Capital Accumulation, Vintage, and Productivity: The Japanese Experience from 1980 to 2007

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Abstract

In this paper we quantitatively examine the relationships between capital accumulation and vintage, as well as productivity of industries in Japan between 1980 and 2007. We based this analysis on a detailed measurement of capital stock as reported in financial data of firms listed on the Tokyo Stock Exchange and several secondary markets, like Mothers, We measured the vintage index and total factor productivity and carried out preliminary work required during empirical analysis. Subsequently, we conducted different kinds of estimations. Based on the empirical analyses, we confirmed that vintage had an effect on productivity in all industries studied. This effect was notable in the material, general machinery and transport equipment industries. In addition, by observing chronological changes of the vintage effect, we confirmed that vintage exerted a significant influence during the period of economic expansion,.particularly during the economic upturn which started in 2000, where strong vintage effects were generally observed in all the industries. It was clear that the rejuvenation of capital equipments during that period resulted out of the existence of a strong productivity effect. On the other hand, during the bubble period of late 1980s, vintage exerted no observable effects on productivity despite vivacious increases in investment.This shows that investment during this period was not necessarily productive and was likely to produce just a temporary boom. In light of this, we reconfirmed that the relationship

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between vintage and productivity changed in subtle ways in response to the phases of economic cycles.

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1. Introduction

After the collapse of the bubble economy in the early 1990s, the Japanese economy experienced almost 10 years of recession, termed as the 'ten lost years'. Many factors have been suggested as causes of this long-term stagnation, but the most prominent is the argument citing Japan's decrease in productivity. Hayashi and Prescott (2002) expounded a sensational message that the prolonged decline of total factor productivity (TFP) in Japan was the root of the economic stagnation and heated discussion has revolved around the trend of productivity in Japan ever since. However, the discussion seems to center on measurement methods of productivity, productivity by industry and characteristics by firm. There seems to be less focus on the question of 'What factors influence productivity'? Therefore, this study identifies the mechanism of the determination and fluctuation of productivity in relation to capital accumulation and examines in detail the concept that new technology is embodied in new capital. Such an observation should allow us to reaffirm the multidimensional role of capital accumulation i.e.investment in equipment and register, insights into the relationship between productivity and the macro-economy in post-1980s Japan.

This study is constructed as follows. Section 2 introduces the concept of capital vintage and provides a detailed overview of prior studies regarding capital vintage and productivity. Section 3 presents the theoretical model at the basis of this analysis. Section 4 explains the data, followed by a detailed report of the demonstration results. Conclusions obtained in this analysis are summarised in the final section.

2. Overview

The study of capital accumulation and growth in a country's economy dates back to the research of Harrod and Domar and their findings are still studied as critical themes in macro-economics. Capital accumulation and increased investment in equipment generates economic growth through an expansion of production capacity while increasing effective demand through a multiplier process. However, in the discussions of Harrod and Domar, the relationship among capital accumulation, technological progress and economic growth is not always explicitly examined. Research into the relationship of technological progress and capital accumulation in economic growth was left to later studies.

On the other hand, in the 1950s, growth theories under the full employment economy were beginning to be actively researched by economists such as Solow and Swan (1956). This era brought in the flourishing of the 'neo-classical growth theory'. These theories, under a full employment economy, explicitly discussed the role of technological progress and the types of technology but regarded these factors as exogenous, like manna from heaven. Neo-classical growth theory, later in the form of an endogenously assumed savings rate, develops as the optimum growth theory during and after the 1960s. However, that period featured interesting thinking about the impact of endogenous technological progress on economic growth. Arrow (1962) argued that accumulation of experience in economic agents, particularly in firms, induces productivity, or, in other words, technological progress. According to Arrow, introduction of new machinery and equipment, i.e. new investment in equipment, provides learning opportunities for labourers involved in production. Higher productivity through their learning appears as technological progress that accelerates economic growth.

Solow (1960) investigated investment in new equipment from an aspect different from Arrow (1962). He considered new machinery and equipment to include novel technology, different from conventional technologies and asked whether introduction of unconventional equipment improves productivity more than conventional technology. While Arrow emphasised workers' improved adaptability following introduction of new equipment, 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 was installed indicates the level of technological standard. Therefore, by naming the age of the equipment 'vintage', Solow theoretically clarified the relationship of capital accumulation, technological progress and economic growth. Solow (1960) also attempted a quantitative analysis in which he set and estimated a production function that has real capital embodying technological progress as the production factor and calculated the rate of embodied technological progress. Nelson (1964) followed Solow's (1960) idea, 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 the capital is undergoing extensive analyses in the same direction of productivity fluctuation in an actual macro-economy. Since the 1970s, productivity has been declining in major developed countries such as the United States. In view of this circumstance, 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 over 1965–1973 to 1973–1978, only 0.1% is accounted for by the decline of embodied technological progress.

Analysis of the embodiment hypothesis was pursued vigorously in the 1990s, likely because U.S. productivity rose notably during the latter 1990s. In the U.S., the growth rate of equipment investment, centering on IT, accelerated from an average 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, 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 speed as is represented in Moore's Law and may suggest a clear relationship between capital vintage and productivity. Recognizing that possibility, academia revived the embodiment hypothesis. Wolff (1991, 1996) applied Nelson's (1964) method to examine the G7 countries at the industry level. Wolff (1991) explained the productivity decrease of the 1970s and in 1996 examined the productivity in 1973. Both analyses demonstrated that the 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) analysed the embodiment hypothesis within the long-term time-series 1949–1983 using capital goods prices adjusted by quality. According to Hulten, approximately 20% of the TFP growth rate 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 rate of contribution of the embodied technological progress differs little between the two periods. Gittleman et al., (2006) conducted a detailed analysis in which they re-calculated TFP considering the economic obsolescence rate associated with capital vintage and the depreciation rate of capital stock. Their analysis based on the data between 1947–1997 from the U.S. Bureau of Economic Analysis (BEA) pointed out that the rate of technological progress embodied in capital is approximately 5% of the TFP growth rate. Sakallearis (2001) utilised Nelson's (1964) framework in analysing 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 micro-data at the firm level are being pursued vigorously. Bahk and Gort (1993) attempted to estimate the production function with labour, human capital, physical capital and capital vintage as production factors in considering the learning process in productive activities. Their investigation used panel data of 2,150 plants. Power (1998) used micro-data from about 14,000 plants in American manufacturing between 1972 and 1988 in his analysis. 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. Sakallearis and Wilson (2004) utilised Nelson's (1964) framework in analysing micro-data of 24,000 plants in American manufacturing between 1972 and 1996. According to their findings, the rate of technological progress embodied in capital accounts for 8%–17% of the TFP growth rate.

Interest in the embodiment hypothesis is longstanding in Japan. Watanabe and Egaitsu (1967) confirmed quantitatively using Nelson's (1964) method that the embodiment hypothesis was established during the Japanese economy's high-growth period (sample period is 1952–1962). However, when Japan entered its low-growth period during and after the late 1970s, the increasing age of capital associated with faltering capital investment was pointed out and the resulting stagnation of productivity became worrisome. The Japan Development Bank (1979) conducted a pioneering attempt that estimated the vintage series in Japan and this was followed by a more sophisticated vintage calculation by Japan Development Bank (1981,1983,1984), Kuninori and Takahashi (1984) and Suzuki and Miyagawa (1986). After the stagnation of 'the ten lost years', active discussion regarding productivity and economic growth in Japan occurred in the 2000s. Hayashi and Prescott (2003) opened the discussion. The works of Miyagawa and Hamagata (2006) and Tokui, Inui and Ochiai (2008) are fascinating attempts in this trend that have analysed in detail the relationship of capital accumulation, capital age and productivity in the context of Japan's long-term recession.

Miyagawa and Hamagata (2006) captured the qualitative improvement of 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 late 1980s from two aspects: the consideration of capital vintage and the introduction of new technology on implementing large-scale equipment investment (investment spike). Their intriguing conclusions are that new technological progress likely will be introduced along with large-scale investment and will be embodied in capital goods of young vintage.

Unlike these quantitative analyses, the Development Bank of Japan (2005) sought detailed data about Japanese equipment investment through a questionnaire survey of individual firms. This survey investigates interesting matters, uniquely allowed for awareness surveys, such as (1) the level of awareness of equipment aging, (2) disadvantages of aging equipment and (3) prospects for future equipment age. Based on its 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 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 in an approach consistent with the calculation of capital stock. The traditional calculation of capital stock used accounting methods on disposal amounts by way of the declining balance method and the straight-line method to calculate capital stock. Nevertheless, this assumption is strictly based on an accounting concept and does not reflect actual physical depletion. Hence, this study calculated the gross capital stock based on acquisition cost and successfully measured the capital vintage in a manner consistent with this calculation. Although there are many prior studies regarding capital vintage and productivity, but this study's analysis, which calculates capital vintage time-series by firm using micro-data, is unprecedented. This study's second notable contribution is in using vintage series to analyse fluctuation factors of productivity in detail. Its third contribution is a detailed examination of how the effects of vintage on productivity relate to the economic cycle. This point also has not been fully explained in traditional quantitative analyses.

3. Model

The theoretical framework used as a base for this analysis is essentially identical to that presented in Nelson (1964). Various firms build up capital stock in the form of Equation (1).

$$K_t = K_{t-1} + I_t \qquad (1)$$

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

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

Currently (period t), firms decide the production level (Y_t), based on the labour input level of period t (L_t) and the capital stock of the end of period t-1. In this situation, from the capital stock at the end of period t-1, the production level is represented by Y_{ts}, based on the capital equipment (I_{t-1s}), of period s ($v = s \leq t-1$). When the firms are equipped with the Cobb-Douglas production function structure, they can be represented by

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

In this situation, L_{ts} represents the number of employees at period t who operate the capital equipment installed at period s ($s \leq t-1$) and A_{ts} represents the technology level at period t of capital equipment installed at period s. Equation (4) can be derived from the maximum profits of the firm and with the most suitable labour input.

$$L_{ts} = \frac{\alpha P_t}{w_t} Y_{ts} \tag{4}$$

Equation (5) can be derived by rearranging the formula, after substituting Equation (4) into Equation (3).

$$Y_{ts} = A_{ts}^{\frac{1}{1-\alpha}} \left(\frac{\alpha P_t}{w_t} \right)^{\frac{\alpha}{1-\alpha}} I_{t-1s} \tag{5}$$

At this point, the capital stock at the end of period t-1 will be accounted for and the production level of the current period (t) can be edited to be similar to Equation (6), when the proportion of investments of period s at the time of establishment is assumed to be θ_{ts} .

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

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

TFP can be defined with Equation (7).

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

Equation (8) can be derived by rearranging the equation after substituting Equation (6) into Equation (7).

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

The technological progress is set according to the exponential figure below.

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

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

When s is larger, in other words when the date of capital establishment is closer, the level of technological progress will be larger.

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

At this point, perform a Maclaurin expansion near λ=0 on the 3rd item on the right of Equation (10) and rearrange to obtain Equation (11).

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

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

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

From Equation (12), it is shown that the vintage index is dependent on two elements: the time of equipment installation (s) and the proportion (θ_{ts}) of equipment that accounts for the capital stock of period s at the end of period t-1. In other words, when installation time is recent and the value of s approaches t, the vintage index decreases and this value will be more prominent when the proportion of new equipment increases. Using this vintage index, final TFP can be expressed as Equation (13) by re-writing Equation (11).

$$\ln(TFP_t) = \ln(B) + (\mu + \lambda)t - \lambda Vin_t \tag{13}$$

From Equation (13), it is known that TFP can be explained by the constant value, time trend and vintage. For $\lambda \geq 0$ as shown in (9), the coefficient value of the time trend can be assumed to be positive. In addition, when the vintage index is smaller, in other words depending on the recent active equipment investments, when the capital equipment is rejuvenated, the scale of the increase of TFP can be expected.

4. Data

4-1 Calculation of the capital stock

There is a demand for carrying out estimation of the capital stock data with the data of production capabilities that is needed for the estimation of productivity. There are two differences between capital stock in terms of production abilities and tangible fixed assets, in accounting terms. First, tangible fixed assets with the depreciation subtracted from the balance sheets are accounted in net capital stock (KNN) and the purchase cost, including accumulated depreciation, carried the tangible fixed assets schedule is accounted for as gross capital stock (KGN). The capital stock with production abilities as an index can be measured by the existing amount of equipment. With this, it is preferable to be the gross capital stock[1]. For accounting purposes, fixed tangible assets is a nominal value, but because the capital stock as an index of production abilities is represented by the amount of equipment, there is need for a real concept.

Based on the macro or industrial level, there are two methods of measuring real gross capital stock: the benchmark method and the perpetual inventory method. At the firm level, other than the methods stated above, Griliches and Mairesse (1984) is realised with the deflator (PI) of the average age of equipment (AA_t) and the nominal gross capital stock (KGN).

$$K_{Griliches}(t) = KGN(t) \times \frac{PI(1972)}{PI(t - AA_t)} \tag{14}$$

The average age of equipment (AA_t) is defined by subtracting the amount of accumulated depreciation (CDEP) from the average service period of the five-year moving average of the nominal gross capital stock (KGN)/depreciation amount[2]. This method reflects the changes of the deflator ($PI(t\text{-}AA_t)$) of the current period and presents the possible problem of causing more changes to the real capital stock than to nominal capital stock (KGN).

To calculate firm-level capital stock using the benchmark method[3], real investment (INt/PIt) and the physical depletion rate (δ) can be calculated using

$$K_{BYM}(t) = (1 - \delta) K_{BYM}(t-1) + IN(t)/P(t) \tag{15}$$

with the initial nominal capital stock as a benchmark. The initial value to be used as a benchmark is affected by the estimation results.

Our study adopted the perpetual inventory method.[4] Nominal gross capital stock (KGN) is obtained from the current volume of previous investments. With the proportion of the equipment of year t installed in year v assumed, ϕ as real gross capital stock (KGR), can be obtained with the deflator (PI) of the various periods of past investments.

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[1] OECD (2001) is based on the Age-Efficiency Profile, that recommends estimation of macro / industrial level capital stock, but when handling industrial data, it can only be used in the concept of aggregating various kinds of assets such as buildings, construction, machinery and equipment etc. Therefore, it states that estimation based on Age-Efficiency Profile is not advisable.

[2] Using the same method, Hall (1990).

[3] See Hayashi-Inoue(1991).

[4] The method was adopted in Tokutsu (1981) and Tokutsu-Hagiwara (1992).

$$KGN(t)=\sum_{v=-\infty}^{t}\phi(v,t)IN(v) \tag{16}$$

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

$$KGR(t)=\sum_{v=-\infty}^{t}\phi(v,t)\frac{IN(v)}{PI(v)} \tag{17}$$

When compared to the capital stock of the previous period[5],

$$KGR(t)=KGR(t-1)+\frac{IR(t)}{PI(t)}-SR(t) \tag{18}$$

$$SR(t)=\sum_{v=-\infty}^{t-1}[\phi(v,t-1)-\phi(v,t)]\frac{IN(v)}{PI(v)} \tag{19}$$

This paper estimates gross capital stock assuming 'One-Hoss Shay Decay'. In other words, the data used in

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

The data from the tangible fixed assets schedule is recorded in the annual report which listed companies are obligated to report and disclose to the Financial Services Agency. The tangible fixed assets schedule includes such items as the increase in current-period tangible fixed assets (IN), the decrease in current-period tangible fixed assets (SN), balance 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) tangible fixed assets (net capital stock: KNN). In these periods, the below mentioned relations are established.

$$KGN_t=KGN_{t-1}+IN_t-SN_t \tag{20}$$

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[5] In case of fixed percentage in reducing balance method,

$$\phi(v,t)=(1-d)\phi(v,t-1),\quad \phi(v,v)=1.$$

In case of straight line method

$$\phi(v,t)=\begin{cases}1/T & v\le t\le v+T\\ 0 & v+T<t\end{cases}.$$

Although these rules are adequate in accounting, capital stock as production capability does not decay under such rules.

$$KNN_t = KGN_t - CDEP_t \qquad (21)$$

In the Japan Development Bank Corporate Finance data bank, total tangible fixed assets, buildings, structures, machinery, ships, vehicles and transportation equipment, tools, rental fixed assets, other depreciable asset, land and construction in process account are categorised. In addition, the increase in current-period tangible fixed assets (IN), current-period tangible fixed assets decrease (SN), end-of-period balance 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) are recorded. Current-period depreciation amount, total amount and construction-in-process account are not recorded into the database. In addition, the increase in amount in the current period is small compared to the acquisition cost recorded. Consequently, using 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 can be achieved by adding to the increased amount if the gap is positive and adding the absolute value to the decreased amount when the gap is a negative value.

Depreciable assets are defined by subtracting non-depreciable assets (land, construction-in-process account, etc.) from the total amount[6]. The acquisition cost (Nominal Gross Capital Stock: KGN) related to depreciable assets is estimated based on the amount of the current-period increase (Nominal investment: IN) and the amount of current-period depreciation (Nominal retirement: SN) based on the following procedures. Also, the acquisition cost in the most recent period (t = t1) when dated back to the past and subtracting from the amount of the current period increase, the point in time (v_t) at 0 or negative in the beginning is determined. In other words, v_t is

$$\sum_{s=v_t+1}^{t} IN_s < KGN_t \le \sum_{s=v_t}^{t} IN_s \qquad (22)$$

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

$$\omega_t = \frac{KGN_t - \sum_{s=v_t+1}^{t} IN_s}{IN_{v_t}}, \quad 0 < \omega_t \le 1 \qquad (23)$$

[6] Making data at individual asset level, like building or machinery is possible, but coverage of tangible asset increase at the level is about 60% of its balance. Therefore such detailed approach is not adopted.

and after period v_t +1, the summation of investments until the aforementioned point in time is comprised of the acquisition costs at the point in time, t.

$$KGN_t = \omega_t IN_{v_t} + \sum_{s=v_t+1}^{t} IN_s \tag{24}$$

By following this approach, it is possible to determine which investments comprise capital stock in each period and to create an accurate measure of real gross capital stock. Using even the oldest data, the acquisition cost fails to reach zero or negative at point in time v (period t_d). Proceed with retroactive estimation of the amount of the current-period increase (IN_t). If the most recent service life is available ($\theta_{td+1}=t_d+1-v_{td+1}$)[7], fix the value and use it. The amount of current-period depreciation (SN_t) will correspond to the current-period increase amount of （$t-\theta_{td+1}$）.

$$IN_{t-\theta_{td+1}} = SN_t \ , \ t_0 \le t \le t_d \tag{25}$$

From $IN_{t-\theta_{td+1}} = SN_t \ , \ t_0 \le t \le t_d$, retroactive business affiliation of the investments can be achieved. By using this data, the procedures in the first stage can be continued.

This is the same as executing the benchmark method, but it has a unique characteristic of processing with the service life obtained from the recent perpetual inventory method when realising current-period depreciation.

Firm data from portions of 1956 to March 2008 (FY 2007) can be used. Among the 74,918 in the 1980–2007 data sample, 58,701 cases (78%) of capital stock data have been created. The service life of 93% of these cases is not fixed and by using the available data for amounts of the current-period increase, the real gross capital stock data are created. The number of firms in the various years is displayed in Figure 1.

4-2 Creation of the Vintage Index

The vintage index is determined by the average age of existing equipment.

$$Vin = \frac{\sum_{v=-\infty}^{t} (t-v)\phi(v,t)IR(v)}{KGR(t)}$$

(26)

With diminishing-balance depreciation as a prerequisite, we can obtain:

7 In case the most recent service life is not available, we abandon making data of the firm.

$$Vin_t = \frac{\sum_{v=-\infty}^{t} v(1-d)^{t-v} IR(v)}{KGR(t)} \tag{27}$$

$$\begin{aligned} Vin_t KGR(t) &= \sum_{v=-\infty}^{t} (t-v)(1-d)^{t-v} IR(v) \\ &= IR(t) + (1-d)\left[\sum_{v=-\infty}^{t-1} (t-1-v)(1-d)^{t-v} IR(v) + \sum_{v=-\infty}^{t-1} (1-d)^{t-1-v} IR(v)\right] \\ &= IR(t) + (1-d)\left[Vin_{t-1} KGR(t-1) + KGR(t-1)\right] \end{aligned} \tag{28}$$

$$Vin_t = \frac{IR(t)}{KGR(t)} + (1-d)(1+Vin_{t-1})\frac{KGR(t-1)}{KGR(t)} \tag{29}$$

With the initial Vin0 as an assumption, calculation can be done sequentially. In the industry-level research of Japan[8], Vin_{1970} is calculated as 7 years, based on the national wealth survey conducted in 1970.

Mairesse (1978), who calculated the vintage index for firm levels, has set the vintage index of the oldest possible useable data and created the vintage index under the prerequisite that there is no scrapping. Following this method, this draft is able to create a consistent vintage index and measure of capital stock at the firm level without assuming an initial vintage index, like Vin_{1970}.

$$Vin_t = (t - v_t)\omega_t \frac{IN_{v_t}/PI_{v_t}}{KGR_t} + \sum_{s=v_t+1}^{t} (t-s)\frac{IN_s/PI_s}{KGR_t} \tag{30}$$

TFP is defined by using real value added, real gross capital stock of the previous end of period （KGRt-1）, number of employees (L) and the average distribution rate of industries (α), into the formula

$$TFP = \log VR_t - \alpha \log KGR_{t-1} - (1-\alpha)\log L_t \, . \tag{31}$$

At this point, rK = depreciation + interest and discount expense + rent + ordinary income + taxes, WL = labour cost + officers' bonuses + salaries and allowances + provision of allowance for bonuses + welfare expenses + provision of allowance for employee retirement benefits, real value-added (VA) = rK + WL obtained by dividing the GDP deflator. Profit parameter (α) is obtained from the average value of the profit distribution rate of the corresponding industry between 1980 and 2007. The number of employees (L) is the number at the end of the period.

Figure 2 shows changes in the vintage index of the various industries. With regard to subtle differences in trends in different industries, we can see in panoramic view that vintage increased during

8 See Miyagawa-Hamagata (2006)

the period of economic recession and decreased during the period of economic expansion. This is particularly so during the bubble of the late 1980s and the boom (Izanami period) after 2000, where vintage decreased steadily. During economic expansion, capital equipment was rejuvenated on the back of the increase in capital investment and this resulted in the decrease in vintage. In contrast, during economic recession, because of stagnation in installation and renewal of new equipment and the increase in age of equipment, the vintage index also increased. This trend can be observed in the diagram, thereby confirming our measurement of the vintage index was correct.

5. Empirical Evidence

5-1 Estimation Results (1)

First, we conducted estimations for the period 1980–2007. Table 1 shows the summary of the random effects model and Table 2 shows the summary of results of the fixed-effects model. We targeted 13 manufacturing industries, eight non-manufacturing industries and all industries for estimation purposes. The method of estimation was based on Equation (13) drawn from Section 3. The specific method of estimation is given in Equation (32):

$$LTFP_{it} = \alpha + \beta trend + \gamma Vin_{it} + \varepsilon_{it} \qquad (32)$$

$$LTFP_{it} = \ln(TFP_{it}) \qquad \alpha = \ln(B) \qquad \beta = \mu + \lambda \qquad \gamma = -\lambda$$

The LTFP here represents the logarithm value of total factor productivity. The trends represent the time trends and Vin represents the vintage index that was measured in advance. As the dependent variables are logarithm values, the coefficient β and γ represent the semi-elasticity. The coefficient γ is expected to be negative because the smaller the value of the vintage index, that is, the younger the equipment age of the capital stock, the stronger will be the effects of productivity improvement.

The following discussions and explanations are based mainly on results of the random effects model and, where appropriate, point out differences with the fixed-effects model. The vintage coefficient was significant across all industries and recorded a value of 0.01. This means that once the average age of capital increases by one year, total factor productivity will fall to 0.01%. Breaking down the manufacturing industries into the materials industry (pulp and paper, chemicals, coal and petroleum products, stone, clay and glass, primary metal and fabricated metal) and the machinery industry (4 types of machines), we see that the effect of the vintage coefficient was stronger in the materials industry. This trend is also observed in the fixed-effects model. In general, the materials industry is made up of heavy industries, where set-up and installation of capital equipment are infrequent. This means that despite the lower frequency of renewal of capital stock in the materials industry compared to the machinery industry, at renewal time it is highly likely that new technology introduced will be markedly different from the previous technology. For example, in the petroleum refining and chemical industries, the vintage coefficient values are relatively higher, which highlight such characteristics. Even in non-manufacturing industries, slightly different results are obtained in the fixed-effects model even though vintage coefficients are significantly negative.

The impact of the trend (β) differs across industries. In the random effects model, the vintage has a significant positive impact on all industries. This suggests that between 1980 and 2007, there were factors that backed the uptrend in total factor productivity on a macroeconomic level in Japan. However, after examining the details closely we were unable to detect these characteristics in the materials industry at all, leaving us to postulate that the factor driving the uptrend must have been in non-manufacturing.

Finally, we shall discuss the impact on the constant term. The constant term (α) is different from the factors behind the trend, as can be seen in Equation (9) in the theoretical model of Section 3. Instead, it represents a technology improvement factor. This factor is of no relation to temporal changes such as economic cycles and economic expansions, but it is believed to be a factor which reflects a range of industry-specific management attitudes regarding research & development and new products. This factor is significantly positive across all industries. We were able to confirm that factors not seen as linked to uptrend and vintage actually spurred total factor productivity. These effects may differ slightly across industries, but we were able to observe a positive effect on the whole.

5-2 Estimation Results (2)

Next we shall present estimations by industry. Table 1-1 and Table 1-2 show estimations based on Equation (12) and results of the estimation (rolling regression) conducted on 22 industries on a year-by-year basis. During the estimation period of six years, the initial estimation period occurred between 1980 and 1984, while the last estimation period occurred between 2000 and 2007. The shaded portion shows the period that was determined as the economic recession period by the Cabinet Office.

During the economic expansion period in the first half of the 1980s, the vintage coefficient was significantly negative in the industries in general. This shows that the increase of new equipment investment backed by economic expansion, rejuvenated the age of the capital equipments and thereby spurred an improvement in productivity (hereafter referred to as the ‘vintage effect’). This vintage effect was confirmed during the Izanami boom period starting from 2002. The effect was especially distinct in the primary metal and chemical industries within the materials industry and in the general machinery and transport machinery industries within the machinery manufacturing industry. This growth period lasted longer than the Izanagi economy 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 spiked exports in Japan's materials 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 materials industry.

We shall now focus on characteristics of the 1987–1991 expansion. During this period, the capital equipment boom was larger than the Izanami boom after the 2000s, but the vintage effect was less strong, as the diagram shows. With regard to the materials industry in particular, industries with positive vintage coefficient values were sporadic and few. In other words, despite buoyant capital investment during the bubble period, the rejuvenation of the age of capital equipment did not necessarily bring about an improvement in productivity.

To explore the reasons for this phenomenon, we conduct two complementary investigations. First, the rolling estimated coefficients of vintage in Equation (17) are regressed by the intensity of research and development (abbreviated R&D intensity) and by the researcher-employee ratio[9]. To investigate that regression, we selected two types of dependent variables: the coefficient of embodied technological progress ($\hat{\lambda} = -\hat{\gamma}$ in Equation (17) and the coefficient of disembodied technical progress ($\hat{\mu}$ in Equation.(17)) [10] . The estimation results appear in Table 2. Both R&D intensity and the researcher-employee ratio exert positively significant effects on disembodied technical progress ($\hat{\mu}$). These explanatory variables, however, do not show the correct sign. That indicates the enforcement of research and development stimulates disembodied technological progress and it does not necessarily link to embodied technological progress. In this complementary estimation, industrial level data (16 industries) is used 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 looked at the share of non-factory buildings (dormitories, employee recreation centres and others) included in capital stock during the various periods and we examined changes in that share. Capital equipment in these facilities did not necessarily feature the latest technology and did not directly instigate improvements in productivity. Table 2 shows the share of buildings, excluding factory facilities, in various industries (recorded as Kshare). In addition, we recorded the average values of the coefficients during the period, which were measured according to rolling estimation. From this table we see that more than half of the periods which registered the highest Kshare were from the bubble period. During the same period, we also see that vintage coefficient values were remarkably low compared to other periods. In contrast, during the Izanami boom after 2000,

9 R&D intensity and researcher-employee ratio in 16 industries are collected from the *Report of Survey of research and development* (Ministry of Internal Affairs and Communications).

10 $\hat{\mu}$ is calculated by subtracting $\hat{\lambda}$ from $\hat{\beta}$.

Kshare was comparatively low while 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 is strongly reliant on the content of the capital equipment.

6. Conclusions

Based on the financial data of listed companies, this paper quantitatively examined the relationship between the vintage of Japanese capital equipment and productivity. As the foundation of our empirical analysis we conducted a detailed measurement of the capital stock. We next measured the vintage index and total factor productivity and completed the preliminary work required during empirical analysis. Eventually we reached the following points based on results of our estimations.

First, we were able to confirm the vintage effect by examining the entire period. It was especially distinct in materials, general machinery and transport machinery industries. Second, we looked at temporal changes in vintage effects and observed them during periods of economic expansion, 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 was a result of strong productivity effect. On the other hand, during the late 1980s, despite vivacious increase in investment, the vintage effect exerted observable effect on productivity. This shows that investment during this period was not necessarily productive in reality and is highly likely to be just a temporary boom.

We have made negligible attempts to deeply analyse the factors that determine productivity. Besides reconfirming the effect of vintage on productivity, we succeeded in examining closely the multi-faceted role vintage plays during different economic cycles. The global economy still has not shown clear signs of recovery; however our analysis shows that sustained economic expansion and recovery requires higher productivity and that capital accumulation is significant, effective and indispensable in improving productivity.

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Figure 1

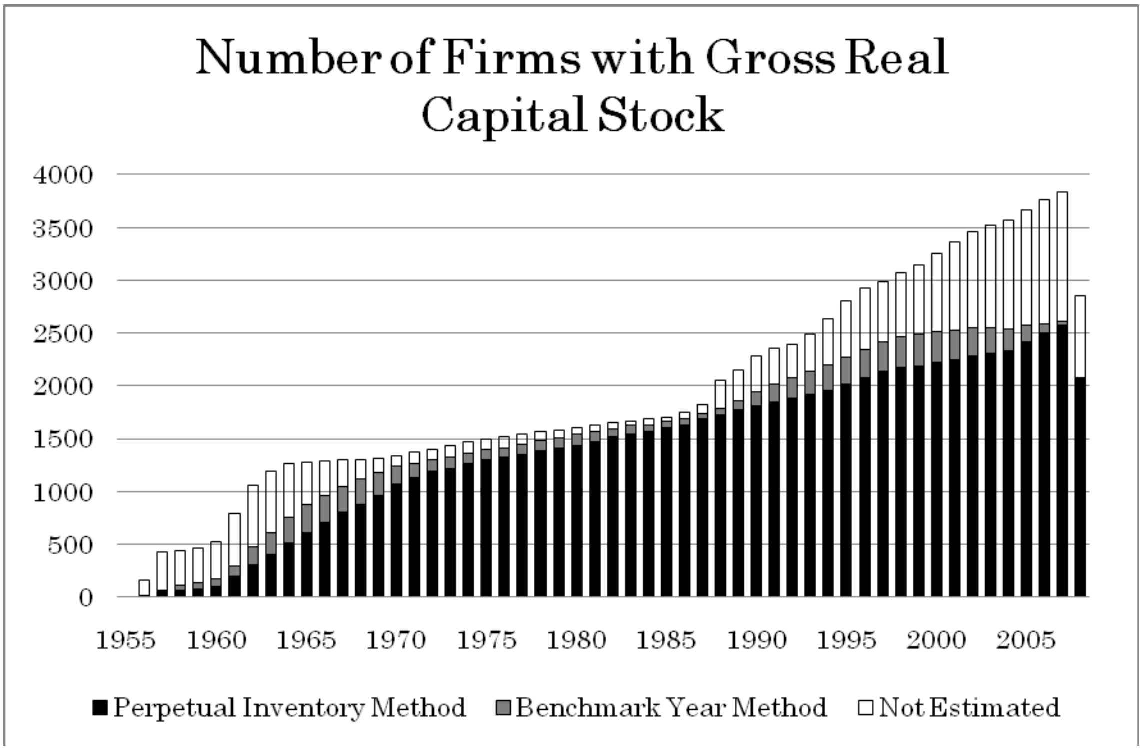


Figure.2 Vintage Index 1980-2007

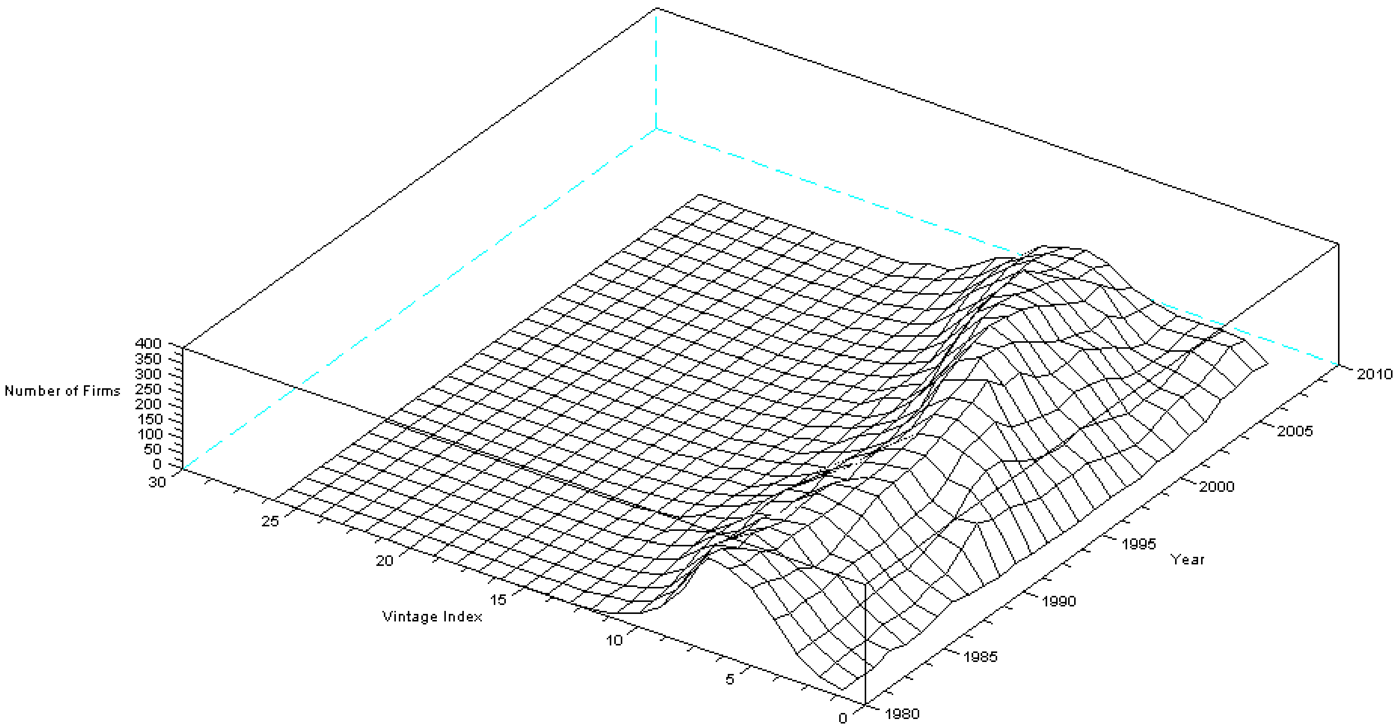
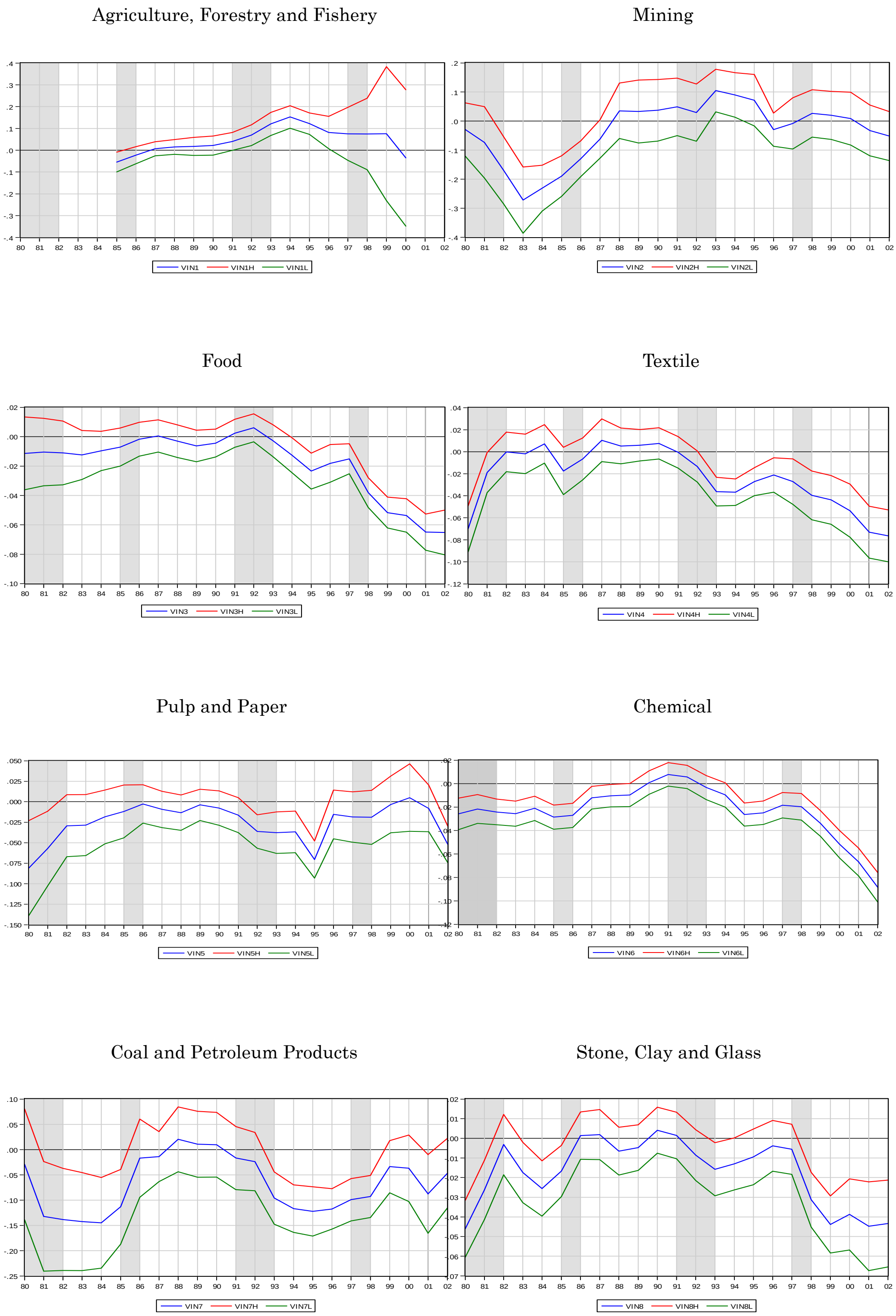
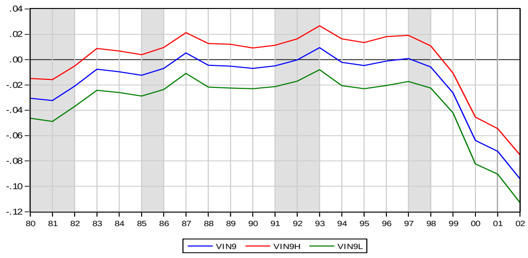


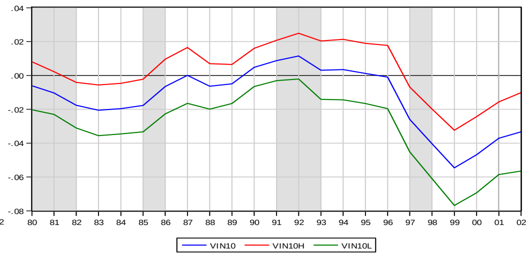
Figure 3 Estimation Results (2)



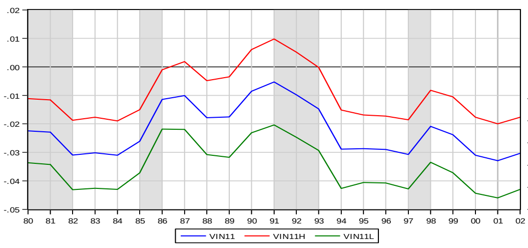
Primary Metal



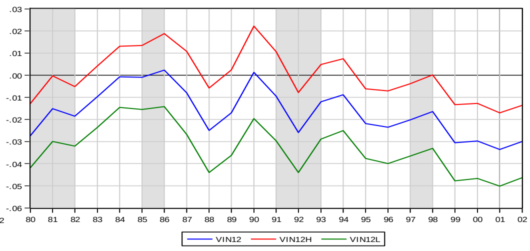
Fabricated Metal



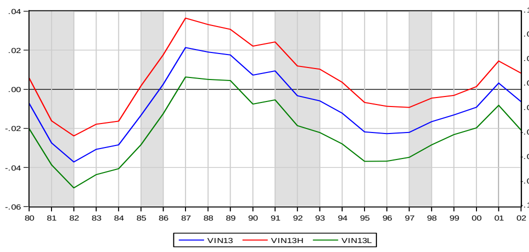
Machinery



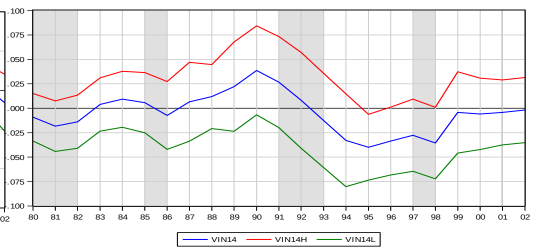
Electric Equipment



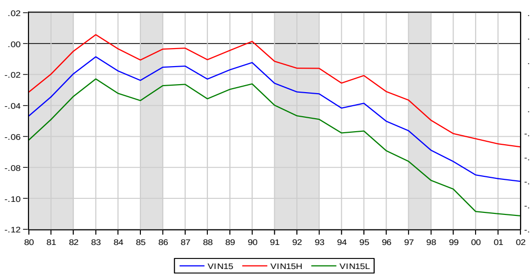
Transport Equipment



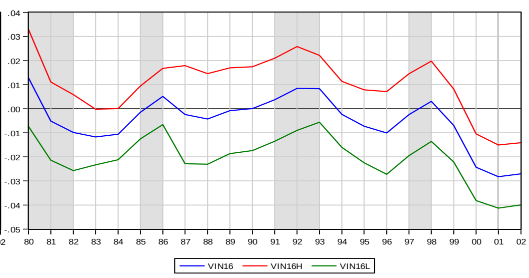
Precision Instrument



Other Manufacturing

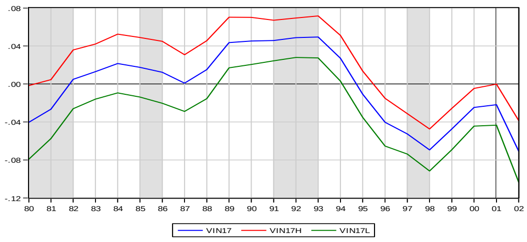


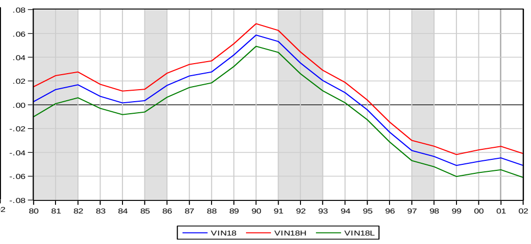
Construction



Electricity, Gas and Water

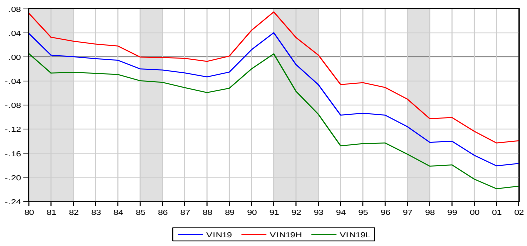
Commerce

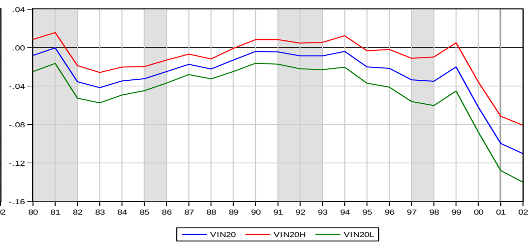




Real Estate

Transport and Communication





Service

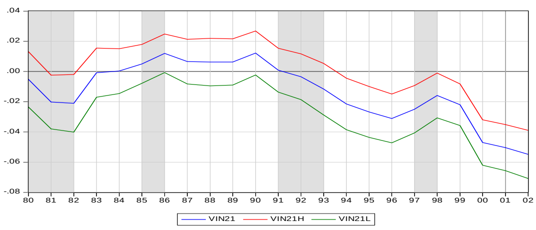


Table 1-1 estimation results (1)

1980-2007

Fixed Effect Model

	Const	Time	Vin	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
Chamical	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

Table 1-2 estimation results (2)

1980-2007

Random Effect Model

	Const	Time	Vin	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
λ	-0.70206	-0.00024
	(0.005)	(0.105)
μ	1.15101	0.00082
	(0.000)	(0.000)

2-2 Random Effect model

Dependent variable	R&D intensity	Researcher-Employee ratio
λ	-0.43786	-0.00002
	(0.029)	(0.841)
μ	0.86296	0.00066
	(0.000)	(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

Kshare is industry share of building in capital stock. Shaded are is the highest share.

Vintage coefficient is average of estimate in Figure 3.