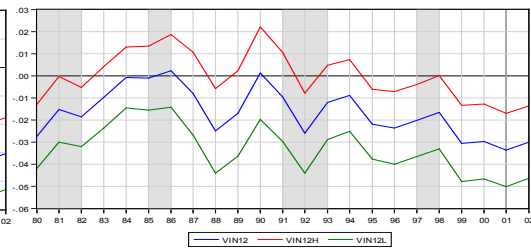
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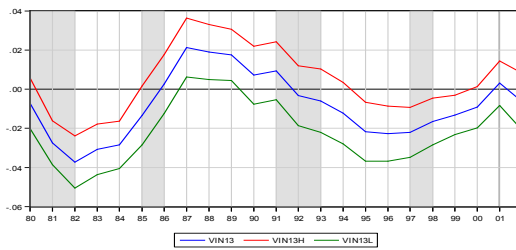
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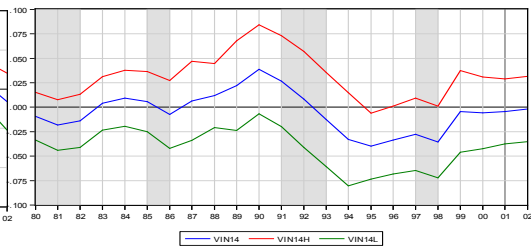
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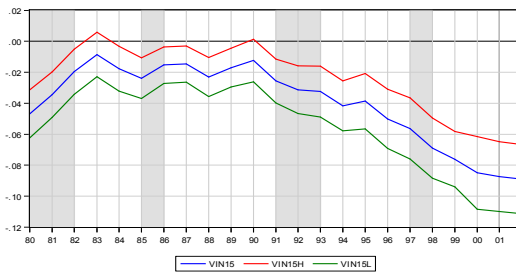
Transport Equipment



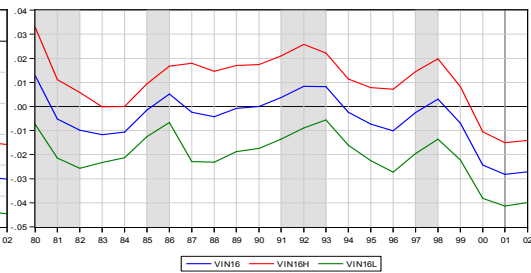
Precision Instrument



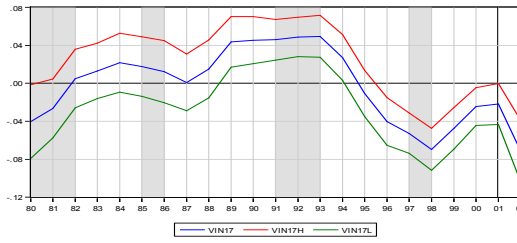
Other Manufacturing



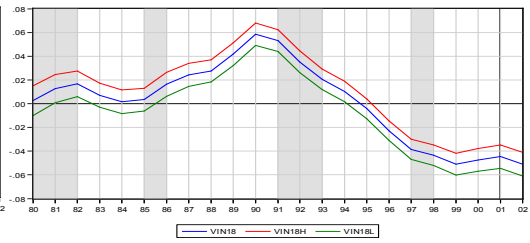
Construction



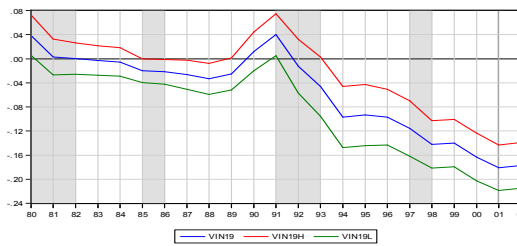
Electricity, Gas and Water



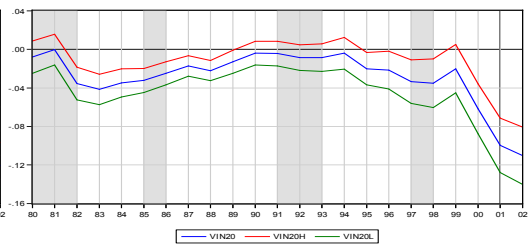
Commerce



Real Estate



Transport and Communication



Service

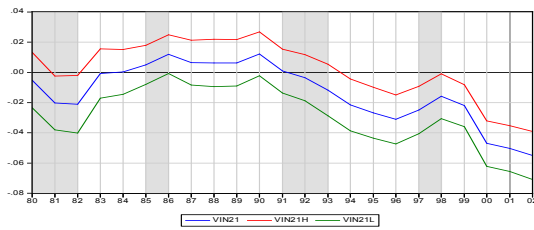


Table 1-1 estimation results (1)

1980-2007

Fixed Effect Model

	Constant	Time trend	Vintage	Group	Obs
All Industry	3.953(8.72)***	0.001(4.64)***	-0.018(-22.88)****	3074	58286
Agr. F. F.	-2.269(-0.36)	0.004(1.27)	0.001(1.18)	2	39
Mining	39.118(3.76)****	-0.017(-3.36)***	-0.045(-2.83)***	7	191
Food	0.811(0.54)	0.002(3.41)***	-0.031(-11.33)***	144	3171
Textile	-2.940(-1.29)	0.004(3.89)***	-0.018(-4.91)***	73	1752
Pulp	24.020(7.14)***	-0.009(-5.45)***	-0.006(-1.07)	37	809
Chemical	3.999(3.54)***	0.0007(1.31)	-0.031(-14.36)***	200	4690
Coal and P.	14.098(1.05)	-0.005(-0.76)	-0.079(-4.62)***	8	208
Stone, Clay	7.494(4.51)***	-0.0007(-0.83)	-0.013(-4.44)***	90	1878
Pri. Metal	2.318(0.97)	0.001(1.45)	-0.019(-4.57)***	114	2649
Fab. Metal	4.701(1.79)**	0.0008(0.64)	-0.021(-4.93)***	88	1901
Machinery	5.730(3.49)***	0.0002(0.24)	-0.009(-3.33)****	245	5511
Elec.	7.859(5.09)***	-0.0008(-1.07)	-0.013(-4.29)***	258	5182
Trans. Eq.	-7.243(-5.30)***	0.006(10.09)***	0.004(1.53)	144	3337
Precision	0.530(0.15)	0.002(1.54)	-0.001(-0.14)	52	1042
Other Man.	2.782(1.50)	0.001(1.82)**	-0.026(-8.46)***	178	3336
Construction	-0.900(-0.67)	0.004(6.01)**	-0.022(-8.35)***	212	4438
E.G.W.	49.820(13.66)***	-0.023(-12.75)***	-0.010(-1.75)*	24	607
Commerce	22.515(18.75)	-0.008(-14.19)	-0.003(-1.91)***	608	9347
Real Estate	16.269(2.63)***	-0.006(-2.02)**	-0.039(-4.52)***	88	1157
Trans&Com	-19.716(-9.07)***	0.013(11.97)***	-0.024(-5.33)***	147	3144
Service	-5.495(-2.38)***	0.005(5.17)***	-0.008(-2.48)***	355	3897

\*\*\*, \*\*, and \* are significant at 1%, 5% and 10% significance level.



Table 1-2 estimation results (2)

1980-2007

Random Effect Model

	Constant	Time trend	Vintage	Group	Obs
All Industry	6.674(14.58)***	-0.0003(-1.63)	-0.012(-14.87)***	3074	58286
Agri. F. F.	-14.427(-1.93)**	0.010(2.70)***	0.0003(0.03)	2	39
Mining	32.141(3.22)***	-0.014(-2.80)***	-0.061(-3.81)***	7	191
Food	1.263(0.83)	0.002(3.02)***	-0.030(-10.57)***	144	3171
Textile	-2.211(-0.97)	0.004(3.55)***	-0.016(-4.24)***	73	1752
Pulp	26.043(7.69)***	-0.010(-6.01)***	-0.002(-0.42)	37	809
Chemical	4.916(4.34)***	0.0002(0.45)	-0.029(-13.16)***	200	4690
Coal and P.	26.536(1.75)*	-0.011(-1.51)	-0.051(-2.30)***	8	208
Stone&Clay	7.958(4.70)***	-0.0009(-1.09)	-0.012(-3.85)***	90	1878
Pri. Metal	4.539(1.86)*	0.0006(0.51)	-0.015(-3.37)***	114	2649
Fab. Metal	3.675(1.34)	0.001(0.99)	-0.023(-4.92)***	88	1901
Machinery	8.912(5.21)***	-0.001(-1.65)*	-0.002(-0.89)	245	5511
Elec. Eq.	9.853(6.25)***	-0.001(-2.34)***	-0.008(-2.75)***	258	5182
Trans. Eq.	-6.052(-4.37)***	0.006(9.06)***	0.007(2.58)***	144	3337
Precision	2.255(0.60)	0.001(1.03)	0.002(0.29)	52	1042
Other Man.	4.822(2.58)***	0.0006(0.66)	-0.022(-6.98)***	178	3336
Construction	-0.731(-0.54)	0.004(5.83)***	-0.021(-7.80)***	212	4438
E.G.W.	52.005(14.42)***	-0.024(-13.52)***	-0.006(-1.10)	24	607
Commerce	25.065(20.67)***	-0.009(-16.21)***	0.001(0.73)	608	9347
Real Estate	40.456(6.75)***	-0.018(-6.23)***	0.002(0.32)	88	1157
Trans& Com	-17.100(-7.77)***	0.011(10.57)***	-0.017(-3.66)***	147	3144
Service	-1.719(-0.73)	0.003(3.37)***	-0.001(-0.44)	355	3897

Table2. Determinants of Rolling Estimated Coefficients of Vintage

2-1 Fixed Effect model

Dependent variable	R&D intensity	Researcher-Employee ratio
$\lambda$	-0.70206 (0.005)	-0.00024 (0.105)
$\mu$	1.15101 (0.000)	0.00082 (0.000)

2-2 Random Effect model

Dependent variable	R&D intensity	Researcher-Employee ratio
$\lambda$	-0.43786 (0.029)	-0.00002 (0.841)
$\mu$	0.86296 (0.000)	0.00066 (0.000)

Table 3 Vintage Coefficient and Components of Capital Stock

	1980-1986		1987-1991		1992-2001		2002-2007	
	Kshare	Vintage coefficient	Kshare	Vintage coefficient	Kshare	Vintage coefficient	Kshare	Vintage coefficient
Agri. F.F.	0.669	-0.038	0.584	0.020	0.663	0.082	0.636	NA
Mining	0.164	-0.157	0.384	0.018	0.335	0.028	0.280	-0.042
Food	0.258	-0.009	0.274	-0.002	0.243	-0.027	0.247	-0.065
Textile	0.241	-0.015	0.269	0.006	0.154	-0.037	0.125	-0.075
Pulp	0.296	-0.033	0.460	-0.010	0.290	-0.024	0.235	-0.030
Chemical	0.283	-0.025	0.424	-0.005	0.259	-0.025	0.248	-0.078
Coal & P.	0.376	-0.102	0.381	0.002	0.489	-0.083	0.519	-0.067
Stone, Clay	0.289	-0.019	0.329	-0.001	0.192	-0.021	0.194	-0.044
Pri. Metal	0.389	-0.017	0.545	-0.003	0.339	-0.017	0.252	-0.083
Fab. Metal	0.391	-0.014	0.234	0.000	0.233	-0.019	0.254	-0.035
Machinery	0.153	-0.025	0.157	-0.012	0.101	-0.025	0.111	-0.032
Elec. Eq.	0.375	-0.010	0.237	-0.012	0.136	-0.022	0.123	-0.032
Trans. Eq.	0.195	-0.020	0.320	0.015	0.158	-0.012	0.115	-0.002
Precision	0.310	-0.004	0.096	0.021	0.066	-0.019	0.063	-0.003
Other Man.	0.198	-0.024	0.182	-0.019	0.188	-0.057	0.185	-0.088
Construction	0.241	-0.003	0.315	-0.001	0.178	-0.006	0.079	-0.028
E.G.W	0.704	0.000	0.564	0.030	0.491	-0.014	0.452	-0.046
Commerce	0.521	0.009	0.564	0.041	0.418	-0.019	0.299	-0.048
Real Estate	0.992	-0.001	0.988	-0.007	0.983	-0.109	0.994	-0.179
Trans& Com	0.553	-0.025	0.570	-0.012	0.550	-0.031	0.582	-0.105
Service	0.509	-0.004	0.398	0.006	0.285	-0.025	0.174	-0.053

K share is industry share of building in capital stock (shaded are is the highest share). Vintage coefficient is average of estimate in Figure 3.