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Complementarity and Substitutability between Tangible and Intangible Capital: Evidence from Japanese firm-level data*

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Abstract

Using Japanese firm-level panel data spanning from 2000 to 2013, we estimate industry-level production functions that explicitly take into account the substitutability and complementarity between tangible and intangible capital. The estimation results show substantial heterogeneity among industries in terms of substitutability and complementarity between tangible and intangible capital. We further find that the relation between tangible and intangible capital in the production function accounts for their relation in investments. These findings show the necessity to take into account the relation between the dynamics of tangible and intangible capital for precisely understanding the mechanisms governing a firm's growth.

Keywords: Intangible capital, Production function, Complementarity and substitutability, Investment
JEL classification: D24, E22.

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1. Introduction

Intangible capital drives economic growth in modern economies.[1] This capital also accounts for a substantial part of corporate investment and capital. In Japan, for example, while firms have decreased investments in tangible capital over the last two decades, they have steadily increased their investment in intangible capital over the same period. This investment reached a level equal to 42% of tangible capital investment in 2010 (Figure 1).[2]

Although the role of intangible capital in production and investment has been increasing nowadays, its relation with tangible capital has not been fully explored in the literature. Against this background, the present study analyzes the complementarity and substitutability of tangible and intangible capital in production and investment to fill the void in the current literature. Specifically, we construct a large firm-level data set that spans the period from 2000 to 2013. The data set comprises the information on intangible capital, such as software, R&D, and advertisement, and the tangible capital and labor of Japanese firms. Using these data, we estimate industry-level production functions that account for the substitutability and complementarity between tangible and intangible capital. We further estimate tangible capital investment functions that account for the relation between tangible and intangible capital.

In the context of the increasing role of intangible capital in production and investment, a number of theoretical and empirical studies have emerged over the last two decades. As for theoretical models, McGrattan and Prescott (2010a, b) and Malik et al. (2014) develop business-cycle models that incorporate intangible capital, while De (2014) develops an endogenous economic growth model with intangible capital.[3] While these developments in the research on intangibles support the understanding of the firms' production and growth and their aggregate implications, most only use a

[1] See Corrado et al., 2009 for the US, Fukao et al., 2009 for Japan, and Piekkola for Europe, among others.
[2] Tangible capital investment includes outsourced software development.
[3] There is a vast amount of literature that focuses on the role of a specific class of intangible capital in economic growth or business cycles, including knowledge capital (Romer, 1990, Jones, 1995, and Klette and Kortum, 2004, among others) and customer capital (Gourio and Rudanko, 2014a, b).

Cobb-Douglas production function with tangible and intangible capital, which is not necessarily empirically warranted.

Although a number of studies estimate production functions that incorporate intangible capital, many of them use either aggregate or industry-level data and only a few use firm-level data. As for firm-level studies, De and Dutta (2007) and Verbič and Polanec (2014) estimate a Cobb-Douglas production function that they augment with intangible capital; while Breshnahan et al. (2002), Bugamelli and Pagano (2003), and Biagi and Parisi (2012), and Bloom et al. (2012) further account for the interaction among some forms of intangible capital, especially among IT capital, human capital, and organizational capital. To the best our knowledge, however, none of the preceding studies accounts for the interaction between tangible capital (except for a part of IT capital) and intangible capital. This is the point we specifically examine in this study.

Notably, a number of studies exist on tangible capital investment that take into account the effects of intangible capital. Bond and Cummins (2000), Brynjolfsson et al. (2002), and Takizawa (2015) estimate Tobin's Q-type tangible investment functions that they augment with intangible capital; while Lach and Schankerman (1989), Lach and Rob (1996), and Chiao (2001) estimate the role of R&D investment in tangible capital investment. Although the latter type of studies is closely related to our study, they only account for R&D and focus on its dynamic pattern as compared to tangible capital investment. As one exception, Arrighetti et al. (2014) estimate a function for intangible capital investment as a function of tangible and intangible capital. Although their study is also closely related to ours, it is still distinct from this study in the sense that they do not associate the investment function with the production technology as we do.

Our estimation strategy for production functions draws on Blundell and Bond (2000) and accounts for multiple capitals and labor under the assumption that total factor productivity (TFP) follows the first-order autocorrelation (AR(1)). From the estimation, we find substantial heterogeneity among industries in terms of the substitutability and complementarity between tangible and intangible capital. As illustrative features, for example, tangible and intangible capitals are more complementary for the industries where average firm size is smaller, and where industry size measured by value added is larger. We further find that the estimated relation between tangible and intangible capital in the production function provides an informative industry-level feature that can account for the relation between tangible capital investment and intangible capital investment.

The remainder of the study is as follows. Section 2 reviews the related literature and outlines the contribution of the present study in greater detail. Section 3 and 4 describe our data and method, respectively, while Sections 5 and 6 report the results for production and investment, respectively. Section 7 concludes.

2. Related literature

The aim of this paper is to explore the complementarity and substitutability of tangible and intangible capital in production and investment at the firm level. For this purpose, we follow the method developed by Corrado et al. (2005, 2009) to measure intangible capital. As one extant study employing this method, Fukao et al. (2009) apply this method to measure the aggregate amount of intangible capital in Japan, and find that the ratio of intangible capital to GDP has increased over the last two decades in Japan.[4]

In the context of the role of intangible capital, the extant literature related to the present study falls into four groups. The first group includes economic-growth or business-cycle models that incorporate intangible capital. McGrattan and Prescott (2010a), as a prominent work, develop a multi-country general equilibrium model that includes intangible capital to explain the return differentials for inward and outward foreign direct investment in the United States. McGrattan and

[4] Arato and Yamada (2012) follow another approach to measure intangible capital developed by McGrattan and Prescott (2005) and estimate the economic value in the 1980s and 1990s of corporate assets in Japan. They show that the equities were correctly priced in 1980-1986 if intangible capital is taken into consideration.

Prescott (2010b) also add intangible capital and non-neutral technology change into the basic neoclassical growth model to explain the US boom in the 1990s. Following these studies, Malik et al. (2014) explore the relation between intangible capital and business cycles by introducing intangible capital into a standard real business-cycle model. In the context of endogenous growth model, De (2014) provides the theoretical model that adds intangible capital. Note that, as a common feature shared in these studies, labor produces intangible capital, and tangible capital and intangible capital are used as an input to output.

While these models incorporate intangible capital in general into standard growth or business-cycle models, the second strand of literature focuses on a specific class of intangible capital. Romer (1990) and Jones (1995) are the prominent studies on the role of R&D or knowledge capital. Klette and Kortum (2004) explicitly describe the accumulation process of knowledge capital to explain a wide range of stylized facts on patents and R&D. As for organizational capital, Atkeson and Kehoe (2005) and Luttmer (2007, 2011) provide theoretical models of producer dynamics to explain the plants' life cycle and the firms' size distribution respectively. Gourio and Rudanko (2014a,b) construct a theoretical model on customer capital. They introduce search frictions into product markets that generate the long-term customer relationship. The customer base is a form of intangible capital that affects the decisions on tangible capital investment.

The third strand of related literature examines the estimation of a production function that incorporates intangible capital. Note that, as an important difference between these extant studies and ours, many of these studies use either aggregate or industry-level data while the use of firm-level data is still infrequent.[5] De and Dutta (2007) estimate the Cobb-Douglas production function with R&D capital, brand capital, and organizational capital for the data on major Indian IT software companies by using a system GMM.[6] Verbič and Polanec (2014) also estimate the Cobb-Douglas production

[5] Roth and Thum (2013) estimate the production function with intangible capital at the country level.
[6] Griliches and Mairesse (1995) and Mairesse and Hall (1996) extend the standard Cobb-Douglas production function

function with intangible capital for Slovenian firm-level data to investigate the importance of intangible capital in transition economies. A number of extant studies also focus on the complementarity among different types of intangible capital. Breshnahan et al. (2002) argue, for example, that IT investment requires human capital and organizational capital. Bugamelli and Pagano (2004) study the complementarity between IT investment and human capital in Italy. They conclude that this complementarity works as a barrier to IT investment. In the similar vein, Bloom et al. (2012) estimate the production function with IT capital and organizational capital. They show that the foreign affiliates of US multinationals in Europe obtain higher productivity from IT capital. Contrary to these studies supporting the complementarity among intangibles, Biagi and Parisi (2012) explore the relation between different types of intangible capital in Italy and find no evidence of complementarity between IT investment and organizational change. Note that, although these studies analyze the complementarity between IT capital and other intangible capitals, to the best of our knowledge, no study analyzes the complementarity between tangible and intangible capital.

Lastly, the present study is closely related to the studies on the effects of intangible capital on tangible capital investment or market value, which can be further decomposed into two groups. The first group of the study implements the estimation of Tobin's Q-type tangible investment functions augmented with intangible capital. Bond and Cummins (2000), for example, extend the standard Tobin's Q model of investment by including intangible capital. Brynjolfsson et al. (2002) also regress the market value of firms on various types of capital. They find that IT capital and organizational capital affects the stock market valuation of firms. Further, they find that these two types of intangible capital are complementary investments. Using the data on the financial statements of listed firms in Japan, Takizawa (2015) explores the effects of intangible capital on the firm's value and the role of financial constraint on intangible capital investment. The second group of the literature studying the

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to include R&D.

effects of intangible capital on tangible capital investment or market value focuses on the dynamic relation between tangible capital investment and R&D investment. Mairesse and Siu (1984), for example, use the multivariate autoregressive framework for the return of stock holding, sales growth, tangible capital investment, and R&D investment. Their results show that the growth rate of tangible capital investment and R&D investment are not strongly correlated with each other. Somewhat different from this finding, Lach and Schankerman (1989) use the data on 191 firms in the US science-based industries and find that R&D investment Granger-causes tangible capital investment but that tangible capital investment does not Granger-cause R&D investment. This dynamic relation between R&D and tangible capital investments is consistent with the hypothesis that ideas produced by R&D induces the investment of tangible capital. According to this hypothesis, while R&D investment generates a new idea, the implementation of the idea requires tangible capital investment. In this context, Lach and Rob (1996) confirm the same dynamic relation between R&D and tangible capital investment at the industry level as Lach and Schankerman (1989) find at the firm level. Note that against these findings, Chiao (2001) shows that the dynamic relation found in Lach and Schankerman (1989) does not hold when the range of the sample used for the analysis is extended. Chiao (2001) claims that the current tangible capital investment and current R&D investment have the effects on each other. Note that, although these studies certainly address the relation between intangible and tangible capital, these consider only R&D as an intangible capital investment.

Given the abovementioned extant studies, we think the contribution of this study is at least twofold. The first contribution is that by specifically using firm-level data, we estimate a production function that incorporates the complementarity and substitutability of tangible and intangible capital, which has not been discussed in the extant studies. In doing so, we allow for a large variation in the complementarity and substitutability of the two types of capital across industries. Second, we show that the complementarity and substitutability of tangible and intangible capital in the production function at the industry level is an important factor explaining the joint dynamics of tangible capital and intangible capital, which has not been discussed in the extant literature.

3. Data

The data source for this paper is from the *Basic Survey of Japanese Business Structure and Activities* (BSJBSA) published by the Ministry of Economy, Trade and Industry. The main purpose of this annual survey is to gauge quantitatively the activities of Japanese enterprises, including capital investment, exports, foreign direct investment, and investment in R&D. To this end, the survey covers the universe of enterprises in Japan with more than 50 employees and with paid-up capital of over 30 million yen. We apply the perpetual inventory (PI) method to such a large firm-level panel data set in order to construct the data for intangible capital. The sample period is from 1994FY to 2013FY. The observation period for the estimation of the production and investment functions spans the period from 2000 to 2013.

To construct the data of output and factor inputs, first, we use each firm's total sales as the nominal gross output. As for wholesale and retail industries, the nominal gross output is measured as each firm's total sales minus total purchases of goods. Then, this nominal gross output is deflated by the output deflator taken from the Japan Industrial Productivity Database (JIP) 2015 to convert it into values in constant prices (i.e., real gross output) based on the year 2000. Second, the nominal intermediate input is defined as the sum of the cost of sales and selling, and the general and administrative expenses less wages and depreciation. Using the intermediate deflator in the JIP database, this nominal intermediate input is converted into values in constant prices (i.e., real intermediate input) for the year 2000. Third, the real value added is defined as the difference between the real gross output and the real intermediate input. Fourth, as a labor input, we use each firm's total number of workers multiplied by the sectoral working hours from the JIP.

The data for tangible capital stock is constructed as follows. First, we define the initial capital input (K_{sIND}) as the nominal book value of tangible fixed assets from the BSJBSA multiplied by the book-to-market value ratio for each industry ($\alpha_{IND,t}$) at each data point corresponding to each K_{sIND}. We calculate the book-to-market value ratio for each industry ($\alpha_{IND,t}$) by using the data of real capital stock ($K_{IND,t}^{JIP}$) and real value added ($Y_{IND,t}^{JIP}$) at each data point taken from the JIP database as follows:

$$\frac{Y_{IND,t}^{JIP}}{K_{IND,t}^{JIP}} = \frac{\sum_i Y_{IND,i,t}^{\text{BSJBSA}}}{\sum_i BVK_{IND,i,t}^{\text{BSJBSA}} * \alpha_{IND,t}}$$

where $\sum_i Y_{IND,i,t}^{\text{BSJBSA}}$ is the sum of the firms' value added (*i* is the index of a firm), and $\sum_i BVK_{IND,i,t}^{\text{BSJBSA}}$ is the sum of the nominal book value of tangible fixed assets of industry *IND* in BSJBSA. Second, we calculate the net capital stock of industry *IND* for the succeeding years by using the PI method. We use each firm's current purchase of property, plant, and equipment as the nominal investment. We deflate the nominal investment with the investment deflator in the JIP database. The sectoral depreciation rate is also taken from the JIP database.

In order to construct the variables that account for intangible capital stock, we follow the method used in Corrado et al. (2009) and measure the investment and the stock of three types of intangibles: software, R&D, and advertisement. Note that Corrado et al. (2009) classify intangible assets into the following three categories: computerized information, innovative property, and economic competencies. According to them, software investment, which comprises of custom software, packaged software, and own account software, is recognized as a major part of the investment in computerized information; and R&D accounts for a large part of the innovative property, while advertisement represents a part of the investment in economic competencies, which comprises brand equity, firm-specific human capital, and organizational change. In this sense, the three items we measure for the present study account for the three categories of intangibles considered in Corrado et al. (2009).

To measure the abovementioned three items (i.e., software, R&D, and advertisement) for each firm, we follow Miyagawa, Takizawa, and Edamura (2013). For software, first, the ratio of workers engaged in information processing to the total number of employees is multiplied by the total cash earnings in order to measure the value of software investment. Then, we add the cost of information processing to this number to compute the total software investment. Finally, we deflate the nominal software investment by the deflator for software investment obtained from the JIP database to obtain the real software investment. For R&D, we subtract the cost of acquiring fixed assets for research from the cost of R&D (i.e., in-house R&D and contract R&D) to compute the value of the investment in R&D. We use the output deflator for (private) research in the JIP database to deflate the nominal R&D investment. Finally, for advertisement, we obtain the data for advertising expenses from the BSJBSA. We use the output deflator for advertising in the JIP database as the deflator for advertising investments. Note that all of the information is obtained from the BSJBSA.

For all of the data in the three intangible investment categories, we use the PI method where we use FY1994 as the base year to construct a data series of intangible assets from FY2000. All of the depreciation rates used for this computation follow those of Corrado et al. (2012). The depreciation rates for software, R&D, and advertising are 31.5%, 15%, and 55%, respectively. We define the total intangible assets as the sum of software stocks, R&D stocks, and advertisement stocks.[7] According to the JIP database, software, science and engineering R&D, and brand equity account for about 70% of the total intangible assets in Japan.

[7] While we sum up all the stock levels of these three intangible assets in the present study, another way to measure the amount of intangibles used for inputs of production is to compute the service costs associated with each intangible separately with taking into account the different rental prices for each intangible. Given it is highly difficult to obtain precise measure for such rental price, we follow the current method employed the most of extant studies.

4. Methods and variables

In this section, we first describe the empirical methods we use to measure the substitutability and complementarity between tangible and intangible capital. We then explain the methods to study, how the relation between the growth of tangible capital, which is traditionally used to represent a firm's growth, and the growth of intangible capital depends on the substitutability and complementarity between the two types of capital in production. For the first part of our analysis, we estimate industry-level production functions that allow the two types of capital (i.e., tangible and intangible) to be substitutable or complementary and how this parameter varies over industries. The second part of our analysis, which uses firm-level panel data, we regress the growth of tangible capital on the growth of intangible capital. As an important independent variable, we include the interaction term for the growth of intangible capital and the industry-level substitutability and complementarity parameter obtained in the first part of our analysis while controlling for the industry-level or firm-level TFP growth, firm-level fixed effect, and the year-specific effect. We presume that firms in the industry that exhibit complementarity (substitutability) between tangible and intangible capital increase (decrease) their tangible assets as the intangible assets grow.

For the production function estimation, we consider the following Cobb-Douglas function that we augment with the interaction between tangible and intangible capital:

$$LN(Y)_{i,t} = \beta_l LN(L)_{i,t} + \beta_{ktan} LN(Ktan)_{i,t} + \beta_{kintan} LN(Kintan)_{i,t}$$
$$+\beta_{tan\times intan} LN(Ktan)_{i,t} \times LN(Kintan)_{i,t} + \eta_i + year_t + \omega_{i,t} + \varepsilon_{i,t} \quad (1)$$

where

$$\omega_{i.t} = \rho\omega_{i.t-1} + \xi_{i,t}\ , \quad |\rho| < 1 \quad (2)$$

$$\varepsilon_{it}, \xi_{i,t} \sim MA(0) \quad (3)$$

The left hand-side of equation (1) accounts for the natural logarithm of output produced by firm *i* in period *t*. As the inputs for this production, the $LN(L)_{i,t}$ denotes the natural logarithm of the labor input used by firm *i* in period *t;* and the $LN(Ktan)_{i,t}$ and the $LN(Kintan)_{i,t}$ denote the natural logarithms of the tangible capital input and the intangible capital input respectively. We measure these variables at the end of period *t*. In order to examine the substitutability and complementarity between tangible capital and intangible capital, we also include the interaction term between $LN(Ktan)_{i,t}$ and $LN(Kintan)_{i,t}$. Following the literature, we include the firm-level fixed effect η_i, year fixed effect $year_t$, and the TFP $\omega_{i,t}$. We assume that $\omega_{i,t}$ follows an AR(1) process described by equation (2). The $\varepsilon_{i,t}$ represents a measurement error.

In order to consistently estimate the coefficients associated with capital inputs, we use the system GMM estimator following Blundell and Bond (2000). Specifically, the model has a dynamic (common factor) presentation

$$\begin{aligned} LN(Y)_{i,t} = {} & \beta_l LN(L)_{i,t} - \rho\beta_l LN(L)_{i,t-1} + \beta_{ktan} LN(Ktan)_{i,t} - \rho\beta_{ktan} LN(Ktan)_{i,t-1} \\ & + \beta_{kintan} LN(Kintan)_{i,t} - \rho\beta_{kintan} LN(Kintan)_{i,t-1} \\ & + \beta_{tan\times intan} LN(Ktan)_{i,t} \times LN(Kintan)_{i,t} - \rho\beta_{tan\times intan} LN(Ktan)_{i,t} \times LN(Kintan)_{i,t-1} \\ & + \rho LN(Y)_{i,t-1} + \eta_i(1-\rho) + year_t - \rho year_{t-1} + \xi_{i,t} + \varepsilon_{i,t} - \rho\varepsilon_{i,t-1} \end{aligned} \tag{4}$$

or

$$\begin{aligned} LN(Y)_{i,t} = {} & \pi_1 LN(L)_{i,t} + \pi_2 LN(L)_{i,t-1} + \pi_3 LN(Ktan)_{i,t} + \pi_4 LN(Ktan)_{i,t-1} \\ & + \pi_5 LN(Kintan)_{i,t} + \pi_6 LN(Kintan)_{i,t-1} \\ & + \pi_7 LN(Ktan)_{i,t} \times LN(Kintan)_{i,t} + \pi_8 LN(Ktan)_{i,t} \times LN(Kintan)_{i,t-1} \\ & + \pi_9 LN(Y)_{i,t-1} + \eta_i^* + year_t^* + \omega_{i,t} \end{aligned} \tag{5}$$

subject to four non-linear (common factor) restrictions: $\pi_2 = -\pi_1\pi_9$, $\pi_4 = -\pi_3\pi_9$, $\pi_6 = -\pi_5\pi_9$,

$\pi_8 = -\pi_7\pi_9$. We first obtain consistent estimates of the unrestricted parameter $\pi = (\pi_1,,,\pi_9)$ and var(π), using the system GMM (Blundell and Bond, 1998). Noticing that $\omega_{i,t}{\sim}MA(1)$, we use the following moment conditions:

$$\mathrm{E}\big(x_{i,t-s}\Delta\omega_{i,t}\big) = 0 \tag{6}$$

and

$$\mathrm{E}\big(\Delta x_{i,t-s}(\eta_i^* + \omega_{i,t})\big) = 0 \tag{7}$$

where $x_{i,t} = \big(LN(L)_{i,t}, LN(Ktan)_{i,t}, LN(Kintan)_{i,t}, LN(Ktan)_{i,t} \times LN(Kintan)_{i,t}, LN(Y)_{i,t}\big)$ and $s \geq 3$.

Next, using consistent estimates of the unrestricted parameters and their variance-covariance matrix, we impose the above restrictions by minimum distance to obtain the restricted parameter vector $(\beta_l, \beta_{ktan}, \beta_{kintan}, \beta_{tan\times intan}, \rho)$. We are interested especially in the industry-level coefficients $\beta_{tan\times intan}(IND)$ where *IND* denotes the industry identification number. Table 1 lists the industry classifications used in this analysis, which is obtained from the JIP database, providing information on whether the industry is IT-intensive and non-manufacturing or not as well. We define IT-intensive industry as the one where the intensity of IT capital, which denotes the ratio of the stock of IT capital to that of tangible capital, is higher than the median over industries.

Next, we define the substitutability and complementarity as follows:

$$\begin{aligned} &Ktan\ and\ Kintan\ are\ substitute\ if\ \delta(LN(Ktan))/\delta(Rintan) > 0 \\ &\qquad\qquad\qquad complemenatry\ if\ \delta(LN(Ktan))/\delta(Rintan) < 0 \end{aligned} \tag{8}$$

where $Rintan$ denotes the real rental rate of intangible capital. The appendix (equation (A5)) shows that, given the production function (1), $\delta(LN(Ktan))/\delta(Rintan)$ is negative if $\beta_{tan\times intan}(IND)$ is either positive or negative with a sufficiently small absolute value. On the other hand, if $\beta_{tan\times intan}(IND)$ is negative and its absolute value is sufficiently large, then $\delta(LN(Ktan))/\delta(Rintan)$ is positive.

The optimal level of $Ktan$ should depend on the rental rates of tangible capital and intangible capital as well as on the idiosyncratic productivity shocks. However, the rental rates of these two types of capital are difficult to accurately observe. Furthermore, the rental rate of intangible capital is especially difficult to observe given that the composition of intangible capital is substantially different across firms and over time. We therefore choose to estimate a reduced-form of tangible capital investment in which the intangible capital investment, instead of the rental rate of intangible capital, is included as a regressor. The appendix (equation (A10)) shows that the optimal tangible capital should depend positively (negatively) on the optimal intangible capital if the two types of capital are complementary (substitute) while controlling for productivity. Unlike intangible capital, the difference in the composition of tangible capital across firms is not likely to change substantially over time. In that case, we can capture the change in the rental rate of tangible capital for each firm by year dummies and firm fixed effects. Therefore, we run the following firm-level panel estimation:

$$\Delta LN(Ktan)_{i,t} = \gamma_{intan}\Delta LN(Kintan)_{i,t} + \gamma_{intan\times\beta}\Delta LN(Kintan)_{i,t} \times \beta_{tan\times intan}(IND_i)$$
$$+\delta\Delta LN(TFP)_{i,t} + \eta_i + year_t + \varepsilon_{i,t} \qquad (9)$$

The left hand-side of the equation denotes the growth rate of tangible capital for firm *i* from year *t-1* to *t*. We regress this variable on (i) the growth of intangible capital $\Delta LN(Kintan)$, (ii) its interaction term with the $\beta_{tan\times intan}(IND_i)$ that corresponds to the industry in which firm *i* belongs (IND_i), (iii) the growth rate of TFP, $\Delta LN(TFP)_{i,t}$, which is measured as either industry-level or firm-level, (iv) the firm-level fixed effect η_i, and (v) the year-fixed effect $year_t$. The $\gamma_{intan\times\beta}$ should be positive given the above argument. If this estimated coefficient shows a larger positive number, then it indicates that the correlation between $\Delta LN(Ktan)_{i,t}$ and $\Delta LN(Kintan)_{i,t}$ moves toward positive as $\beta_{tan\times intan}(IND_i)$ becomes larger (i.e., becoming more complementary). As noted above, we use two alternative measures for $\Delta LN(TFP)_{i,t}$. One is the log difference in the industry-level TFP reported in the JIP database, while the other is the difference in the estimated residual from equation (4), $\eta_i + year_t + \omega_{i,t} + \varepsilon_{i,t}$. We admit that neither is far from perfect. The JIP's industry-level TFP is a Solow residual obtained without accounting for intangible capital, while the estimated firm-level residual contains measurement errors. Given that no other better proxy is available, we use these two alternatively as one control variable in our estimation.

Table 2 summarizes all of the summary statistics for the variables used in the analysis. While the data we use for estimating production functions are available for the period from 2000 to 2013, the estimation of equation (5) spans the period from 2003 to 2013 since we use three and more lagged variables as instruments. The data for estimating investment functions using the industry-level TP cover the period from 2000 to 2012 because data on the industry-level TFP are available only up to 2012.

5. Results from production function estimation

In this section, we present the estimation results for the substitutability and complementarity between tangible and intangible capital. Figure 2 compares the estimated $\beta_{tan\times intan}(IND)$ with and without the common factor restrictions. It shows that for most industries, these two sets of the estimates are close to each other, although they are substantially different for some industries. Figure 3 shows the estimated $\beta_{tan\times intan}(IND)$ with the common factor restrictions in descending order with the vertical axis representing the industry categories. The figure shows that there is a great deal of heterogeneity in terms of the substitutability and complementarity between tangible and intangible capital. The coefficient $\beta_{tan\times intan}(IND)$ represents the sensitivity of the change in tangible capital (intangible capital) to that in the intangible capital (tangible capital) under, for example, the reduction in the price of intangible capital (tangible capital). If this number is large and positive, then the increase in intangible capital due to the reduction in the price of intangible capital is likely to be associated with the increase in tangible capital, which can be interpreted as the complementarity between tangible and intangible capital. However, if this number is negative and has a large absolute value, then the increase in intangible capital due to the reduction in the price of intangible capital is likely to be associated with a decline in tangible capital. As illustrated by these examples, the estimates for the coefficient $\beta_{tan\times intan}(IND)$ shed a new light on the determinants of capital investment.

To explore the characteristics of industries in which tangible and intangible capital are more complementary than in other industries, we regress $\beta_{tan\times intan}(IND)$ on various industry-level variables including the size of each industry measured by value-added (*IndustrySize*), average firm size measured by value-added (*AverageFirmSize*), a dummy variable for IT industry (*IT_Dummy*), a dummy variable for non-manufacturing industry (*NonManufactuaring_Dummy*), and average R&D intensity to each industry (*RD_intensity*). Table 3 shows that the industries with larger industry size and smaller average firm size tend to exhibit higher complementarity between tangible and intangible capital, although the latter result is statistically weak. The dummies for IT and non-manufacturing industries do not take significant coefficients.

6. Results for investment estimation

In this section, we present the estimation results for equation (9), which accounts for the association between (i) the correlation between tangible and intangible capital growth and (ii) our measure for the substitutability and complementarity between tangible and intangible capital. Table 4 summarizes the estimation results. Depending on the measures of $\Delta LN(TFP)_{i,t}$, The upper panel shows the result from JIP industry-level $\Delta LN(TFP)_{i,t}$, while the lower panel reports the result from the firm-level estimated $\Delta LN(TFP)_{i,t}$.

First, the coefficients on $\Delta LN(TFP)_{i,t}$ are positive and significant, as is expected, irrespectively of the productivity measures. Next, the coefficient associated with $\Delta LN(Kintan)_{i,t}$ is negative (i.e., $\gamma_{intan} < 0$) and significantly away from zero irrespectively of which productivity measure we use. Because this coefficient represents the conditional slope of $\Delta LN(Kintan)_{i,t}$ in the case of $\beta_{tan \times intan}(IND_i) = 0$, this result indicates that if $\beta_{tan \times intan}(IND_i) = 0$, then the growth in intangible capital replaces about 30% of the tangible capital. Finally, the coefficient associated with $\Delta LN(Kintan)_{i,t} \times \beta_{tan \times intan}(IND_i)$ shows a statistically significant positive number regardless of the TFP measures. This number means that as the degree of complementarity between tangible and intangible capital becomes larger, the growth in intangible capital tends to be accompanied by larger tangible capital.

In terms of the economic significance, however, we find that even with a relatively high $\beta_{tan \times intan}(IND_i)$ (e.g., 0.045 for special industry machinery), the overall marginal effect associated with $\Delta LN(Kintan)_{i,t}$ is still negative (i.e., -0.26 and -0.27 from the industry-level TFP estimate and the firm-level TFP estimate, respectively). Although this negative estimate is somewhat puzzling, the present result shows that $\beta_{tan \times intan}(IND_i)$ is one of the important factors in explaining the joint dynamics of tangible and intangible capital.

Such a large negative relation between tangible and intangible capital may be the consequence of financial constraints associated with investment in either or both types of capital. To explore this possibility, we split the sample into two subsamples depending on whether $Ktan_{i,t}$ is greater than the median or not. Since smaller firms are more likely to be financially constrained, we expect that a large negative relation between the two types of capital can be observed for smaller firms if financial constraints drive the result. The estimate results are summarized in Table 5. The two upper panels account for the results of subsample estimation using industry-level TFP while the two lower panels are for that using firm-level TFP. Both in the upper and lower panels, the right and left panel accounts for the results associated with large and small firms, respectively. From Table 5, we find that while $\beta_{tan\times intan}(IND_i)$ is positive and significant only for the smaller firms, the coefficient on $\Delta LN(Kintan)_{i,t}$ is negative and larger in its absolute value for the smaller firms. By a simple calculation, we can confirm that except for the industries with very high $\beta_{tan\times intan}(IND_i)$, increase in the intangible capital lead to larger reduction in tangible capital in the case of small firms. Given the result in the lower panels in Table 5, the marginal effect associated with $\Delta LN(Kintan)_{i,t}$ for small firms is computed as the sum of -0.332 and 2.407*$\beta_{tan\times intan}(IND_i)$ while the marginal effect associated with $\Delta LN(Kintan)_{i,t}$ for large firms is the sum of -0.262 and -0.426*$\beta_{tan\times intan}(IND_i)$. This means that an increase in the intangible capital leads to a larger reduction in tangible capital in the case of small firms if $\beta_{tan\times intan}(IND_i) < 0.025$, which accounts for most of the industries.[8] In other words, smaller firms tend to decrease more largely its tangible capital as the intangible capital is accumulated, which is consistent with our conjecture based on the financial constraint.

How can we evaluate the macroeconomic implication of our results? Given the estimate coefficients associated with each variable, we implement the following exercise. First, using the estimated investment function for tangible capital, we estimate how tangible capital reacts to a one percent increase in intangible capital in each industry. Second, plugging this industry-level estimates for the responses of tangible capital to the one percent increase in intangible capital into the estimated production function, we estimate the change in output generated by the one percent increase in intangible capital with taking into account the endogenous reaction of tangible capital in each industry. Third, multiplying this industry-level growth rate to the actual added-value associated with each

[8] In this calculation, we ignore the fact that the coefficient associated with the cross term is not statistically away from zero in the case of large firm. Note that even if we treat this coefficient is zero in the calculation above, the implication is qualitatively the same.

industry and summing over those values, we project the change in aggregate-level change in output (i.e., real value added).[9]

The result of this exercise shows that output accounting for the industries covered in our data set, which is around 195 trillion yen, increases by 238 billion yen. Given that output covered by our sample accounts 39% (=195/500) of GDP in Japan, one rough estimate for the aggregate impact generated by the one percent increase in intangible asset could be 610 billion yen (238/0.39). As the standard deviation of $\Delta LN(Kintan)_{i,t}$ in our data set is 0.289, the increase in intangible capital by one standard deviation (i.e., 28.9%) leads to 17.629 trillion, which is not negligible. This result suggests that even after taking into account the (negative) endogenous response of tangible asset to the accumulation of intangible asset, intangible investment leads to economic growth.

7. Concluding remarks

This study analyzes the complementarity and substitutability of tangible and intangible capital in production and investment. Specifically, we construct a large firm-level data set that includes the intangible capital of software, R&D, and advertisement and tangible capital and labor in Japanese firms that spans the period from 2000 to 2013. We estimate industry-level production functions that account for the substitutability and complementarity between tangible and intangible capital. We find substantial heterogeneity among industries in terms of substitutability and complementarity. As illustrative features, we also find that tangible and intangible capitals are more complementary for the industries where average firm size is smaller, and where industry size measured by value added is larger. The estimate further shows that the relation between tangible and intangible capital in the production functions can account for the relation between tangible capital and intangible capital investments, although the overall relations between the two types of investments are negative.

[9] In this exercise, we replace the actual added-value associated with the each industry where the value takes negative number with zero

Our results have important implications for the policy debate on how to support growth in firms. Our results bear important policy implications especially for policies that favor either type of capital. Subsidies and tax credit for intangible capital investment, for example, might severely reduce tangible capital investment, which may eventually reduce production if the elasticity of production in terms of tangible capital is relatively large. These illustrations suggest that it is necessary to take into account the detailed mechanisms of production for a disaggregated group (e.g., an industry) when designing effective policy measures as well as evaluating the outcomes of those measures.

A limitation of this study is that it only focuses on the heterogeneity among industries. In other words, we assume that within an industry, the technology is identical. Given that production functions could be significantly different between firms with different sizes, future research might want to further disaggregate industries by the firms' size as units for measuring the substitutability and complementarity among tangible and intangible capital. Second, the firms' characteristics, especially the financial constraints faced by firms, could be used to obtain more detailed dynamics in the tangible and intangible capital. Given that intangible capital is difficult to use as collateral, if firms with production functions that exhibit complementarity between their tangible and intangible capital face financial frictions because of this constraint, then their tangible investment is also suppressed. The literature does not fully examine this channel. Third, another important direction would be to introduce measurements for different labor inputs (e.g., skilled and unskilled) and examine the substitutability and complementarity among multiple types of capital and multiple types of labor (see, e.g., Jäger 2016). We believe all of these potential extensions could provide further insights for a better understanding of the firms' production process and their growth.

Appendix

In this appendix, we rewrite *Ktan* and *Kintan* as K_1 and K_2, respectively, and $\exp(\eta_i + year_t + \omega_{it})$ as *A*. We drop the subscripts *i* and *t*. We assume that L_{it} is fixed and denote the production function as $AF(K_1, K_2)$, the competitive firm's problem is to maximize their profit:

$$\max \ AF(K_1, K_2) - R_1 K_1 - R_2 K_2$$

where R_1 and R_2 are the real rental rates of K_1 and K_2, respectively. The first-order conditions are

(A1) $AF_1(K_1, K_2) - R_1 = 0$.

(A2) $AF_2(K_1, K_2) - R_2 = 0$

And the second-order conditions are

(A3) $\Delta \equiv F_{11}F_{22} - F_{12}^2 > 0$, $F_{11} < 0$.

A. The effects of R_1 on K_1 and K_2

Totally differentiating (A1) and (A2) with respect to R_1, we get

(A3) $A\begin{bmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{bmatrix}\begin{bmatrix} \partial K_1/\partial R_1 \\ \partial K_2/\partial R_1 \end{bmatrix} - \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$.

Rearranging the yields generates

(A4) $\begin{bmatrix} \partial K_1/\partial R_1 \\ \partial K_2/\partial R_1 \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} F_{22} & -F_{12} \\ -F_{21} & F_{11} \end{bmatrix}\begin{bmatrix} 1/A \\ 0 \end{bmatrix} = \frac{1}{A\Delta}\begin{bmatrix} F_{22} \\ -F_{21} \end{bmatrix}$.

Equation (A4) shows that

$$\frac{\partial LN(K_2)}{\partial R_1}\begin{cases} < 0 & if \quad F_{21} > 0 \ (complementary) \\ = 0 & if \quad F_{21} = 0 \\ > 0 & if \quad F_{21} < 0 \ (substitutable) \end{cases}.$$

The production function of equation (1) in the main text suggests that

(A5)

$$F_{21} = \left(\left(LN(K_{\tan})LN(K_{\mathrm{int}\,an})\right)\beta_{\tan\times\mathrm{int}\,an}{}^2 + \left(LN(K_{\tan})\beta_{\tan} + LN(K_{\mathrm{int}\,an})\beta_{\mathrm{int}\,an} + 1\right)\beta_{\tan\times\mathrm{int}\,an} + \beta_{\tan}\beta_{\mathrm{int}\,an}\right) \times \frac{Y}{K_{\tan}K_{\mathrm{int}\,an}}$$

Equation (A5) shows that if $\beta_{\tan\times\mathrm{int}\,an}$ is positive, then $F_{21} > 0$. Even when $\beta_{\tan\times\mathrm{int}\,an}$ is negative, if its absolute value is sufficiently small, then $F_{21} > 0$. However, if $\beta_{\tan\times\mathrm{int}\,an}$ is negative and its absolute value is sufficiently large, then $F_{21} < 0$.

B. The relationship between dK_1 and dK_2

Totally differentiating $K_1 = K_1(A, R_1, R_2)$, we obtain

(A6) $$dK_1 = \frac{\partial K_1}{\partial A} dA + \frac{\partial K_1}{\partial R_1} dR_1 + \frac{\partial K_1}{\partial R_2} dR_2$$

Substituting (A4) and (A5) into (A6) yields

(A7) $$dK_1 = \frac{1}{A\Delta}(-F_{22}F_1 + F_{12}F_2)dA + \frac{1}{A\Delta}F_{22}dR_1 - \frac{1}{A\Delta}F_{12}dR_2 .$$

Similarly,

(A8) $$dK_2 = \frac{1}{A\Delta}(-F_{11}F_2 + F_{21}F_1)dA - \frac{1}{A\Delta}F_{21}dR_1 + \frac{1}{A\Delta}F_{11}dR_2 .$$

Rearranging (A8) leads to

(A9) $$dR_2 = \frac{A\Delta}{F_{11}}dK_2 + \frac{(F_{11}F_2 - F_{21}F_1)}{F_{11}}dA + \frac{F_{21}}{F_{11}}dR_1 .$$

Substituting (A9) into (A7) yields

(A10) $$dK_1 = \frac{1}{A\Delta}\left(\frac{F_{12}^2 - F_{11}F_{22}}{F_{11}}\right)dA + \frac{1}{A\Delta}\left(F_{22} - \frac{F_{12}^2}{F_1}\right)dR_1 - \frac{F_{12}}{F_{11}}dK_2$$

(+) (-) (+ if complementary,
- if substitutable).

Equation (A10) indicates that the coefficient on dK_2 is positive (negative) if K_1 and K_2 are complementary (substitute).

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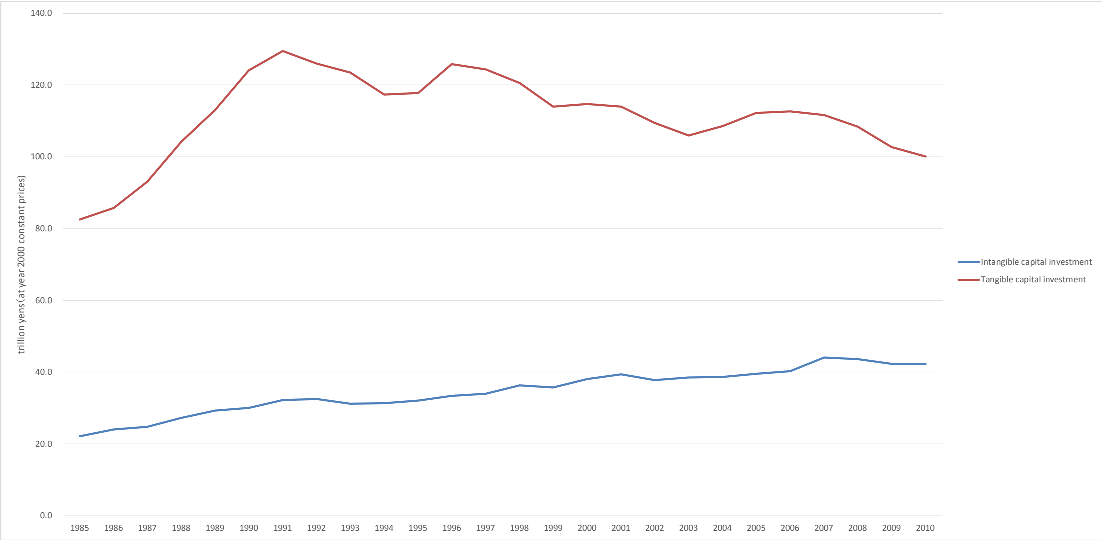
<Figures and Tables>

Figure 1. Aggregate tangible and intangible capital investment: Japan, 1985-2010.



Source: Research Institute of Economy, Trade and Industry (RIETI), JIP Database 2015.

Note. Tangible capital investment includes outsourced software investment.

Figure 2. Estimated coefficients for $LN(Ktan)_{i,t} \times LN(Kintan)_{i,t}$ under constraints and unconstrained coefficients for $LN(Ktan)_{i,t} \times LN(Kintan)_{i,t}$.

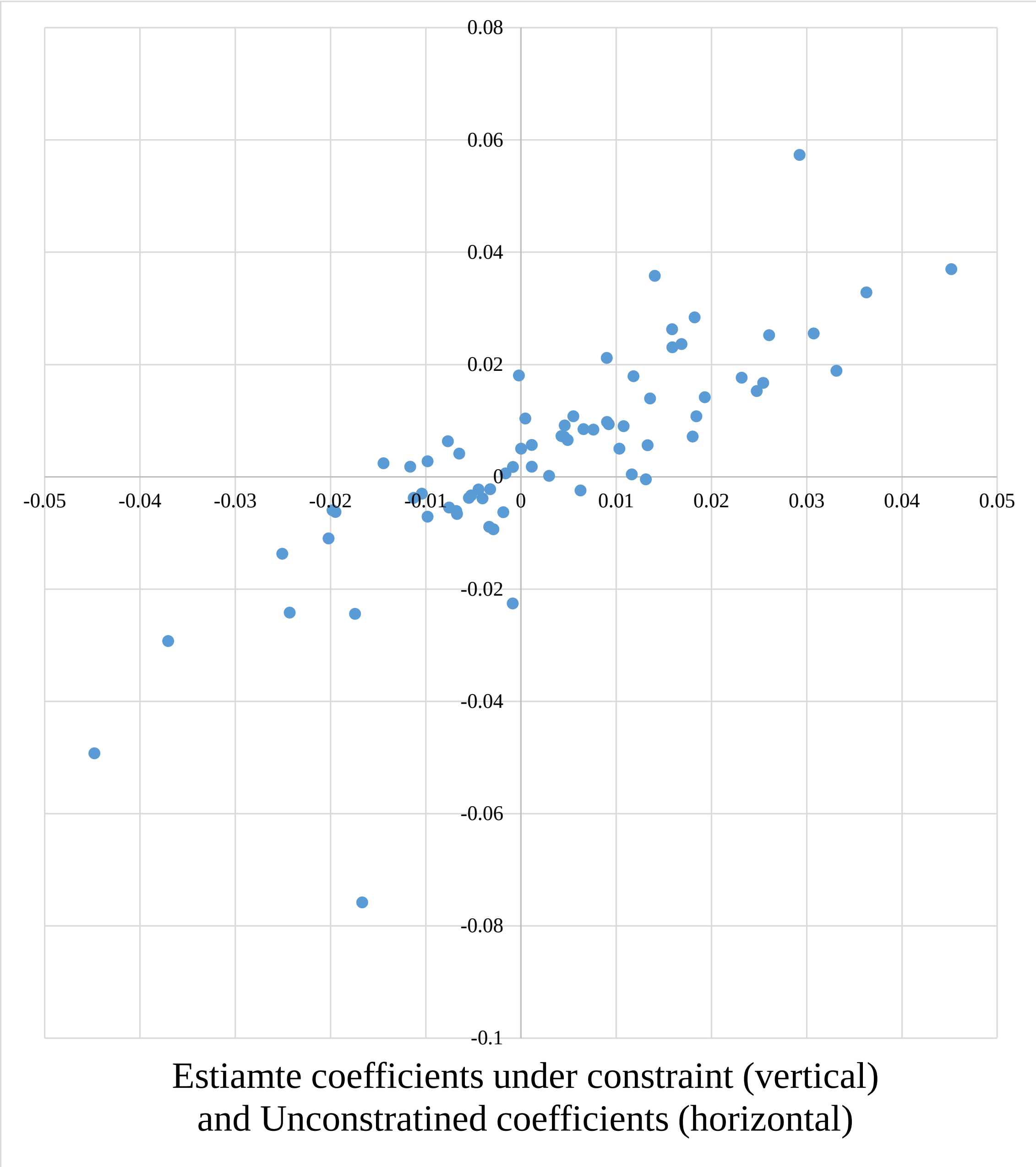


Figure 3. Estimated coefficients for $LN(Ktan)_{i,t} \times LN(Kintan)_{i,t}$.

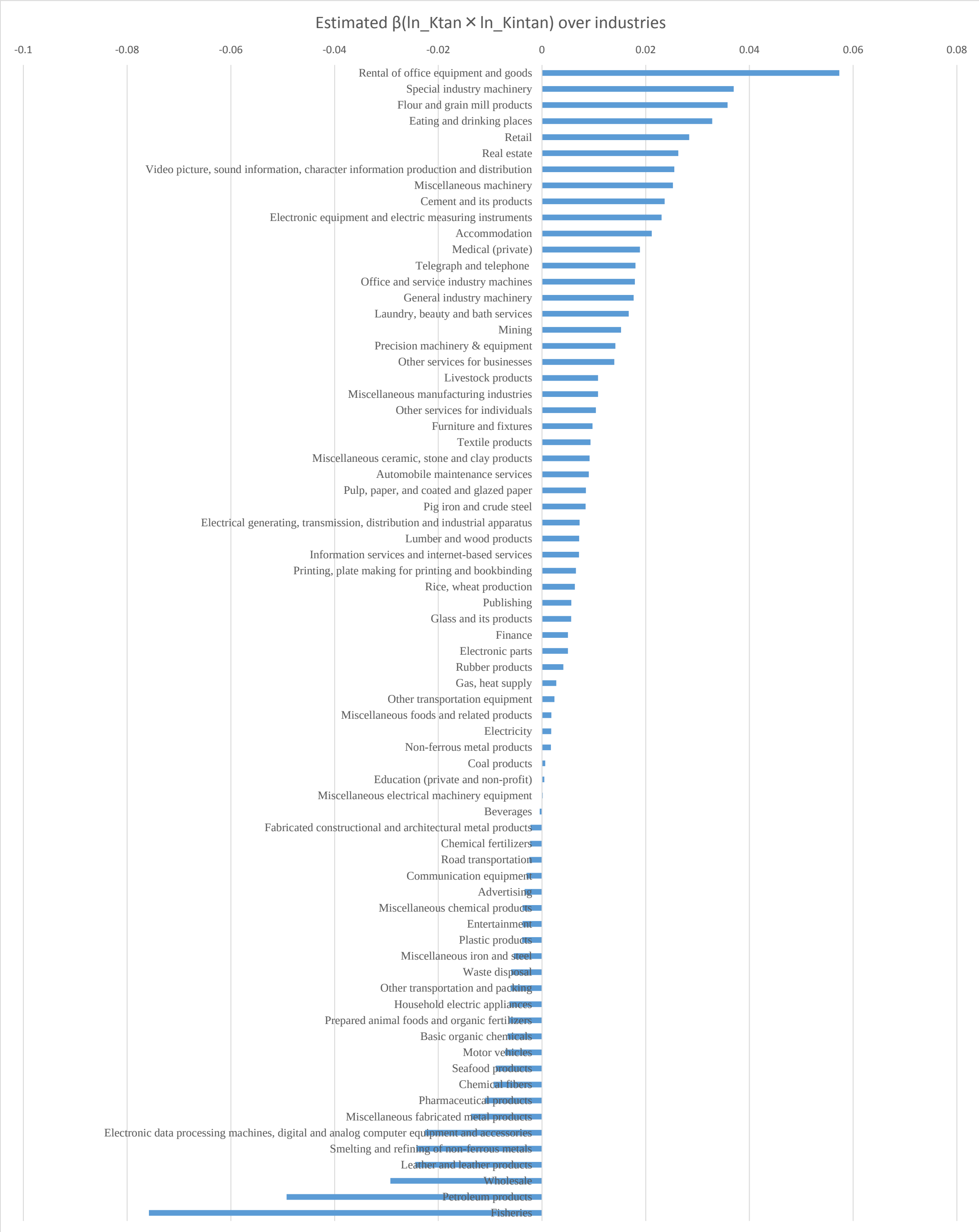
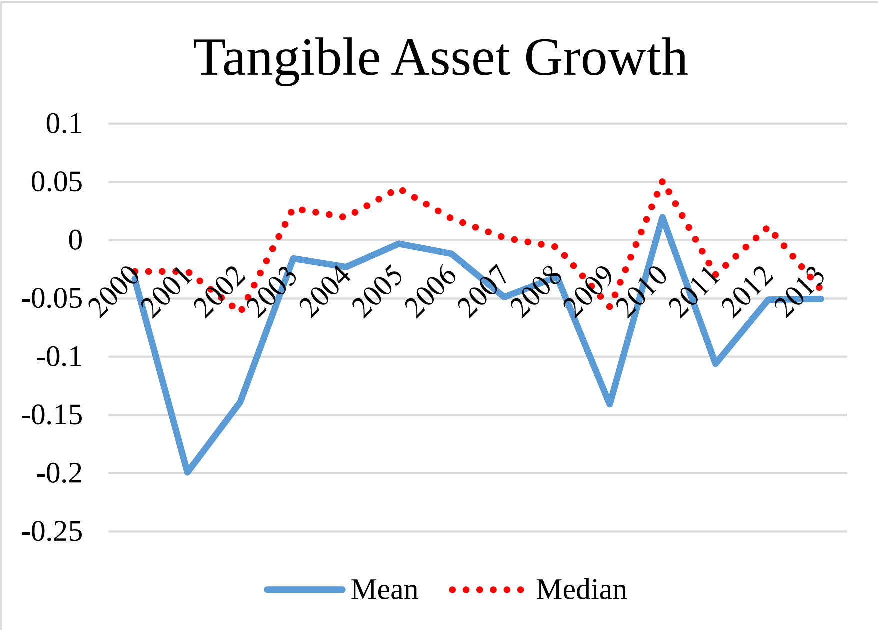
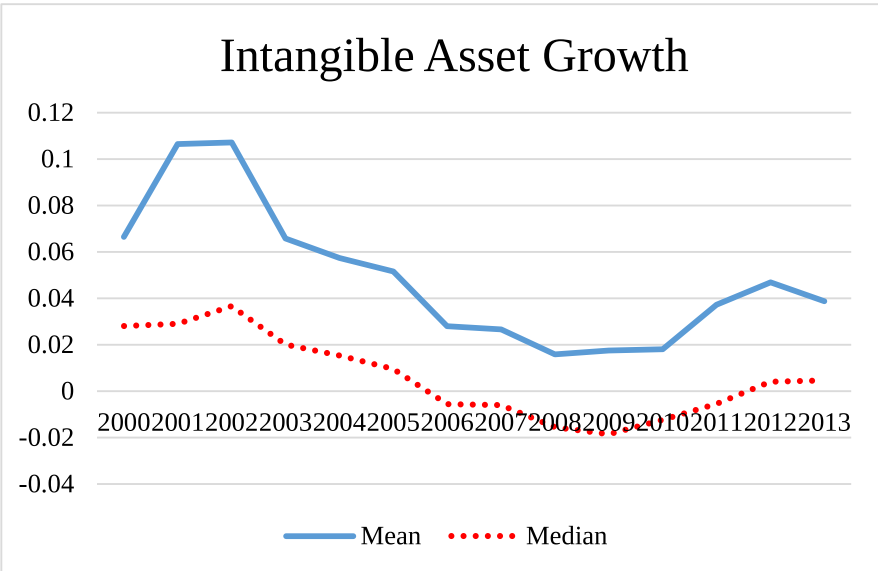


Figure 4. Tangible and Intangible capital investment: Japan, 1985-2010.





Note: The upper and lower panels account for the growth of tangible and intangible assets based on the data we use for the estimation in the present paper.

Table 1. Industry classification in JIP.

JIP Classification No.	Sector Name	IT dummy	Non-manufacturing dummy	R&D intensive dummy
1	Rice, wheat production	0	1	0
2	Miscellaneous crop farming	0	1	0
3	Livestock and sericulture farming	0	1	0
4	Agricultural services	0	1	0
5	Forestry	0	1	0
6	Fisheries	0	1	0
7	Mining	0	1	1
8	Livestock products	1	0	1
9	Seafood products	1	0	0
10	Flour and grain mill products	1	0	0
11	Miscellaneous foods and related products	0	0	1
12	Prepared animal foods and organic fertilizers	0	0	0
13	Beverages	0	0	1
14	Tobacco	1	0	1
15	Textile products	0	0	1
16	Lumber and wood products	0	0	0
17	Furniture and fixtures	1	0	1
18	Pulp, paper, and coated and glazed paper	0	0	1
19	Paper products	0	0	0
20	Printing, plate making for printing and bookbinding	1	0	1
21	Leather and leather products	1	0	0
22	Rubber products	0	0	1
23	Chemical fertilizers	1	0	1
24	Basic inorganic chemicals	1	0	1
25	Basic organic chemicals	0	0	1
26	Organic chemicals	0	0	1
27	Chemical fibers	1	0	1
28	Miscellaneous chemical products	0	0	1
29	Pharmaceutical products	1	0	1
30	Petroleum products	0	0	1
31	Coal products	0	0	1
32	Glass and its products	0	0	1
33	Cement and its products	0	0	0
34	Pottery	1	0	1
35	Miscellaneous ceramic, stone and clay products	0	0	0
36	Pig iron and crude steel	0	0	0
37	Miscellaneous iron and steel	0	0	1
38	Smelting and refining of non-ferrous metals	1	0	1
39	Non-ferrous metal products	0	0	1
40	Fabricated constructional and architectural metal products	1	0	1
41	Miscellaneous fabricated metal products	1	0	1
42	General industry machinery	1	0	1
43	Special industry machinery	1	0	1
44	Miscellaneous machinery	1	0	1
45	Office and service industry machines	1	0	1
46	Electrical generating, transmission, distribution and industrial apparatus	1	0	1
47	Household electric appliances	1	0	1
48	Electronic data processing machines, digital and analog computer equipment and accessories	1	0	1
49	Communication equipment	1	0	1
50	Electronic equipment and electric measuring instruments	1	0	1

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51 Semiconductor devices and integrated circuits	0	0	1
52 Electronic parts	1	0	1
53 Miscellaneous electrical machinery equipment	1	0	1
54 Motor vehicles	0	0	1
55 Motor vehicle parts and accessories	0	0	1
56 Other transportation equipment	1	0	1
57 Precision machinery & equipment	1	0	1
58 Plastic products	0	0	1
59 Miscellaneous manufacturing industries	1	0	1
60 Construction	0	1	1
61 Civil engineering	0	1	0
62 Electricity	0	1	0
63 Gas, heat supply	1	1	0
64 Waterworks	0	1	0
65 Water supply for industrial use	0	1	0
66 Waste disposal	0	1	0
67 Wholesale	1	1	0
68 Retail	1	1	0
69 Finance	1	1	0
70 Insurance	1	1	0
71 Real estate	0	1	0
72 Housing	0	1	0
73 Railway	0	1	0
74 Road transportation	0	1	0
75 Water transportation	0	1	0
76 Air transportation	0	1	0
77 Other transportation and packing	0	1	0
78 Telegraph and telephone	1	1	0
79 Mail	1	1	0
80 Education (private and non-profit)	0	1	0
81 Research (private)	1	1	1
82 Medical (private)	1	1	0
83 Hygiene (private and non-profit)	1	1	0
84 Other public services	0	1	0
85 Advertising	1	1	0
86 Rental of office equipment and goods	1	1	0
87 Automobile maintenance services	0	1	0
88 Other services for businesses	1	1	0
89 Entertainment	0	1	0
90 Broadcasting	1	1	0
91 Information services and internet-based services	1	1	1
92 Publishing	1	1	0
93 Video picture, sound information, character information production and distribution	1	1	1
94 Eating and drinking places	0	1	0
95 Accommodation	0	1	0
96 Laundry, beauty and bath services	1	1	0
97 Other services for individuals	1	1	0

Table 2. Summary statistics.

Variable	Mean	Median	Std. Dev	Minimum	Maximum	Observations
LN(Ktan)	6.002	6.018	1.837	-3.040	14.839	333,743
LN(Kintan)	5.117	4.952	1.979	-9.009	15.286	333,743
ΔLN(Ktan)	-0.060	-0.006	0.651	-8.139	7.768	333,743
ΔLN(Kintan)	0.048	0.005	0.289	-0.799	9.094	333,743
ΔLN(TFP)$_{IND}$	0.004	0.004	0.044	-0.276	0.351	307,760
ΔLN(TFP)$_{Residual}$	0.012	0.010	0.596	-9.787	9.046	333,743
LN(Value added)	7.099	6.878	1.288	-1.006	15.870	333,743
LN(Labor)	5.218	4.981	1.026	3.752	11.830	333,743
Value added	5513.124	970.498	56950.020	0	7800530	333,743
Labor	441.631	145.575	1773.663	42.593	137323	333,743
Ktan	3159.651	410.654	27390.080	0.048	2782125	333,743
Kintan	3051.951	141.389	44697.670	0.000	4351219	333,743

Note: These are the summary statistics for the observations used for the estimation of equation (9).

Table 3. Estimated coefficients associated with cross term and industry features.

Dependent Variable: β(ln_Ktan×ln_Kintan)

	Coefficient		Standar error	t-value
IndustrySize	0.003	*	0.002	1.930
AverageFirmSize	-0.004	*	0.002	-1.680
const	-0.008		0.017	-0.450
Number of obs	70			
F(2,67)	1.950			
Prob > F	0.151			
Adj R-sq:	0.027			
Root MSE	0.019			

Dependent Variable: β(ln_Ktan×ln_Kintan)

	Coefficient		Standar error	t-value
IT_Dummy	0.005		0.005	1.160
NonManufactuaring_Dummy	0.004		0.007	0.590
RD_intensity	-0.003		0.007	-0.520
IndustrySize	0.003	*	0.002	1.820
AverageFirmSize	-0.004		0.002	-1.640
const	-0.010		0.017	-0.610
Number of obs	70			
F(5,64)	1.450			
Prob > F	0.218			
Adj R-sq:	0.032			
Root MSE	0.019			

Table 4. Baseline estimation.

Dependent Variable: ΔLN(Ktan)

	Coefficient		Standar error	t-value
ΔLN(Kintan)	-0.314	***	0.005	-65.770
ΔLN(Kintan)$\times\beta_{tan\times intan}(IND_i)$	1.172	***	0.257	4.560
$\Delta LN(TFP)_{IND}$	0.366	***	0.031	11.860
Constant	0.080	***	0.004	19.410
Year dummy	Yes			
Number of obs	318247			
F(15,274642)	638.250			
Prob > F	0.000			
R-sq:				
within	0.034			
between	0.083			
overall	0.038			

Dependent Variable: ΔLN(Ktan)

	Coefficient		Standar error	t-value
ΔLN(Kintan)	-0.315	***	0.005	-67.830
ΔLN(Kintan)$\times\beta_{tan\times intan}$(FIRM)	0.901	***	0.248	3.630
ΔLN(TFP)	0.009	***	0.002	4.750
Constant	0.053	***	0.004	13.040
Year dummy	Yes			
Number of obs	333743			
F(15,294014)	43678.000			
Prob > F	0.000			
R-sq:				
within	0.032			
between	0.103			
overall	0.037			

Note: These are the results of the estimation based on equation (9).

Table 5. Subsample based on firm size.

Dependent Variable: ΔLN(Ktan)

Large firms	Coefficient		Standar error	t-value
ΔLN(Kintan)	-0.262	***	0.007	-37.980
ΔLN(Kintan)×$\beta_{tan\times intan}$(IND$_i$)	-0.362		0.310	-1.170
ΔLN(TFP)$_{IND}$	0.293	***	0.035	8.350
Constant	0.080	***	0.005	16.580
Year dummy	Yes			
Number of obs	158766			
F(15,134629)	215.190			
Prob > F	0.000			
R-sq:				
within	0.023			
between	0.073			
overall	0.030			

Dependent Variable: ΔLN(Ktan)

Small firms	Coefficient		Standar error	t-value
ΔLN(Kintan)	-0.331	***	0.007	-50.550
ΔLN(Kintan)×$\beta_{tan\times intan}$(IND$_i$)	2.849	***	0.398	7.150
ΔLN(TFP)$_{IND}$	0.325	***	0.050	6.450
Constant	0.070	***	0.007	10.650
Year dummy	Yes			
Number of obs	159481			
F(15,130201)	434.280			
Prob > F	0.000			
R-sq:				
within	0.048			
between	0.019			
overall	0.037			

Dependent Variable: ΔLN(Ktan)

Large firms	Coefficient		Standar error	t-value
ΔLN(Kintan)	-0.262	***	0.007	-39.450
ΔLN(Kintan)×$\beta_{tan\times intan}$(FIRM)	-0.426		0.298	-1.430
ΔLN(TFP)	0.001		0.002	0.570
Constant	0.040	***	0.005	8.280
Year dummy	Yes			
Number of obs	168557			
F(15,145461)	200.410			
Prob > F	0.000			
R-sq:				
within	0.022			
between	0.075			
overall	0.028			

Dependent Variable: ΔLN(Ktan)

Small firms	Coefficient		Standar error	t-value
ΔLN(Kintan)	-0.332	***	0.006	-51.610
ΔLN(Kintan)×$\beta_{tan\times intan}$(FIRM)	2.407	***	0.387	6.230
ΔLN(TFP)	0.000		0.003	-0.090
Constant	0.059	***	0.007	8.960
Year dummy	Yes			
Number of obs	165186			
F(15,233743)	404.830			
Prob > F	0.000			
R-sq:				
within	0.046			
between	0.028			
overall	0.038			

Note: These are the results of the estimation based on equation (9).