Firm Age, Productivity, and Intangible Capital

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Abstract

We examine the role of intangible capital investment in firm growth in sales and productivity over age. To this end, we first document how firm sales evolve with age using a large dataset from Japan covering the periods of 1991 and 1994-2015. Second, we construct a model to show the relationship between firm sales and the three parameters: markup, physical productivity (TFPQ), and factor price distortion, which vary across firms and over time. We estimate these parameters at the firm-year level using the dataset and quantify the impacts of each parameter on sales growth by simulating the hypothetical sales growth with each parameter fixed to the initial value for each firm. Third, we estimate the effects of intangible capital on sales through each parameter of sales. Our findings can be summarized as follows. First, firm sales grow with age up to about 30 years after entry. Second, TFPQ increases with firm age and has dominant effects on sales growth compared to markup and factor price distortion. Third, intangible capital has significant effects on sales growth through TFPQ. Among the three types of intangible capital, organizational capital accounts for a major portion of sales growth.

Keywords: Firm age, Total Factor Productivity, Intangible capital, Markup, Distortions

JEL classification: D24, E22.

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1. Introduction

Since the IT revolution in the U.S. during the 1990s, much effort has been made to measure the intangible capital and to analyze its roles in firm activities (e.g. Bresnahan, Brynjolfsson, and Hitt, 2002). Recently, some researchers attribute the decline in business dynamism to the concentration of intangible capital (Akcigit and Ates, 2019a, b; De Ridder, 2019). These studies have well documented the roles of the intangible capital for aggregate economic growths and firm growth theoretically, but empirical studies on the roles of intangible capital in firm growth are limited.

In this paper, we explore the roles of intangible capital in firm growth and productivity by focusing on the dynamics of intangible capital investment over firm age. While many studies have studied the determinants of the investment in intangible capital, there are no papers focusing on its relationship with firm age. Figure 1 shows the mean log difference of intangible capital by firm age for the firms in our sample from Japan over the period of 1995-2015. Firms are classified into five age groups: age 2-9, age 10-29, age 30-49, age 50-69, and age 70 and over. In the figure, the mean of the youngest firms is the highest in every year over the observation period. The second youngest firms have the second highest investment rate and other three groups are almost the same. It is seen that young firms more actively undertake the investment in intangible capital even during severe recessions. This figure suggests the importance of focusing on the roles of firm age to consider the accumulation of intangible capital.

The roles of young firms are closely explored for some dimensions of firm activities other than intangible capital. It is now well known that the size of plants and firms grows in terms of sales and employment with their ages and that younger plants and firms have higher growth rates in the U.S. (e.g. Davis, Haltiwanger, and Schuh, 1996). Such an age-size relationship is observed in Japan as well. Figure 2 shows the log difference in sales and production factors of Japanese firms in our sample. The growth rates in sales and all production factors are higher for younger firms. The growth rates decline with firm age and reach zero around 30-40 years after establishment. In addition, the growth rate in sales is higher than the growth rates in production factors, which implies that productivity is increasing with firm age to the extent that productivity is measured as the ratio of sales.

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4 In this paper, we focus on the intangible capital and firm growth in Japan. In case of Japan, some studies point out that the accumulation of intangible capital is slow and negative in some years. Fukao, Miyagawa, Mukai, Shinoda, and Tonogi (2009) found that although the ratio of intangible investment to GDP in Japan has risen from the 1980s to the 2000s, it is lower than the U.S. In addition, the growth rate of intangible capital in Japan declined from the late 1980s to the early 2000s. Chun, Fukao, Hisa, and Miyagawa (2012) compared the intangible capital in Japan and Korea at industry level and found the growth rate in intangibles became negative in some industries in Japan in the 2000s.
5 In Table A1 in Appendix, we regress the investment rate of intangible capital on firm age, lagged sales, and lagged intangible capital stock to show that the high investment rate of the young firm is not perfectly explained by the small size of the young firm.
to the weighted average of production factors.\(^7\)

What is less known is the mechanism that drives such age-size and age-productivity relationships. One strand of literature stresses the selection mechanism through which less productive firms exit and more productive firms survive (Baily, Hulten, and Campbell, 1992; Jovanovic, 1982; and Ericson and Pakes, 1995). Another strand of literature examines the role of organizational capital that plants and firms accumulate as they age (Atkeson and Kehoe, 2005; Hsieh and Klenow, 2014). While empirical studies on the selection mechanism are relatively rich, those on organizational capital are still scarce. We provide new empirical evidence on the latter mechanism using a large panel data set of Japanese firms.

We examine the roles of intangible capital including organizational capital in firms’ growth in sales and productivity over age. For this aim, we first construct a model to show the relationship between firm sales and the three parameters: physical productivity (TFPQ), markup, and factor price distortion. While Hsieh and Klenow (2009) show that log of sales is proportional to the difference between logs of TFPQ and revenue productivity (TFPR) under the assumption of constant markup across firms, we decompose TFPR into markup and factor price distortion both of which vary across firms and over time. Next, we examine how these three parameters evolve with age. We further examine the quantitative impacts of the three parameters on sales growth by simulating the hypothetical sales growth in the case when each parameter were fixed to the initial value. Then, we proceed to analyze the role of intangible capital in the age-size and age-productivity relationships. We construct firm-level panel data of intangible capital consisting of organizational capital, software, and R&D stocks and regress the changes in sales, TFPQ, markup, and factor price distortion on firm age and the changes in intangible capital.

Our findings can be summarized as follows. First, firm sales grow with age up to about 30 years after entry. Second, TFPQ increases with age and has a dominant positive effect on the sales growth up to about 30 years after entry. On the other hand, the markup increases with age and hence has a negative effect on sales growth, while the distortion decreases with age and has a positive effect on sales growth. Third, intangible capital has significant effects on firm growth through TFPQ. Among the three types of intangible capital, organizational capital accounts for a major part of the growth of sales. Software and R&D stocks also have some effects on markup and factor price distortion.


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\(^7\) This definition of productivity is based on revenue-based productivity (TFPR). We show below that our measure of physical productivity (TFPQ) also increases with age.
establishment size in terms of labor and productivity grow less as establishments age in Mexico and India than in the US, suggesting that they accumulate less organizational capital in India and Mexico than in the US. They further find that TFPR rises much more steeply with TFPQ in India and Mexico than in the US, suggesting that distortions such as taxes, factor costs, financial frictions, and transportation and trade costs become larger with age in India and Mexico than in the US. Both Atkeson and Kehoe (2005) and Hsieh and Klenow (2014) suggest that plant-specific investment in organizational capital plays a key role in plant growth in terms of size and productivity. However, they do not directly measure organizational capital or other types of intangible capital. We take a different approach from them. We measure firm-level intangible capital to examine whether intangible capital actually plays a significant role in firms’ life-cycle growth. As far as we know, the present study is the first that examines the role of intangible capital in the relationship between firm or plant age and productivity.

Bahk and Gort (1993), Power (1998) and Jensen, McGuckin, and Stiroh (2001) are also related to the present study in that they study how productivity evolves with plant age. Bahk and Gort (1993), using data of US manufacturing plants for the period of 1972 to 1986, examine learning-by-doing based on a production function with labor, human capital, physical capital, and vintage as inputs. Power (1998), using data of US manufacturing plants for the period of 1972-1988, show that investment in physical capital is not correlated with productivity or productivity growth. Jensen, McGuckin, and Stiroh (2001) examine the evolution of productivity in US manufacturing plants from 1963 to 1992 and show that while recent cohorts enter with higher productivity than earlier entrants did (vintage effect), surviving cohorts show productivity increases as they age (survival effect) and that these two effects roughly offset each other. These studies are suggestive of the evolution of productivity with plant age, but they do not take into consideration the role of intangible capital, except for the human capital in Bahk and Gort (1993).

Finally, Foster, Haltiwanger, and Syverson (2016) and Fujii, Saito, and Senga (2017) focus on a specific factor for the age-productivity relationship. Foster, Haltiwanger and Syverson (2016) show that even in commodity-like markets, establishment growth is largely driven by rising demand for the plant’s products rather than by initial productivity gaps as it ages, suggesting the importance of a demand accumulation process such as building a customer base. Their study is suggestive of the importance of intangible capital, that is, a customer base, but does not directly examine its role. Fujii, Saito, and Senga (2017) investigate how the inter-firm transaction network evolves over the firm lifecycle and obtain evidence suggesting that the observed relationship between firm age and firm growth may be due to the lifecycle pattern of building inter-firm networks.

8 In these papers, plant age is used to explore the role of learning-by-doing. See Thompson (2010) for the survey of the literature on learning-by-doing.

9 The role of customer base is explored in Gourio and Rudanko (2014).
The remainder of the paper is organized as follows. Section 2 presents the underlying framework for our analysis. Section 3 describes the data and measurement method for productivity and intangible capital. Section 4 provides the basic facts on the age-sales and age-productivity relationships. In Section 5, we evaluate the role of intangible capital in firm growth by conducting regression and simulation analyses based on the estimated parameters. The last section concludes.

2. Framework

In this section, we introduce a framework to express the firm sales by underlying parameters of TFPQ, demand elasticity (or markup), and distortion on input prices. Thus we do not impose the relationships between firm age and productivity and other parameters a priori. Using this framework, we explain the possible mechanism that generates the relationship between age and sales. We further discuss the roles of intangible capital in the mechanism of the age-sales relationship.

We consider a static partial equilibrium model with monopolistic competition. The framework is a natural extension of Hsieh and Klenow (2009; 2014). Unlike them, however, we allow heterogeneous markups across firms and increasing or decreasing returns to scale. By so doing, we can analyze the behavior of a firm more realistically but cannot evaluate the economic welfare that requires aggregation across firms.

In industry $s$, there are a continuum of goods and each of them is produced by a firm. Below we do not specify industry by subscripts unless it is necessary to avoid confusion. The firm $i$ produces output in year $t$ according to the following production function

$$Q_{it} = A_{it} K_{it}^{\alpha_K} L_{it}^{\alpha_L} M_{it}^{\alpha_M}, \ a_k + a_l + a_m = \gamma$$

where $Q_{it}$ denotes output, $A_{it}$ denotes Hicks-neutral technology or TFPQ, and $K_{it}$, $L_{it}$, and $M_{it}$ denote capital, labor, and intermediate, respectively. The $\alpha_X$ for input $X = K, L, M$ is the elasticity of output with respect to input $X$. These elasticities are assumed to be common across firms within an industry. Summation of the elasticities $\gamma$ denotes the degree of scale returns. Unlike Hsieh and Klenow (2009), we do not impose constant returns to scale.

The demand for firm $i$’s goods is assumed to take the following form:

$$Q_{it} = B P^{-\epsilon_{it}}_{it},$$

where $P_{it}$ is output price at the firm level, $B$ is a constant demand shift parameter for the industry, and $\epsilon_{it}$ is the time-variant price elasticity for firm $i$ ($\epsilon_{it} > 1$). Equation (2) leads to

$$Q_{it} = B^{1-\mu_{it}} (P_{it} Q_{it})^{\mu_{it}},$$
where $\mu_{lt} = \frac{\epsilon_{lt}}{\epsilon_{l-1}}$. Equation (3) enables us to obtain output from sales.

Following Hsieh and Klenow (2009), the profit function is assumed to be the following:

$$\pi_{lt} = P_{lt}Q_{lt} - (1 + \tau_{Klt})RK_{lt} - (1 + \tau_{Llt})wL_{lt} - P_{M}M_{lt}, \quad (4)$$

where $R$, $w$, and $P_{M}$ denote factor prices for each input, $\tau_{Klt}$ and $\tau_{Llt}$ represent distortions at firm level. Positive values of these distortions imply that the firm suffers from unfavorable treatments such as taxes or restrictions and negative imply firms enjoy their favorable treatments such as subsidies.

Profit maximization leads to

$$\frac{dP_{lt}Q_{lt}}{dQ_{lt}} = \left(1 - \frac{1}{\epsilon_{lt}}\right)P_{lt} = MC_{lt}$$

where $MC_{lt}$ denotes the marginal cost. Then the markup can be derived as follows:

$$\frac{P_{lt}}{MC_{lt}} = \frac{\epsilon_{lt}}{\epsilon_{lt} - 1} = \mu_{lt}$$

In addition, the first order conditions for profit maximization with respect to each of inputs lead to,

$$\frac{RK_{lt}}{P_{lt}Q_{lt}} = \frac{a_{K}}{\mu_{lt}(1 + \tau_{Klt})} \quad (5a)$$

$$\frac{wL_{lt}}{P_{lt}Q_{lt}} = \frac{a_{L}}{\mu_{lt}(1 + \tau_{Llt})} \quad (5b)$$

$$\frac{P_{M}M_{lt}}{P_{lt}Q_{lt}} = \frac{a_{M}}{\mu_{lt}} \quad (5c)$$

Let us define the input distortion and composite factor price as

$$\tau_{lt} = (1 + \tau_{Llt})a_{L}(1 + \tau_{Klt})a_{K} \quad (6)$$

$$c = \left(\frac{a_{L}}{w}\right)^{-a_{L}}\left(\frac{a_{K}}{R}\right)^{-a_{K}}\left(\frac{a_{M}}{P_{M}}\right)^{-a_{M}} \quad (7)$$
Then, combining equations (5a)-(5c), we obtain

$$\tau_{it} = \frac{\left( P_{it} Q_{it} \right)^\gamma}{K_{it}^\mu \tau_{it}^\mu M_{it}^\mu \mu_{it}^\mu}$$  \hspace{1cm} (8)

Combining (5a)-(5c) with the production function (1) and equations (3) and (8), we can express output and sales, respectively, as

$$Q_{it} = \frac{A_{it}}{\tau_{it}^\gamma} \left( \frac{P_{it} Q_{it}}{\mu_{it}} \right)^\gamma$$  \hspace{1cm} (9)

$$P_{it} Q_{it} = \left( \frac{A_{it} B^{\mu_{it}^{-1}}}{\mu_{it}^\gamma \tau_{it}^\mu} \right)^{\frac{1}{\mu_{it}^{-\gamma}}}$$  \hspace{1cm} (10)

We use equation (10) to decompose sales into TFPQ, markup, factor distortion, and a constant term which includes industry-wide composite factor prices and demand shifters. Equation (10) shows that sales increases with TFPQ and decreases with markup and distortions if $\mu_{it} - \gamma > 0$, which we assume hereafter for all $i$ and $t$.

We consider all of TFPQ, markup, and factor distortion as functions of firm age and intangible capital. Firm age affects TFPQ via learning-by-doing, by which firms accumulate knowledge through production experience. Another important channel of enhancing TFPQ is the accumulation of intangible capital. Unlike tangible capital, intangibles take a long time to adjust to the statically optimal level. Knowledge capital is accumulated by R&D, for example, of which the transaction is limited because it is unobservable.\(^\text{10}\)

Markup and factor distortion are also affected by firm age and intangible capital though many channels. For example, firms can reduce borrowing costs over time as they build reputation in capital markets (Sakai, Uesugi, and Watanabe, 2010). In extreme cases, zombie firms may enjoy their favorable treatment (Caballero, Hoshi, and Kashyap, 2008). On the other hand, start-ups may be subsidized. The net effect of firm age on distortions is, therefore, difficult to predict.\(^\text{11}\) Furthermore, firm age can affect markup as well if older firms obtain better reputation in the product market. Similarly, intangible capital can affect both factor distortions and markup. Availability of outside financing in intangible capital investment is limited because intangibles are not pledgeable as

\(^{10}\) If age reflects vintage capital, TFPQ can decrease with age.

\(^{11}\) Another interesting mechanism is the precision of prediction made by firms. As in Jovanovic (1982) and Arkolakis, Papageorgiou, and Timoshenko (2018), old firms can predict their demand more precisely. This channel results in the small variation in markup for older firms.
collateral, leading to higher factor distortions. Advertising and R&D may make their products more differentiated to consumers, which is likely to lead to higher markup.

3. Data and measurement

We use the data of Basic Survey of Japanese Business Structure and Activities (BSJBSA). The Ministry of Economy, Trade and Industry (METI) conducts the survey and collects detailed information on enterprises with 50 or more employees and with paid-up capital over 30 million. BSJBSA covers firms that fall into mining, manufacturing, wholesale and retailing industries, and some other non-manufacturing industries. The data that are available to us cover the period of 1991 and 1994-2015. To deal with the revision of industry classification during the period, we use a concordance table in the Japan Industrial Productivity Database.

3.1 Firm age

We firstly measure the firm age. In the BSJBSA, firms report years of establishment. Some firms, however, report different established years in different survey years. We regard these cases as misreporting and choose the most frequently reported years of establishment for each firm. In addition, we correct the established year to the year that the firm first appears in the BSJBSA if the reported established year is later than the year it appears. Then we calculate firm age by subtracting the established year from the survey year. Finally, we drop firms with zero age to exclude partial year effects in Bernard, Boler, Massari, Reyes, and Taglioni (2017). Figure 3 shows the distribution of firm age in 2015. Due to the threshold of BSJBSA, the numbers of young firms included in the sample are relatively small. The number of firms with more than 70 years old are also small because many firms in Japan were established in the postwar period.

3.2 Elasticities of inputs and firm-level parameters

We assume the output elasticities of production function (1), $\alpha_K$, $\alpha_L$, $\alpha_M$, are common across firms within an industry. Then we use the first order condition with respect to intermediates (5c) to estimate intermediate elasticity $\alpha_{MS}$ and markup $\mu_{It}$. To identify the markup, we impose the assumption that the firms that fall in the lowest 10 percent of the markup in each industry have a unit markup, $\mu_{It} = 1$. Equation (5c) shows that these firms correspond to the firms that fall in the highest 10 percent of the share of intermediates cost to sales. We therefore obtain $\alpha_{MS}$ as the 90 percentile of $P_{M5}/P_{It}$ for each industry.

Once we obtain $\alpha_{MS}$, we can derive the markup for each firm by taking the ratio of the estimated elasticity to the intermediate share.
This method is consistent with the approach developed by De Loecker and Warzynski (2012) in that markup is derived from the output elasticity of an input \( \alpha_M \) divided by revenue share of that input \( \frac{p_m Q_m}{P M M} \), although we do not derive \( \alpha_M \) by estimating the production function.\(^{12}\) This method can be considered as a simplified version of De Loecker and Warzynski (2012). We set the markups of lower 10 percent firms as the minimum values conditional on strictly above one in each industry.\(^{13}\)

We use other first order conditions (5a) and (5b) to estimate the labor and capital elasticities. We assume that the median values of factor distortions for each input is zero in each industry.

\[
\begin{align*}
\text{Med}_s [\ln (1 + \tau_{L,M})] &= 0, \\
\text{Med}_s [\ln (1 + \tau_{K,M})] &= 0,
\end{align*}
\]  
\(^{(12)}\)  
\(^{(13)}\)

where \( \text{Med}_s \) denotes the industry-level median value. By assuming symmetric distributions for \( \tau_{L,M} \) and \( \tau_{K,M} \), factor elasticities are estimated by the following equations

\[
\begin{align*}
\alpha_L &= \text{Med}_s \left( \frac{\mu_t w_s L_{it}}{P_{it} Q_{it}} \right), \\
\alpha_K &= \text{Med}_s \left( \frac{\mu_t R K_{it}}{P_{it} Q_{it}} \right).
\end{align*}
\]  
\(^{(14)}\)  
\(^{(15)}\)

We use reported wage bill as \( w_s L_{it} \) to obtain \( \alpha_L \). We use tangible fixed assets as \( K_{it} \), and set \( R = 0.1 \) following Hsieh and Klenow (2009) to obtain \( \alpha_K \).

Next, we derive TFPQ. From equations (1) and (3), we can define the composite of TFPQ and demand shifter as

\[
A'_t = \frac{(P_{it} Q_{it})^{\mu_t}}{K_{it}^{\mu_t} M_{it}^{\mu_t} L_{it}^{\mu_t}} = A_t B^{\mu_t - 1}.
\]  
\(^{(16)}\)

We first calculate this composite term by using estimated parameters.

\(^{12}\) See Nishioka and Tanaka (2019) for the application of De Loecker and Warzynski (2012) to the Japanese plant-level data. We do not estimate the production function to obtain the input elasticities because output quantity data are not available for the BSJBSA that contains non-manufacturing firms as well as manufacturing firms.

\(^{13}\) For seven out of 101 industries, the median shares of intermediates are less than 10%. We dropped these industries because the estimated markups and factor elasticities are extraordinarily high. After this process, our sample includes 94 industries.
Taking first-order differences of logged values, we obtain

\[ \Delta \ln A_{it}' = \Delta \ln A_{it} + \ln B \Delta \mu_{it} \]  (18)

We assume that the TFPQ growth rate is composed of the firm fixed effect, year fixed effect, and random shock as

\[ \Delta \ln A_{it} = \delta_i + \delta_t + \mu_{it} \]  (19)

Then, equation (18) can be represented by

\[ \Delta \ln A_{it}' = \delta_i + \delta_t + \ln B \Delta \mu_{it} + \mu_{it} \]  (20)

We regress \( \Delta \ln \widehat{A}_{it}' \) on \( \Delta \mu_{it} \) with firm- and time- fixed effects using OLS to obtain the coefficient of \( \Delta \mu_{it} \) as \( \ln B \). Then we use equation (16) to retrieve TFPQ from \( \widehat{A}_{it}' \) as

\[ \ln \widehat{A}_{it}' = \ln \widehat{A}_{it} - \ln(\hat{\mu}_{it} - 1) \]  (21)

Finally, we estimate the change in factor distortion by taking log difference in equation (8) as

\[ \Delta \ln \widehat{r}_{it} = \gamma_s \Delta \ln P_{it} Q_{it} - \alpha_{Ks} \Delta \ln K_{it} - \alpha_{Ls} \Delta \ln L_{it} - \alpha_{Ms} \Delta \ln M_{it} - \gamma_s \Delta \ln \widehat{\mu}_{it}. \]  (22)

where \( \gamma_s = \alpha_{Ks} + \alpha_{Ls} + \alpha_{Ms} \) is the estimate of returns to scale.\(^{15}\)

3.3 Intangible Assets

Corrado, Hulten, and Sichel (2009) classify intangible assets into three categories: computerized information, innovative property, and economic competencies. Following them, we measure three types of intangibles; software, R&D, and organizational change from BSJBSA.

\(^{14}\) We also estimated the equation (20) by using dynamic-panel-data technique in Arellano and Bond (1991) and Blundell and Bond (1998), and found that the estimated demand parameters were highly correlated with each other. The correlation coefficient is over 0.95.

\(^{15}\) Although equation (8) includes the composite factor price \( \varepsilon_s \), we use only the rate of change in \( \widehat{r}_{it} \) in the empirical analyses below, and therefore do not need to estimate the industry-level variable \( \varepsilon_s \).
Software investment is a part of investment in computerized information consisting of three types of software; custom software investment, packaged software investment, and own account software investment. To measure the software investment, the ratio of workers engaged in information processing to the total number of employees is multiplied by the total cash earnings. Then, we add the cost of information processing to this number to find total software investment.

R&D investment is a major part of investment in innovative property. We use the expenses of R&D (i.e., in-house R&D and contract R&D) to estimate the value of investment in R&D.

Investment in economic competencies includes organizational change. Following Eisfeldt and Papanikolaou (2013) and Lev and Radhakrishnan (2005), we use sales and general administrative (SG&A) to measure flows to organization capital. We assume that 10% of SG&A accounts for investment in organizational change.

Then we measure the stock values of each type of intangible capitals by Perpetual Inventory Method. The depreciation rates are 33%, 20%, and 60% for software, R&D, and organization capital, respectively. We follow Corrado, Hulten, and Sichel (2009) to set these depreciation rates. For firms that first appear in the sample, we set the initial stock value to the investment value divided by sum of the depreciation rate and the assumed mean of net investment rate, 10%. Finally, we define total intangible capital stock as the sum of these three types of stocks. We denote Software, R&D, and Organization to denote each type of intangible capital stocks.

3.4 Sample Selection and Summary Statistics

We construct a sample by dropping observations that fall in the top and bottom 1% tails of the distribution of any differences in ln(PtQt), lnKt, lnLt, lnMt, lnSoftwareit, lnOrganizationit, ln(R&Dt + 1), μ̂it, lnAt, and lnτit. We also drop the top and bottom 1% tails of deviations from industry median values in μ̂it from our sample.

Table 1 shows the summary statistics for our sample. The mean of firm ages is 42 and close to the median value, 43. On the other hand, the mean of markup is 1.70 and it is higher than the median value, 1.30, due to the lower bound of one and therefore the right-skewed distribution. Means and medians of the change rates in most firm-level variables are all close to zero. It implies that the Japanese economy has no trend during the sample period as a whole, although it went through several business cycles and the domestic and global financial crises. One notable exception is the dispersion of firm sales. Figure A1 shows the distribution of sales at the firm level by decades. The figure shows that the dispersion increases over time. Interestingly, the same trend is observed in the data at the plant level from the Census of Manufacture published by METI and the Economic Census for Business Activity published by the Ministry of Internal Affairs and Communications and METI. Figure A2 shows the distribution of sales at the plant level by decades. The dispersion of sales was increasing during Japan’s lost two decades.
4. Analysis of Sales Growth over Age

In this section, we explore the relationships between firm age and firm size or firm-specific parameters of TFPQ, markup, and factor price distortion. We first take the means of differences for each variable and then accumulate them from age 1 as \( \ln PQ_a = \sum_{age=1}^{a} \ln P_{lt} Q_{lt} / N_t + \sum_{a=2}^{16} \Delta \ln P_{lt} Q_{lt} / N_t \), where \( N_t \) denotes the number of firm-year \( lt \) with age \( a \).\(^{16}\) We also obtain the log of TFPQ \( \ln A_a \), the markup \( \mu_a \), and the log of distortion \( \ln \tau_a \) in a similar way. Figure 4 shows the relationships of the estimated parameters and firm age. As noted in the explanation of Figure 2, the log of sales is increasing with firm age up to age 33. TFPQ is also increasing with firm age up to about age 30 and has a similar path to sales. Because TFPQ is a measure of technological or cost efficiency, Figure 4 shows that young firms improve their technology rapidly. The positive relationship between firm age and TFPQ is qualitatively the same result of the U.S. in Hsieh and Klenow (2014). Markup also increases with firm age, but its growth rate is smaller than those of sales and TFPQ when firms are young.\(^{17}\) In addition, the markup reaches its maximum about 50 years after entry and does not show a clear decline thereafter. The path of markup implies that newly established firms are forced to set price lower and suffer from low markups for an extended period. Finally, the factor price distortion is close to zero at any age. It goes down slightly after establishment, and then increases steadily. The initial decline in the distortion is consistent with the reputation hypothesis in credit market that postulates that firms can reduce borrowing costs over time (Sakai, Uesugi, and Watanabe, 2010), although the magnitude seems to be small.

We found the same results in the data at the plant level from the Census of Manufacture. Figure A3 in Appendix shows the change rates in sales, employment, intermediate, and the ratio of sales to intermediate in 2015 by age group. The ratio of sales to intermediate inputs can be interpreted as a proxy of markup. In the Census of Manufacture, plants report the period of establishment with a longer-than-annual base. We therefore classify the plants into five age groups; 2-4, 5-10, 11-20, 20-30, and over 30.\(^{18}\) The sample covers the plants that had 4 or more employees in 2014 and survived in 2015. In the figure, the rates of change in sales, employment, and intermediate are positive when the plants are young and decreasing with plant age. The change in the ratio of sales to intermediate inputs is positive and almost constant for all age groups.

Before exploring the roles of intangible capital, we evaluate the importance of TFPQ, markup, and distortion in sales by calculating the hypothetical sales that would realize if one of the TFPQ, markup, and distortions did not change over age at the initial level.

\(^{16}\) We do not define \( \ln PQ_a \) as the actual mean of levels, \( \sum_{age=a}^{16} \Delta \ln P_{lt} Q_{lt} / N_t \), to exclude the effects of the differences in initial values.

\(^{17}\) The positive correlation between age and markup is also found in Peters (2019) by firm-level data from Indonesia.

\(^{18}\) We drop plants with age less than two from our sample because we cannot calculate the rate of change in the variables for those plants.
For this aim, we take the log of equation (10) and replace the firm-year index \( t \) with age \( a \) to express the log of sales of the representative firm with age \( a \) as a function of TFPQ, markup, and distortion.

\[
\ln P Q(A_\alpha, \mu_\alpha, \tau_\alpha) = \ln B + \frac{1}{\mu_\alpha - \gamma} (\ln A_\alpha - \gamma \ln \mu_\alpha - \ln \tau_\alpha + (\gamma - 1) \ln B - \ln c)
\]  

(23)

Then we replace one of the arguments, \( A_\alpha, \mu_\alpha, \) and \( \tau_\alpha \), with its initial value, \( A_1, \mu_1, \) and \( \tau_1 \), respectively. Figure 5 shows the dynamics of the hypothetical sales if each one of these three factors is fixed to the initial value. The baseline is the simulated path of sales using equation (23) and as such shows how the actual sales evolves over age. The line labelled “initial TFPQ”, for example, shows the simulated path of sales when we fix TFPQ at the initial value:

\[
\ln \left( \frac{P Q(A_1, \mu_\alpha, \tau_\alpha)}{P Q(A_\alpha, \mu_\alpha, \tau_\alpha)} \right).
\]

It shows that if TFPQ were fixed to the initial value and did not increase with firm age, sales would decrease over age. This result suggests that the rise in TFPQ is central to the firm growth. The hypothetical firm would grow faster if the markup were fixed to the initial level. The rising markup makes sales smaller because the elasticity of demand is assumed to be over one. The changes of factor price distortion have small impacts on sales, but the sales growth would be slightly slower at the young ages if the factor price distortion did not change.

Considering the potential effects of intangibles on TFPQ, markup, and distortion, the accumulation of intangibles with firm age, observed in Figure 1, suggests that the age-productivity relationship may be accounted for by intangible capital. We examine whether and to what extent intangible capital really accounts for the relationship between firm age and sales, on one hand, and TFPQ, markup, and distortion, on the other, in the next section.

5. Roles of Intangible Capital in Firm Growth

5.1 Regression results

In this section, we explore the roles of intangible capital in firm growth. We first estimate the age effects without controlling for intangible capital. The estimated age effects, therefore, include the effects of intangible capital. Then we separate the effects of intangible capital from the age effects.

We first consider the following equation without intangible capital:

\[
Y_{it} = \beta_{it} (a e_{it}) + \beta_{i2} (a e_{it})^2 + \beta_{i3} (a e_{it})^3 + \delta_{i1} + \delta_{i2} + u_{i1} + u_{i2},
\]

(24)

where \( Y_{it} = \ln P_{it}, \ln A_{it}, \mu_{it}, \) and \( \ln \tau_{it} \). The independent variables are the first to third orders of

\(^{19}\) We standardize the sales by the initial value to interpret the simulated paths as the accumulated change rates from establishment.
firm age. We control for the firm fixed effect and time-varying industry effect. Then we estimate the first difference of (24):

$$\Delta Y_{it} = \beta_{Y1} + \beta_{Y2} age_{it} + \beta_{Y3} (age_{it})^2 + \delta_{Y, it} + u_{Y, it},$$  \hspace{1cm} (25)$$

We impose the mean of $\delta_{Y, it}$ equal to zero to identify the first-order age effect ($\beta_{Y1}$) with the estimated constant term. In all specifications, standard errors are clustered at the firm level. Table 2 shows the estimation results of OLS for equation (25). We report the result for $\Delta \ln P_{it} Q_{it}$ as the dependent variable in column (1). It shows that both age and age squared are significant for the log difference in sales. Column (2) shows that they are also significant for the log difference in TFPQ. Column (3) shows that neither of them is significant for the difference in markup while column (4) shows that only age squared is significant for the log difference in distortion.

Then we proceed to explore the roles of intangible capital in firm dynamics by considering the following equations.

$$Y_{it} = \beta'_{Y1} age_{it} + \beta'_{Y2} (age_{it})^2 + \beta'_{Y3} (age_{it})^3 + \beta'_{Y, Intang} \ln Intangible_{it} + \delta'_{Y, it} + \delta'_{st} + u'_{Y, it},$$ \hspace{1cm} (26a)

$$Y_{it} = \beta'_{Y1} age_{it} + \beta'_{Y2} (age_{it})^2 + \beta'_{Y3} (age_{it})^3 + \beta'_{Y, Soft} \ln Software_{it} + \beta'_{Y, Org} \ln Organization_{it} + \beta'_{Y, RD} \ln R&D_{it} \ast 1_{(R&D_{it} > 0)} + \delta'_{Y, RDzero} \ast 1_{(R&D_{it} = 0)} + \delta'_{Y, it} + \delta'_{st} + u'_{Y, it},$$ \hspace{1cm} (26b)

In both equations, the dependent variables are log of sales ($\ln P_{it} Q_{it}$), log of TFPQ ($\ln A_{it}$), markup ($\mu_{it}$), and log of the distortion ($\ln \tau_{it}$). The independent variables are the first to third orders of firm age and either the log of total intangible capital in (26a) or the logs of the three kinds of intangible capital in (26b). Because a substantial number of firms do not conduct R&D at all, we include a dummy for a positive R&D. We estimate the first difference of (26a) and (26b) as follows:

$$\Delta Y_{it} = \beta_{Y1} + \beta_{Y2} age_{it} + \beta_{Y3} (age_{it})^2 + \beta_{Y, Intang} \Delta \ln Intangible_{it} + \delta_{Y, it} + u_{Y, it},$$ \hspace{1cm} (27a)

$$\Delta Y_{it} = \beta_{Y1} + \beta_{Y2} age_{it} + \beta_{Y3} (age_{it})^2 + \beta_{Y, Soft} \Delta \ln Software_{it} + \beta_{Y, Org} \Delta \ln Organization_{it} + \beta_{Y, RD} \Delta \ln R&D_{it} \ast 1_{(R&D_{it} > 0 \& R&D_{it-1} > 0)} + \delta_{Y, RDstart} \ast 1_{(R&D_{it} > 0 \& R&D_{it-1} = 0)} + \delta_{Y, RDzero} \ast 1_{(R&D_{it} = 0 \& R&D_{it-1} = 0)} + \delta_{Y, it} + u_{Y, it}.$$ \hspace{1cm} (27b)

Note that there is no firm that has no R&D in period $t$ but positive R&D in period $t - 1$ because we assume the multiplicative depreciation. We use one- and two-year lagged values of the corresponding intangible capital variables as instruments and estimate equations (27a) and (27b) by two-step GMM as well as OLS.

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Before showing the results of GMM, we briefly summarize the estimation results of OLS, which we report in Table A2 in Appendix. First, total intangible capital is significantly and positively correlated with all of the dependent variables: log of sales, log of TFPQ, markup, and log of distortion. Among the three types of intangibles, the coefficients of organizational capital are the largest, suggesting that the organizational capital plays important roles in firm dynamics.

Table 3 shows the estimation results of GMM. In columns (1)-(3), the dependent variable is the log difference of sales. Column (1) reports the result of equation (27a) and show that the coefficient of the log difference of total intangible capital is positive and significant and that the absolute values of the coefficients of firm age and its squared value are smaller than those in column (1) in Table 2. Column (2) reports the result of equation (27b) and show that the coefficients of log differences in organization capital and R&D are positive and significant. Column (3) reports the result when we include only organizational capital among the three types of intangible capital to deal with the possible multicollinearity that may arise because the investment rates of the three types of intangible capital can be highly correlated with each other. The coefficient for the organizational capital is not largely changed from column (2), suggesting that the multicollinearity is not serious for sales growth.

In columns (4)-(6) of Table 3, the dependent variables are log differences of TFPQ. Column (4) reports the estimation result of equation (27a). The coefficient for the log difference of total intangible capital is positive and statistically significant. Column (5) reports the result from equation (27b) and shows that among the three types of intangible capital, the coefficient of organizational capital is positive, although its size is much smaller than that of total intangible capital in column (4).

In columns (7)-(9), the dependent variable is the difference of markup. Column (7) shows that the coefficient of the log difference of total intangible capital is unexpectedly negative and significant. Column (8) shows that the coefficients of the log differences in the three kinds of intangible capital are not significant except for R&D, which has a negative and marginally significant coefficient.

In columns (10)-(12) the dependent variables are the log differences of the factor price distortion. Column (10) shows that the coefficient of the log difference of total intangible capital is positive and significant. Column (11) shows that the coefficients of the organizational capital and software are unexpectedly negative and marginally significant.

In sum, we find that total intangible capital has significant and positive impacts on sales and TFPQ as we expected. On the other hand, total intangible capital has a significantly negative effect on the markup, which is not consistent with the view that intangible capital helps build reputation in product markets. Finally, total intangible capital has a positive effect on the factor price distortion, which is consistent with the view that investment in intangible capital involves with financial frictions. Among the three types of intangible capital, organizational capital has significantly positive impacts on sales and TFPQ, although its quantitative impacts are smaller than those of total intangible capital.
5.2 Quantitative impacts of intangible capital on each of sales, TFPQ, markup, and distortion

To quantify the impacts of intangible capital on sales growth, we use the results in Tables 2 and 3 to simulate the paths of each of the dependent variables over firm age by accumulating the constant terms and the coefficients of firm age and age squared to extract the pure age effect. Specifically, we use equations (25), (27a) and (27b) to calculate the predicted values with age $a$ as $\hat{Y}_a = \beta_{Y1}a + \beta_{Y2}\sum_{t=1}^a \alpha_t + \beta_{Y3}\sum_{t=1}^a (\alpha_t)^2$. By comparing the predicted paths controlling for intangible capital in Table 3 with the simulated paths without controlling for intangible capital in Table 2, we can tell the quantitative impacts of total intangible capital on the relationships between firm age and sales or other three parameters. Figure 6 shows the predicted paths of sales before and after controlling for either total intangible capital or organizational capital. Specifically, we use the coefficients on age and age squared in columns (1) and (3) in Table 3 for the predicted paths of sales after controlling for total intangible capital and organizational capital, respectively, and those coefficients in column (1) in Table 2 for the predicted path of sales before controlling intangible capital. Similarly, Figures 7-9 show the predicted paths of TFPQ, markup, and distortion before and after controlling for either total intangible capital or organizational capital.

All of the figures show that while the simulated paths without controlling for intangible capital are similar to those with controlling for the organizational capital only, suggesting that the quantitative impacts of the organizational capital on the relationships between firm age and sales, TFPQ, markup, and factor price distortion are quantitatively negligible, even though they have statistically significant impacts on the levels in sales, TFPQ, markup, and factor price distortion. The relationship between firm size and age is not explained by the organizational capital only.

On the other hand, the paths without controlling for intangible capital are substantially different from those when controlling for total intangible capital. Figure 6 shows that a large part of the age effect on sales is mediated by controlling for intangible capital. Figure 7 shows that the positive age effect on TFPQ up to about age 20 is reversed and becomes negative when the effects through intangible capital are excluded. These results show that intangible capital has quantitatively sizable impacts on the evolution of sales and TFPQ over age. Figure 8 shows that controlling for the intangible capital makes clearer the rise in markup over age up to 40, suggesting that the accumulation of the intangible capital mitigates the increase in markup over age. On the other hand, the pure age effects are found to be negative up to age about 20 by controlling for the intangible capital. Figure 9 shows that the accumulation of the intangible capital increases the factor price distortion and obscures the negative pure age effects.

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20 Figure 7 is depicted based on the coefficients in columns (4) and (6) in Table 3 and column (2) in Table 2. Figure 8 is depicted based on the coefficients in columns (7) and (9) in Table 3 and column (3) in Table 2. Figure 9 is depicted based on the coefficients in columns (10) and (12) in Table 3 and column (4) in Table 2.
5.3. Quantitative impacts of organizational and total intangible capital on sales through TFPQ, markup, and distortion

In subsection 5.2, we quantify the impacts of intangible capital on TFPQ, markup, and distortion, respectively. In this subsection, we quantify the total effects of organizational capital and total intangible capital on sales through TFPQ, markup, and distortion. For this aim, we simulate the sales by regarding each of the three factors as functions of the organizational capital or total intangible capital. In the case of organizational capital, we first calculate the TFPQ that is caused by the accumulation of organizational capital, $A(O_d)$, as

$$\ln A(O_d) = \ln A_1 + \tilde{\beta}_{A,O} \sum_{a=2}^{a} \left( \frac{1}{N_a} \sum_{a_C=a} \Delta \ln O_{it} \right)$$

where $\tilde{\beta}_{A,O}$ is the estimated coefficient for the investment of the organizational capital in equation (27b) on the log difference of TFPQ (column (5) in Table 3). We define $A(O_d)$ as $A_1$. We calculate the markup $\mu(O_d)$ and distortion $\tau(O_d)$ that are caused by the accumulation of organizational capital similarly (columns (8) and (11) in Table 3). Then we simulate the paths of sales, $\ln PQ[A(O_d), \mu(O_d), \tau(O_d)]$ and $\ln PQ[A_0, \mu(O_d), \tau(O_d)]$, where the latter is the hypothetical path of sales that would be realized if the accumulation of organizational capital had no effect on TFPQ at all. We compare these two paths of log of sales to explore the channels of which the organizational capital affects the sales growth through TFPQ. We also explore the channels through which organizational capital affects the sales growth through markup and distortion by simulating the paths of sales similarly. These simulated paths of sales are shown in Figure 10. If organizational capital had no effects on TFPQ, a large part of the sales growth would be lost. While the organizational capital affects the dynamics of sales via factor price distortion to some extent, the channel via the markup plays a smaller role in the dynamics of the sales than that through TFPQ.

Finally, we simulate the sales by regarding each of the three factors as functions of the total intangible capital. The hypothetical TFPQ, markup, and distortion are calculated in the similar ways to equation (28). In the calculation, the coefficient for the investment of the organizational capital is replaced with by the estimated coefficient for the investment of the total intangible capital in equation (27a). The paths of sales are similarly simulated to explore the channels of the effects of the intangible capital on the sales growth. The simulated paths are shown in Figure 11. If total intangible capital had no effects on TFPQ, sales would contract rapidly after entry. On the other hand, if factor price distortion were not affected by the intangible capital, sales would grow much faster and larger. We find a relatively small role of the intangible capital through its effect on markup, which is the same result as the simulation result of the organizational capital.
6. Conclusion

In this paper, we explored the roles of intangible capital in firm growth over age through the lens of the model with firm-specific TFPQ, markup, and factor price distortion. For this aim, we constructed firm-level panel data of intangible capital consisting of software, organizational capital, and R&D stocks.

We first investigated the relationships between firm age and sales growth and examine the roles of the three parameters: TFPQ, markup and factor price distortion, on sales growth by simulating the hypothetical sales growth in the case when each parameter were fixed to the initial value. We found that TFPQ increases with age up to about 30 years after entry and has a dominant positive effect on the sales growth. On the other hand, the markup increases with age and hence has a negative effect on sales growth, while the distortion decreases with age at the young ages and has a positive effect on sales growth.

We then examined the role of intangible capital in sales growth. The results show that a large part of the effects of firm age on the changes in sales and TFPQ are accounted for by investment in intangible assets. Among the three types of intangible capital, organizational capital accounts for a major part of the growth of sales. Software and R&D stocks also have some effects on markup and factor price distortion.

Our analysis suggests that intangible capital plays a substantial role in the growth of young firms mainly through TFPQ. However, its exact mechanism has not been explored. The role of selection of firms in sales growth has not been explored, either, due to the coverage of our data. These are left for future research.
References


De Ridder, M. Market power and innovation in the intangible economy. mimeo, 2019.


Figure 1: Investment rate of intangible capital by firm age groups

Source: Authors’ calculation from the Basic Survey of Japanese Business Structure and Activities.

Figure 2: Firm age and growth rates in sales and inputs

Source: Authors’ calculation from the Basic Survey of Japanese Business Structure and Activities.
Figure 3: Firm age distribution in 2015

Source: Authors’ calculation from the Basic Survey of Japanese Business Structure and Activities.

Figure 4: Firm age and firm-level parameters of TFPQ, markup, and distortion

Source: Authors’ calculation from the Basic Survey of Japanese Business Structure and Activities.
Figure 5: Hypothetical firm dynamics if each parameter of TFPQ, markup, and distortion did not change from its initial value

Source: Authors’ calculation from the Basic Survey of Japanese Business Structure and Activities.

Figure 6: Firm age and predicted value for sales before and after controlling for intangible capital

Source: Authors’ calculation, based on Tables 2 and 3.
Figure 7: Firm age and predicted value for TFPQ before and after controlling for intangible capital

Source: Authors’ calculation, based on Tables 2 and 3.

Figure 8: Firm age and predicted value for markup before and after controlling for intangible capital

Source: Authors’ calculation, based on Tables 2 and 3.
Figure 9: Firm age and predicted value for factor price distortion before and after controlling for intangible capital

Source: Authors’ calculation, based on Tables 2 and 3.

Figure 10: Hypothetical firm dynamics if organizational capital had no effect on the parameters of TFPQ, markup, and distortion

Source: Authors’ calculation, based on Table 3.
Figure 11: Hypothetical firm dynamics if total intangible capital had no effect on the parameters of TFPQ, markup, and distortion

Source: Authors’ calculation, based on Table 3.
Table 1: Summary statistics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Max</th>
<th>Min</th>
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Source: Authors’ calculation from the Basic Survey of Japanese Business Structure and Activities.
Table 2 Relationship of sales and its parameters with age: Estimation results from OLS

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In parentheses are clustered standard errors at firm level.

*** p<0.01, ** p<0.05, * p<0.1

Source: Authors’ estimation from the Basic Survey of Japanese Business Structure and Activities.
### Table 3: Relationship of sales and its parameters with age and intangible capital: Estimation results from GMM

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>(1) (\Delta \ln(Sales))</th>
<th>(2) (\Delta \ln(Sales))</th>
<th>(3) (\Delta \ln(Sales))</th>
<th>(4) (\Delta \ln(TFPQ))</th>
<th>(5) (\Delta \ln(TFPQ))</th>
<th>(6) (\Delta \ln(TFPQ))</th>
<th>(7) (\Delta \ln(TFPQ))</th>
<th>(8) (\Delta \ln(TFPQ))</th>
<th>(9) (\Delta \ln(TFPQ))</th>
<th>(10) (\Delta \ln(TFPQ))</th>
<th>(11) (\Delta \ln(TFPQ))</th>
<th>(12) (\Delta \ln(TFPQ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>6.38e-05</td>
<td>-0.000330***</td>
<td>-0.000335***</td>
<td>6.28e-05</td>
<td>-0.000244***</td>
<td>-0.000291***</td>
<td>-0.000141</td>
<td>4.93e-05</td>
<td>6.12e-05</td>
<td>0.000138***</td>
<td>-2.72e-05</td>
<td>-3.76e-05</td>
</tr>
<tr>
<td></td>
<td>(5.84e-05)</td>
<td>(4.17e-05)</td>
<td>(4.35e-05)</td>
<td>(0.000148)</td>
<td>(0.000102)</td>
<td>(0.000103)</td>
<td>(9.42e-05)</td>
<td>(7.26e-05)</td>
<td>(7.32e-05)</td>
<td>(4.26e-05)</td>
<td>(2.99e-05)</td>
<td>(2.89e-05)</td>
</tr>
<tr>
<td>Age^2</td>
<td>-9.90e-05**</td>
<td>0.000144***</td>
<td>0.000161***</td>
<td>-7.87e-06</td>
<td>0.000163</td>
<td>0.000186*</td>
<td>2.96e-05</td>
<td>-8.28e-05</td>
<td>-9.86e-05</td>
<td>-5.24e-05</td>
<td>6.02e-05**</td>
<td>5.11e-05*</td>
</tr>
<tr>
<td></td>
<td>(4.82e-05)</td>
<td>(4.05e-05)</td>
<td>(4.30e-05)</td>
<td>(0.000115)</td>
<td>(0.000101)</td>
<td>(0.000102)</td>
<td>(7.52e-05)</td>
<td>(6.88e-05)</td>
<td>(6.93e-05)</td>
<td>(3.44e-05)</td>
<td>(2.85e-05)</td>
<td>(2.72e-05)</td>
</tr>
<tr>
<td>(\Delta \ln(\text{Total intangible}))</td>
<td>0.755***</td>
<td>0.596***</td>
<td>0.350***</td>
<td>-0.350***</td>
<td>0.286***</td>
<td>0.00608</td>
<td>-0.00584*</td>
<td>(0.0627)</td>
<td>(0.192)</td>
<td>(0.107)</td>
<td>(0.0506)</td>
<td>(0.00049)</td>
</tr>
<tr>
<td>(\Delta \ln(\text{Software}))</td>
<td>-0.00119</td>
<td>-0.0395***</td>
<td>0.0660*</td>
<td>-0.0185</td>
<td>-0.0343</td>
<td>-0.0278</td>
<td>-0.0322***</td>
<td>-0.0407***</td>
<td>(0.00265)</td>
<td>(0.0107)</td>
<td>(0.00908)</td>
<td>(0.00304)</td>
</tr>
<tr>
<td>(\Delta \ln(\text{Organization}))</td>
<td>0.148***</td>
<td>0.153***</td>
<td>0.0660*</td>
<td>-0.0185</td>
<td>-0.0343</td>
<td>-0.0278</td>
<td>-0.0322***</td>
<td>-0.0407***</td>
<td>(0.0107)</td>
<td>(0.0357)</td>
<td>(0.0279)</td>
<td>(0.0299)</td>
</tr>
<tr>
<td>(\Delta \ln(\text{R&amp;D}))</td>
<td>0.0196***</td>
<td>-0.000499</td>
<td>-0.0185*</td>
<td>-0.0185*</td>
<td>-0.0343</td>
<td>-0.0278</td>
<td>-0.0322***</td>
<td>-0.0407***</td>
<td>(0.00352)</td>
<td>(0.0122)</td>
<td>(0.0279)</td>
<td>(0.0299)</td>
</tr>
<tr>
<td>(\Delta \ln(\text{R&amp;D only in } \text{t dummy}))</td>
<td>0.00199</td>
<td>0.0207</td>
<td>0.0111</td>
<td>0.0111</td>
<td>0.00393</td>
<td>0.00393</td>
<td>0.00393</td>
<td>0.00393</td>
<td>(0.00521)</td>
<td>(0.0219)</td>
<td>(0.0201)</td>
<td>(0.0219)</td>
</tr>
<tr>
<td>(\Delta \ln(\text{No R&amp;D in } \text{t and } \text{t-1 dummy}))</td>
<td>0.00436***</td>
<td>0.00352*</td>
<td>0.00182</td>
<td>0.00182</td>
<td>0.00417***</td>
<td>0.00417***</td>
<td>0.00417***</td>
<td>0.00417***</td>
<td>(0.000959)</td>
<td>(0.00186)</td>
<td>(0.00142)</td>
<td>(0.000597)</td>
</tr>
<tr>
<td>Observations</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
<td>261,519</td>
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<tr>
<td>Method</td>
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<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
<td>GMM</td>
</tr>
<tr>
<td>Industry*year fixed effect</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

In parentheses are clustered standard errors at firm level.

*** p<0.01, ** p<0.05, * p<0.1

Source: Authors’ estimation from the Basic Survey of Japanese Business Structure and Activities.
Appendix

Figure A1: Firm size distributions by decade

Source: Authors’ calculation from the Basic Survey of Japanese Business Structure and Activities.

Figure A2: Plant size distributions by decade

Source: Authors’ calculation from the Census of Manufacture and Economic Census for Business Activity.
Figure A3: Plant age and growth rates in sales and inputs

![Figure A3: Plant age and growth rates in sales and inputs](image)

Source: Authors’ calculation from the Census of Manufacture and Economic Census for Business Activity.

Table A1: Estimation results for intangible capital

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Δln(Total intangible)</td>
<td>Δln(Total intangible)</td>
<td>Δln(Total intangible)</td>
<td>Δln(Total intangible)</td>
</tr>
<tr>
<td>Age</td>
<td>-0.000606*** (6.54e-05)</td>
<td>-0.000306*** (6.20e-05)</td>
<td>-0.000306*** (6.20e-05)</td>
<td>-0.000306*** (6.20e-05)</td>
</tr>
<tr>
<td>ln(Age)</td>
<td>-0.0518*** (0.00236)</td>
<td>-0.0140*** (0.00221)</td>
<td>-0.0140*** (0.00221)</td>
<td>-0.0140*** (0.00221)</td>
</tr>
<tr>
<td>Lagged ln(Total intangible)</td>
<td>-0.168*** (0.00300)</td>
<td>-0.168*** (0.00296)</td>
<td>-0.168*** (0.00296)</td>
<td>-0.168*** (0.00296)</td>
</tr>
<tr>
<td>Lagged ln(Sales)</td>
<td>0.125*** (0.00217)</td>
<td>0.125*** (0.00216)</td>
<td>0.125*** (0.00216)</td>
<td>0.125*** (0.00216)</td>
</tr>
<tr>
<td>Observations</td>
<td>390,327</td>
<td>390,327</td>
<td>315,300</td>
<td>315,300</td>
</tr>
<tr>
<td>Firm fixed effects</td>
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<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

In parentheses are clustered standard errors at firm level.

*** p<0.01, ** p<0.05, * p<0.1

Source: Authors’ estimation from the Basic Survey of Japanese Business Structure and Activities.
Table A2: Estimation results of OLS

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>(1) (\Delta \ln(Sales))</th>
<th>(2) (\Delta \ln(Sales))</th>
<th>(3) (\Delta \ln(Sales))</th>
<th>(4) (\Delta \ln(TFPQ))</th>
<th>(5) (\Delta \ln(TFPQ))</th>
<th>(6) (\Delta \ln(TFPQ))</th>
<th>(7) (\Delta \ln(TFPQ))</th>
<th>(8) (\Delta \ln(Markup))</th>
<th>(9) (\Delta \ln(Markup))</th>
<th>(10) (\Delta \ln(Markup))</th>
<th>(11) (\Delta \ln(Markup))</th>
<th>(12) (\Delta \ln(Distortion))</th>
<th>(13) (\Delta \ln(Distortion))</th>
<th>(14) (\Delta \ln(Distortion))</th>
<th>(15) (\Delta \ln(Distortion))</th>
<th>(16) (\Delta \ln(Distortion))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.000537***</td>
<td>-0.000409***</td>
<td>-0.000200***</td>
<td>-0.000165***</td>
<td>-0.000341***</td>
<td>-0.000253***</td>
<td>-0.000341***</td>
<td>-0.000253***</td>
<td>-0.000341***</td>
<td>-0.000253***</td>
<td>-0.000341***</td>
<td>-0.000253***</td>
<td>-0.000341***</td>
<td>-0.000253***</td>
<td>-0.000341***</td>
<td>-0.000253***</td>
</tr>
<tr>
<td>Age^2</td>
<td>0.000278***</td>
<td>0.000196***</td>
<td>0.000210**</td>
<td>0.000210**</td>
<td>0.000210**</td>
<td>0.000210**</td>
<td>0.000210**</td>
<td>0.000210**</td>
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<td>0.000210**</td>
<td>0.000210**</td>
<td>0.000210**</td>
<td>0.000210**</td>
</tr>
<tr>
<td>D ln(Total intangible)</td>
<td>0.0764***</td>
<td>0.0528***</td>
<td>(0.00128)</td>
<td>0.0528***</td>
<td>(0.00128)</td>
<td>0.0528***</td>
<td>(0.00128)</td>
<td>0.0528***</td>
<td>(0.00128)</td>
<td>0.0528***</td>
<td>(0.00128)</td>
<td>0.0528***</td>
<td>(0.00128)</td>
<td>0.0528***</td>
<td>(0.00128)</td>
<td>0.0528***</td>
</tr>
<tr>
<td>D ln(Software)</td>
<td>-0.00962***</td>
<td>-0.0126***</td>
<td>(0.000544)</td>
<td>-0.0126***</td>
<td>(0.000544)</td>
<td>-0.0126***</td>
<td>(0.000544)</td>
<td>-0.0126***</td>
<td>(0.000544)</td>
<td>-0.0126***</td>
<td>(0.000544)</td>
<td>-0.0126***</td>
<td>(0.000544)</td>
<td>-0.0126***</td>
<td>(0.000544)</td>
<td>-0.0126***</td>
</tr>
<tr>
<td>D ln(Organization)</td>
<td>0.422***</td>
<td>0.415***</td>
<td>(0.00345)</td>
<td>0.415***</td>
<td>(0.00345)</td>
<td>0.415***</td>
<td>(0.00345)</td>
<td>0.415***</td>
<td>(0.00345)</td>
<td>0.415***</td>
<td>(0.00345)</td>
<td>0.415***</td>
<td>(0.00345)</td>
<td>0.415***</td>
<td>(0.00345)</td>
<td>0.415***</td>
</tr>
<tr>
<td>D ln(R&amp;D)</td>
<td>0.00363***</td>
<td>-0.00225</td>
<td>(0.00118)</td>
<td>-0.00225</td>
<td>(0.00118)</td>
<td>-0.00225</td>
<td>(0.00118)</td>
<td>-0.00225</td>
<td>(0.00118)</td>
<td>-0.00225</td>
<td>(0.00118)</td>
<td>-0.00225</td>
<td>(0.00118)</td>
<td>-0.00225</td>
<td>(0.00118)</td>
<td>-0.00225</td>
</tr>
<tr>
<td>R&amp;D only in t dummy</td>
<td>-0.00487</td>
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<td>(0.00392)</td>
<td>0.0140</td>
<td>(0.00392)</td>
<td>0.0140</td>
<td>(0.00392)</td>
<td>0.0140</td>
<td>(0.00392)</td>
<td>0.0140</td>
<td>(0.00392)</td>
<td>0.0140</td>
<td>(0.00392)</td>
<td>0.0140</td>
<td>(0.00392)</td>
<td>0.0140</td>
</tr>
<tr>
<td>No R&amp;D in t and t-1 dummy</td>
<td>-0.00266***</td>
<td>0.00283*</td>
<td>(0.000440)</td>
<td>0.00283*</td>
<td>(0.000440)</td>
<td>0.00283*</td>
<td>(0.000440)</td>
<td>0.00283*</td>
<td>(0.000440)</td>
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<tr>
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<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

In parentheses are clustered standard errors at firm level.

*** p<0.01, ** p<0.05, * p<0.1

Source: Authors’ estimation from the Basic Survey of Japanese Business Structure and Activities.