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# Intangible Assets and Firms' Liquidity Holdings: Evidence from Japan


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# Intangible Assets and Firms' Liquidity Holdings: Evidence from Japan*

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Abstract

It has been an important open question why firms hold seemingly "excess" liquidity (e.g., cash). Using Japanese firm-level large panel data accounting for 40,000 firms over the period 2000-2013, first, we find a positive correlation between firms' liquidity holding as measured by the ratio of liquidity assets to total assets and the ratio of intangible to tangible assets held by the firms. This result is consistent with the empirical implication of our theoretical model based on collateral constraints for borrowing, and suggests that the increasing importance of nonpledgeable intangible assets in firms' production process partly explains firms' liquidity holding. Second, we also find that such positive correlation is stronger for the firms in industries associated with higher complementarity between tangible and intangible assets. This result suggests that the firms' liquidity holding reflects the technological heterogeneity among industries.

*Keywords*: Liquidity holding, Intangible assets, Complementarity, Substitutability
*JEL classification*: E22, E44, G31



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## 1. Introduction

Corporate savings have exhibited an increasing trend over the last three decades in many countries including the US, Japan, Germany and China. Karabarbounis and Neiman (2012) show that 30 out of the 44 countries with more than 10 years of data exhibited increasing trends in the share of saving in corporate sector. Such an increase in corporate savings is accompanied by an increase in corporate holdings of liquid assets, especially of cash. Bates et al. (2009), among others, show that the average cash-to-assets ratio of the US corporations increased by 0.46% per year from 1980 to 2006. Given an increasing trend of corporate savings and cash holdings have significant impacts on the flow of funds, and thereby on corporate investment, tax revenues, and distribution of wealth, understanding what drives such dynamics of corporate savings has been one of the most important issues from the viewpoints of policymakers, practitioners, and academic researchers.

However, it has still been an open question both from practical and academic perspectives why firms hold seemingly too much liquidity (e.g., cash). The extant studies have been hypothesizing that firms need to hold liquidity as they face financial friction, and attempting to test if this is the case. To proxy for the degree of financial friction, the extant literature has employed, for example, firms leverage, cash-flow uncertainty, relationship to their lender banks, and so on. Among the sources leading to firms' financial constraint, recent studies have started to pay an attention to firms' intangible investment on, for example, software, advertisement, research and development (R&D), human capital, organization capital, etc. A simple illustration linking these intangible investment and firms' liquidity holdings is as follows. Suppose a firm is facing an intangible investment opportunity and need to finance the investment by relying on external finance sources. Taking into account the possibility that firms cannot pledge these intangibles as a collateral when they finance the investments, those firms attempt to hold a certain amount of liquidity in advance as a sort of precautionary saving. Although this hypothesis seems intuitive, the role of intangible capital as a source of cash holdings has not been analyzed so far except for Falato et al. (2013), who use firm-level data from the US to show that intangible capital is the most important determinant of corporate cash holdings over the last decades. The first goal of the present paper is to employ a firm-level large dataset constructed for Japanese enterprises and test the role of intangible capital as a determinant of corporate liquidity holdings.

While the abovementioned mechanism is intuitive, there are several details missed in the extant discussions. Among many, we think it is important to explicitly analyze how the relationship between firms' liquidity holdings and their intangible investments depends on a technological feature accounting for the degree of complementarity and substitutability between tangibles and intangibles. On one hand, we might presume that firms facing the technology exhibiting higher complementarity between tangibles and intangibles show stronger positive relationship between their liquidity holdings and intangible investments. This is because such a technological feature enhances the mechanism mentioned above. On the other hand, if firms have already accumulated enough amounts of liquidity and find it less profitable to relax the financial constraints they face in future, firms facing the technology exhibiting higher complementarity between tangibles and intangibles might show rather weaker positive relationship between their liquidity holdings and intangible investments. Thus, the second goal of this present paper is to empirically examine the relationship between firms' liquidity holdings and intangible investments in various industries associated with different levels of complementarity and substitutability between tangibles and intangibles.

Toward this end, we use Japanese firm-level large panel data accounting for 40,000 firms over thirteen years from 2000 to 2013, and test the empirical implication of our theoretical model based on collateral constraints for borrowing. The obtained results are summarized as follows. First, we find the positive correlation between firms' liquidity holding, which is measured by the ratio of liquidity assets to total assets, and the levels of intangible assets held by the firms. This result suggests that as the increasing importance of intangible assets, which are not pledgeable in general, in firms' production process partly explains firms' liquidity holding. Second, we also find that such a positive correlation is stronger for the firms belonging to the industries associated with higher complementarity between tangible and intangible assets. This result suggests that the firms' liquidity holding reflects the technological heterogeneity among industries.

The rest of the paper proceeds as follows. Section 2 briefly reviews the related extant literature and discusses the contribution of this study. Section 3 constructs a theoretical model from which we obtain several testable empirical implications while Section 4 explains the empirical methodology and the data we use for our analysis. Section 5 then presents and discusses the results, and Section 6 concludes.

## 2. Related studies

A number of researchers have investigated the reasons for the increasing trend of corporate savings and cash holdings. While different researches put emphasis on different factors, most of the extant studies have been attributing such an increasing trend in firms' cash holding at least partly to financial constraints that firms face. As one prominent study, Bates et al. (2009) empirically examine the reasons for the increase in the cash-to-assets ratios of US corporations from 1980 to 2006, finding that cash ratios increased because firms' cash flows become riskier, firms held fewer inventories and receivables, and firms became increasingly R&D intensive. Their findings are consistent with the theoretical illustration based on firms' precautionary motive for cash holdings but not with the agency conflicts between managers and shareholders (see Jensen, 1986, among others). On the other hand, Harford et al. (2014) focus on a specific type of liquidity risk: refinancing risk. Using data from US firms from 1980 to 2008, they find that the maturity of firms' long-term debt has shortened markedly, which suggests a higher risk of refinancing and explains a large fraction of the increase in cash holdings over time. The present paper aims at contributing the extant studies focusing on financial constraint as one factor leading to firms' cash holding by examining the financial friction associated with firms' intangible investment.

The interaction of technological progress or product market competition on one hand, and financial frictions on the other, as a factor of corporate saving has been analyzed by several recent studies (Karabarbounis and Neiman, 2012; Chen et al., 2017; Hoberg et al., 2014; Qiu and Wan, 2015). Karabarbounis and Neiman (2012) relate the labor share to corporate saving empirically and theoretically using a model featuring CES production and imperfections in the flow of funds between households and corporations. They conclude that a global decline in the cost of capital beginning around1980 induced firms to shift away from labor towards capital, resulting in an increase in corporate saving. Chen et al. (2017) also develop a general equilibrium model with product and capital market imperfections to explore quantitatively the determination of the flow of funds across sectors, and find that changes including declines in the real interest rate, the price of investment, and corporate income taxes generate increases in corporate profits and shifts in the supply of sectoral saving that are of similar magnitude to those observed in the data. Hoberg et al. (2014), constructing measures of product market threats that US firms face, find that higher product market threats decrease firm propensity to make payouts via dividends or repurchases and increase the cash held by firms, especially for firms with less access to financial markets. Finally, Qiu and Wan (2015) obtain evidences showing that firms facing greater technology spillovers hold more cash holdings and that this effect is more pronounced among financially constrained firms and for firms that are likely to benefit more from diffused technology, are more profitable, and face better growth opportunities. We intend to contribute to such a strand of literature on firms' cash holding by explicitly examining the interaction between the firms' technological feature, which is represented by the substitutability and complementarity between tangible and intangible assets, and the financial constraint.

Among these extant studies, the two most closely related papers to the present paper are Almeida and Campello (2007) and Falato et al. (2013), who focus on the role of asset tangibility as a determinant of financial constraints and cash holdings. First, Almeida and Campello (2007) posit that firms holding more intangible assets compared to tangible assets are more likely to face external finance constraints since intangible assets are less pledgeable as collateral. Using a sample of US manufacturing firms drawn from COMPUSTAT between 1985 and 2000, they find that the sensitivity of investment to cash flow increases in the tangibility of firms' assets over the regions of low tangibility while this effect disappears when firms hold high levels of tangibiles. Second, Falato et al. (2013) use accounting data from Compustat over the 1970 to 2000 period to measure US firm-level intangible capital. They further develop a dynamic model of corporate cash holdings with tangible and intangible capital, showing that a shift toward greater reliance on intangible capital is the most important firm-level determinant of corporate cash holdings over the last decades. Similar to these two studies, in the present paper, we also measure firm-level intangible capital and examine how firms' intangible capital accounts for their liquidity holdings. The biggest difference between ours and the extant studies is that we further examine how complementarity and substitutability between tangible and intangible capital accounts for corporate cash holdings. This sheds a new light on the role of intangible capital as a determinant of corporate cash holdings.

Note that the present paper is also related with the literature on how financial constraints lead to cash holdings. As one prominent study, Almeida et al. (2004), using data from US manufacturing firms over the 1971 to 2000 period, find that financially constrained firms have a positive propensity to save cash out of cash flows (cash flow sensitivity of cash), while unconstrained firms do not. Denis and Sibilkov (2009) also examine why cash holdings are more valuable for financially constrained firms than for unconstrained firms, and conclude that greater cash holdings are associated with higher levels of investment for financially constrained firms with high hedging needs and that the association between investment and value is stronger for constrained firms than for unconstrained firms. Their results suggest that greater cash holdings of constrained firms are a natural (value-increasing) response to costly external financing. One of the biggest challenges these researches face is how to classify firms into financially constrained and unconstrained firms. Almeida et al. (2004), for example, use several financial constraints criteria: the payout ratio (the ratio of dividends and stock repurchases to operating income), the asset size, bond ratings, commercial paper ratings, and the Kaplan-Zingales index (Kaplan and Zingales, 1997). Although these measures may be plausible, they may suffer serious endogeneity and selection problems. For example, among the firms that are classified as a financially constrained due to the lack of bond ratings, there may be firms that do not need external finance due to the lack of investment opportunities as well as those that are really constrained. Unlike these studies, we classify firms that are more likely to be constrained and those that are less likely to be constrained by using the technological factors in terms of the complementarity and substitutability of tangible and intangible capitals, which is less susceptible to endogeneity and selection issues.

**3. Model**

3.1 Environment

In this section, we construct a simple theoretical model for firms' savings motives. In order to obtain testable empirical implications on the relationship between financial constraint and firms' technological features represented by tangible and intangible assets, and how the relationship is related to firms' cash holding, we extend the model in Almeida and Campello (2007), Almeida et al. (2004), and Moll (2014) by accounting for intangible capital as well as tangible capital. In this economy, there are a mass of entrepreneurs who live indefinitely. Each entrepreneur's objective function is given by the following power utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\theta}}{1-\theta} \quad (1)$$

In the equation (1), $C_t$ is the level of final good consumption. Each entrepreneur owns one plant and produces output using as inputs $K_t$ units of tangible assets and $H_t$ units of intangible assets subject to the production function $\mathrm{F}(K_t, H_t, e^{a_t})$, where $a_t$ is a stochastic efficiency measure following a continuous-state Markov process with the following transition density:

$$\mathrm{Ptob}(a_{t+1} = a' | a_t = a) = \emptyset(a' | a) \quad (2)$$

Entrepreneurs rent tangible and intangible assets from other entrepreneurs at a rental rate of $R_K$ and $R_H$, respectively. To introduce credit market frictions, we assume that $\tau$ $(0 < \tau < 1)$ fraction of $K$ can be recovered when a plant's tangible assets are seized by its creditors due to failure in repayment while the creditors can recover nothing from intangible assets.[1] The entrepreneur has an amount of $B$ of internal funds available for investment. Given creditors' valuation of assets in the case of liquidation (i.e., $\tau K$), we can establish the standard borrowing constraint $D \leq \tau K$.[2] The entrepreneur's intratemporal optimization problem is constructed as follows:

$$\pi(B, a) = \max_{K,H} F(K, H, e^a) - R_K K - R_H H \tag{3}$$

$$\text{s.t.} \quad K + H \leq B + \tau K$$

Given the interest rate on savings denoted by $r$, and assuming 100% depreciation of $K$ and $H$, we can further construct the entrepreneur's dynamic optimization problem in the following recursive form:

$$V(B, a) = \max \frac{C^{1-\theta}}{1-\theta} + \beta \int V(B', a') \emptyset(a'|a) da \tag{4}$$

$$\text{s.t.} \quad C = (1 + r)B + \pi(B, a) - B'$$

3.2 Solution and simulation

To characterize the solution of the dynamic optimization problem, first, we specify the production function as follows:

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[1] This assumption is based on the empirical findings in, for example, Almeida and Campello (2007) that the dependency of investment on cash flow disappears when firms hold high levels of tangibles.

[2] See Moll (2014, pp3192), among others, for this formation of capital market imperfections. Specifically, suppose that the entrepreneur can steal a fraction $(1 - \tau)$ of $K$ and 100% of $H$, but that by doing so, he would lose $B$ as a punishment. Then, other entrepreneurs (or the financial intermediary) will rent capital up to the point where the entrepreneur would have an incentive to steal the rented capital, implying a collateral constraint $(1 - \tau)K + H \leq B$, or $K + H \leq B + \tau K$.

$$\log(Y) = a + \alpha \log(K) + \beta \log(H) + \gamma \log(K) \log(H) \quad (5)$$

Following Hosono et al. (2016), we use the parameter $\gamma$ to captures the complementarity and substitutability between $K$ and $H$. The efficiency measure $a$ is assumed to follow an AR(1) process:

$$a' = a_0 + \rho a + \epsilon,\ \epsilon \sim N(0, \sigma^2) \quad (6)$$

Assuming $\alpha = 0.5$, $\beta = 0.3$, $a_0 = \log(1.5)$, $\rho = 0.74$, $\sigma = 0.1$, $r = 0.05$, $\tau = 0.5$, $R_K = 1.15$, $R_H = 1.25$, $\theta = 1$, $\delta = 0.9$, and changing the complementarity and substitutability parameter $\gamma$ over the range of $\gamma \in [-0.001, 0.01]$, we can numerically solve for the policy function $B'(B, a)$ for different levels of $\gamma$. Figures 1 depicts the $B'(B, a)$ obtained as a solution for $\gamma = -0.001$. As the current productivity is higher, the entrepreneur expects her future productivity to be also higher, and therefore saves more to avoid missing future investment opportunities due to the financial constraint. Given the current productivity level, the entrepreneur keeps higher savings as her current saving is higher because she can carry over more savings.

Using this policy function and the generated stochastic process of productivity, we simulate the equilibrium levels of savings and capital, then compute savings and capital composition for a given $\gamma$.[3] Specifically, Figures 2A and 2B depict the median values of the saving-to-tangible capital ratio ($B/K$) and the intangible-to-tangible capital ratio ($\mathrm{H/K}$), respectively, for different levels of $\gamma$.[4] Figure 2A shows that as $\gamma$ increases, the saving ratio

[3] We simulate the model for 1,000 firms over 10,000 periods and discard the first 100 periods.
[4] In Figures 2A and 2B, we depict the median values rather than the mean values because the latter is more susceptible to outliers.

tends to be higher especially for relatively large values of $\gamma$ (i.e., $\gamma > 0.04$), while Figure 2B shows that the intangible capital ratio tends to be higher for a higher $\gamma$. These results suggest that the saving-to-tangible capital ratio and the intangible-to-tangible capital ratio are positively correlated across industries (i.e., for different $\gamma$). If $\gamma$ is small or negative, the entrepreneur can relatively easily substitute intangible capital to tangible capital to borrow funds by pledging tangible capital as a collateral. Consequently, the saving ratio and the intangible capital ratio are both smaller for a lower (e.g., negative) $\gamma$. On the other hand, if $\gamma$ is high, the two types of capital are more complementary rather than substitutable, and hence the firm needs both types of capital to increase output. However, simply because only tangible capital is pledgeable as a collateral, the entrepreneur is likely to be financially constrained if she does not have sufficient saving. To lessen the probability of being constrained, the entrepreneur with higher $\gamma$, who exhibits higher intangible capital ratio, saves more. Such a positive correlation between the intangible capital ratio and the saving ratio is the empirical implication we obtain from our theoretical model and we will test in our empirical analysis.

Using the simulated model, we further investigate how the relationship between saving ratio and intangible capital ratio are correlated within an industry (i.e., for a given level of $\gamma$). Figure 3 shows that correlation coefficient between the saving ratio and the intangible capital ratio is positive for a given level of $\gamma$. It further shows that the correlation coefficient tends to be larger for a higher value of $\gamma$. Based on this simulation result, we empirically examine whether the firm-level correlation between the saving ratio and the intangible capital ratio is positive after controlling for the industry-level difference in $\gamma$, and, if so, whether such a positive correlation is stronger for industries with higher $\gamma$.

## 4. Data and empirical methodology

### 4.1 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 for measuring intangible capital is from 1994FY to 2013FY. The observation period for the estimation of firms' liquidity holding 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:

$$\frac{Y_{IND,t}^{JIP}}{K_{IND,t}^{JIP}} = \frac{\sum_i Y_{IND,i,t}^{\text{BSJBSA}}}{\sum_i BVK_{IND,i,t}^{\text{BSJBSA}} * \alpha_{IND,t}} \tag{8}$$

In this expression, $\sum_i Y_{IND,i,t}^{\text{BSJBSA}}$ denotes 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 et al. (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.[5] According to the JIP database, software, science and engineering

[5] 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.

R&D, and brand equity account for about 70% of the total intangible assets in Japan.

4.2 Measure for substitutability and complementarity

In this section, we describe the empirical methods in Hosono et al. (2016) which we use to measure the substitutability and complementarity between tangible and intangible capital. For the production function estimation, we consider the following Cobb-Douglas function that we augment with the interaction between tangible and intangible capital:

$$LN(Y)_{i,t} = \beta_l LN(L)_{i,t} + \beta_{ktan} LN(Ktan)_{i,t} + \beta_{kintan} LN(Kintan)_{i,t}$$
$$+\gamma_{tan\times intan} LN(Ktan)_{i,t} \times LN(Kintan)_{i,t} + \eta_i + year_t + \omega_{i,t} + \varepsilon_{i,t} \quad (9)$$

where

$$\omega_{i.t} = \rho\omega_{i.t-1} + \xi_{i,t}\,,\quad |\rho| < 1 \quad (10)$$

$$\varepsilon_{it}, \xi_{i,t} \sim MA(0) \quad (11)$$

The left hand-side of equation (9) 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-1*. 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 $\eta_i$, 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 (10). 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

$$LN(Y)_{i,t} = \beta_l LN(L)_{i,t} - \rho\beta_l LN(L)_{i,t-1} + \beta_{ktan} LN(Ktan)_{i,t} - \rho\beta_{ktan} LN(Ktan)_{i,t-1}$$
$$+\beta_{kintan} LN(Kintan)_{i,t} - \rho\beta_{kintan} LN(Kintan)_{i,t-1}$$
$$+\gamma_{tan\times intan} LN(Ktan)_{i,t} \times LN(Kintan)_{i,t}$$
$$-\rho\gamma_{tan\times intan} LN(Ktan)_{i,t-1} \times LN(Kintan)_{i,t-1}$$
$$+\rho LN(Y)_{i,t-1} + \eta_i(1-\rho) + year_t - \rho year_{t-1} + \xi_{i,t} + \varepsilon_{i,t} - \rho\varepsilon_{i,t-1} \quad (12)$$

or

$$LN(Y)_{i,t} = \pi_1 LN(L)_{i,t} + \pi_2 LN(L)_{i,t-1} + \pi_3 LN(Ktan)_{i,t} + \pi_4 LN(Ktan)_{i,t-1}$$
$$+\pi_5 LN(Kintan)_{i,t} + \pi_6 LN(Kintan)_{i,t-1}$$
$$+\pi_7 LN(Ktan)_{i,t} \times LN(Kintan)_{i,t} + \pi_8 LN(Ktan)_{i,t-1} \times LN(Kintan)_{i,t-1}$$
$$+\pi_9 LN(Y)_{i,t-1} + \eta_i^* + year_t^* + \omega_{i,t} \quad (13)$$

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:

$$\mathrm{E}\big(x_{i,t-s}\Delta\omega_{i,t}\big) = 0 \quad (14)$$

and

$$\mathrm{E}\big(\Delta x_{i,t-s}(\eta_i^* + \omega_{i,t})\big) = 0 \quad (15)$$

where

$x_{i,t} = \left( LN(L)_{i,t}, LN(Ktan)_{i,t}, LN(Kintan)_{i,t}, LN(Ktan)_{i,t} \times LN(Kintan)_{i,t}, LN(Y)_{i,t} \right)$ 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 $(\beta_l, \beta_{ktan}, \beta_{kintan}, \gamma_{tan\times intan}, \rho)$. Following Hosono et al. (2016), we use the $\gamma_{tan\times intan}$, which is measured in industry-level, as the measure for the complementarity and substitutability between tangibles and intangibles. As $\gamma_{tan\times intan}$ becomes larger (smaller), the technology exhibits higher complementarity (substitutability).

4.3 Empirical framework

In this section, we explain the empirical framework we use to test the empirical implication obtained in the previous section. First, we run the following firm-level panel regression (16) so as to obtain the correlation between firms $i$'s liquidity ratio at the end of period $t$ ( $LIQ\_RATIO_{i,t}$ ) and its intangible ratio at the end of period $t-1$ ($INTAN\_RATIO_{i,t-1}$). In order to control for other firm characteristics denoted by $\boldsymbol{X}_{i,t-1}$, we include the variables accounting for firm size measured by the natural logarithm of total assets at the end of period $t-1$ ($LN\_FASSETS_{i,t-1}$), debt-to-total assets ratio at the end of period $t-1$ ($DEBT\_RATIO_{i,t-1}$), ROA measured as the ratio of the current profit over the period $t-1$ to the total assets at the end of period $t-2$ ($ROA_{i,t-1}$), and the sales growth from the period $t-2$ to $t-1$ ($SALES\_GROWTH_{i,t-1}$) as well as firm-level fixed-effect $\eta_i$ and year-effect $Year_t$. We predict $\beta > 0$, which represents the positive correlation between the liquidity ratio and the intangible ratio.

$$LIQ\_RATIO_{i,t} = \alpha + \beta INTAN\_RATIO_{i,t-1} + \boldsymbol{X}_{i,t-1}\boldsymbol{\delta} + \eta_i + Year_t + \varepsilon_{i,t} \tag{16}$$

In the similar fashion, we also run the regression (17) using the separately measured three intangibles, i.e., the software stock ( $SOFT\_RATIO_{i,t-1}$ ), the advertisement stock ($AD\_RATIO_{i,t-1}$), and the R&D stock ($RD\_RATIO_{i,t-1}$).

$$LIQ\_RATIO_{i,t} = \alpha + \beta_1 SOFT\_RATIO_{i,t-1} + \beta_2 AD\_RATIO_{i,t-1} + \beta_3 RD\_RATIO_{i,t-1}$$
$$+\boldsymbol{X}_{i,t-1}\boldsymbol{\delta} + \eta_s + \eta_i + Year_t + \varepsilon_{i,t} \tag{17}$$

Finally, in order to see the conditional relationship between the liquidity ratio and the intangible ratio on the technological parameter accounting for the degree of complementarity and substitutability ($\gamma$), we estimate the equation (16) and (17) for subsamples corresponding to high $\gamma$ (i.e., higher than its median) and low $\gamma$.

**5. Estimation results**

Table 1 shows descriptive statistics for the variables we use in the empirical analyses below for the whole sample and the subsamples depending on whether the estimated $\gamma$ is below or above its median. While the mean and median values of the liquidity ratio are not very different between the two subsamples, those of the intangible capital ratios are substantially higher for firms with higher $\gamma$.

We first estimate the industry-level estimation of the liquidity ratio using the median values of each industry. Figure 4 and Table 2 show that the liquid asset ratio is positively and significantly associated with the intangible capital ratio. Next, the estimation results for the equation (16) are summarized in the first column of Table 3. First, we can see that the correlation between the liquidity ratio and the intangible ratio is evidently positive. Reflecting the fact that the current data of intangible ratio contain extremely high value in selected observations, the coefficient itself is small but statistically significantly away from zero. This result is confirmed with controlling for the firm size, debt ratio, profitability, and growth opportunity, all of which show statistically significant association with the liquidity ratio as well as the unobservable firm-level fixed effect and time-effect. Second, from the results in the second and third column, the former and the latter of which account for the results based on the high and low $\gamma$, respectively, we can see that the sensitivity of liquidity ratio with respect to the intangible ratio is larger for higher $\gamma$. This implies that at least in our data set, firms facing higher complementarity between tangibles and intangibles find it important to hold larger liquidity so as to avoid financial constraint when they want to increase investments due to, for example, technological progress that increases the marginal revenue of intangible capital. We should note that the economic impact on the liquidity ratio associated with the higher intangible ratio is somewhat small. To illustrate, given the estimated coefficient of $INTAN\_RATIO_{i,t-1}$ shown in the first column of Table 3 and the standard deviation of $INTAN\_RATIO_{i,t-1}$ in Table 1, we can compute the change in $LIQ\_RATIO_{i,t}$ due to the increase in $INTAN\_RATIO_{i,t-1}$ by its standard deviation (i.e., 4.6E-06*84.10) as 0.039%. Although this number becomes larger in the case of high $\gamma$ (second column of Table 2, 0.087%), it is still less than 1% of the standard deviation of $INTAN\_RATIO_{i,t-1}$. This exercise reveals the fact that while the dynamics of liquidity ratio is partly explained by the increasing role of intangibles in firms' production process, there are a large number of additional factors accounting for firms' liquidity holding. Table 4 repeats the same exercise using the equation (17) and suggests that the similar pattern we found in Table 3 is confirmed for the software stock

These results suggest, first, that the empirical property between firms' liquidity holding and intangible investment are consistent with the mechanism sketched in our theoretical model. Firms facing higher complementarity between tangibles and intangibles, which presumably exhibits higher intangible ratio, shows higher liquidity ratio. This relationship is generated by the difficulty for firms to use intangibles as collateral. Expecting the future productivity shock, firms commit to precautionary saving to avoid the shortage of finance due to such collateral constraint. According to our estimation result, software and advertisement stocks seem susceptible to such a constraint, thus show higher correlation with the liquidity holding. Second, the obtained results also suggest that, at least in our dataset, firms find it beneficial to relax their future financial constraint by accumulating liquidity holdings. As demonstrated in our simulation exercise, if firms expect only small gains from their intangible investments in future due to, for example, lower expectation of the future productivity shock and/or lower marginal revenue with respect to intangibles, firms might find it less profitable to relax their financial constraint.

## 6. Concluding remarks

In this paper, using a Japanese firm-level large panel data accounting for 40,000 firms over the years from 2000 to 2013, we test the empirical implication of our theoretical model based on collateral constraints for borrowing, and find, first, the positive correlation between firms' liquidity holding, which is measured by the ratio of liquidity assets to total assets, and the levels of intangible assets held by the firms. This result suggests that as the increasing importance of nonpledgeable intangible assets in firms' production process partly explains firms' liquidity holding. Second, we also find that such a positive correlation is stronger for the firms belonging to the industries associated with higher complementarity between tangible and intangible assets. This result suggests that the firms' liquidity holding reflects the technological heterogeneity among industries.

Our results suggest that increasing liquidity holdings by the corporate is a rational response to the more important role of intangible capitals as a production factor than before given the financial system as it is. Any policies that aim at reducing corporate liquidity holdings would end up with reducing tangible and intangible capital investment and hence firm growth unless such policies lead to relaxing the collateral constraint associated with intangible capital.[6] Our results further suggest that the damage from policies that aim at reducing corporate liquidity differs across industries depending on the substitutability and complementarity between tangible and intangible capital.

There are several questions remained in the present paper. First, we have not precisely understood the exact mechanism on the firm-level relationship among the liquidity ratio, intangible ratio, and the degree of complementarity and substitutability. It is necessary to obtain more precise empirical description on how the relationship between liquidity holding and intangible ratio depends on the technological feature represented by the degree of complementarity and substitutability between tangibles and intangibles. Second, it is also necessary to account for the small economic impact on liquidity holding originated from the variation in intangible ratio. As we detail in the present paper, only a small fraction of the variation of liquidity ratio can be explained by that of intangible asset in the current analysis, which is far less than the results reported in, for example, Falato et al. (2013). Thus, it would be highly necessary to account for whether such a small economic impact reflects any measurement

[6] Precisely speaking, the exogenous reduction in cash holding is accompanied by the reduction in borrowing, which end up with lower intangibles due to borrowing constraint. Depending on the degree of substitutability and complementarity, such a reduction in intangibles can lead to the reduction in tangibles, and thus the reduction in total assets held by firms.

error in intangibles, the existence of any omitted variables, or other institutional features (e.g., availability of financing channel for intangibles). All these discussion contribute to more precise understanding about the background mechanisms leading to firms' liquidity holding.

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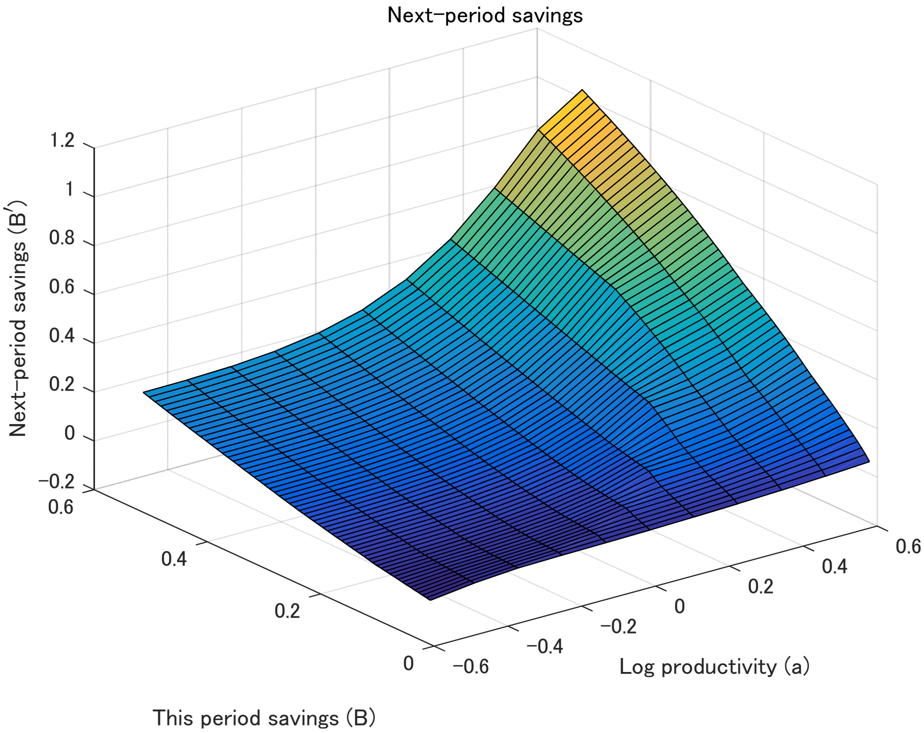
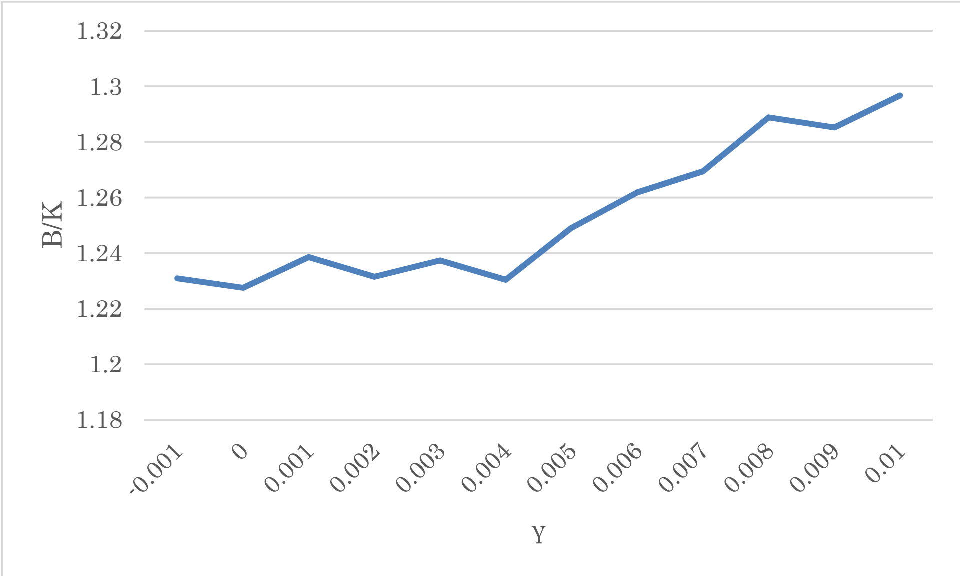
**Figures and Tables**

Figure 1. Optimal Saving Function



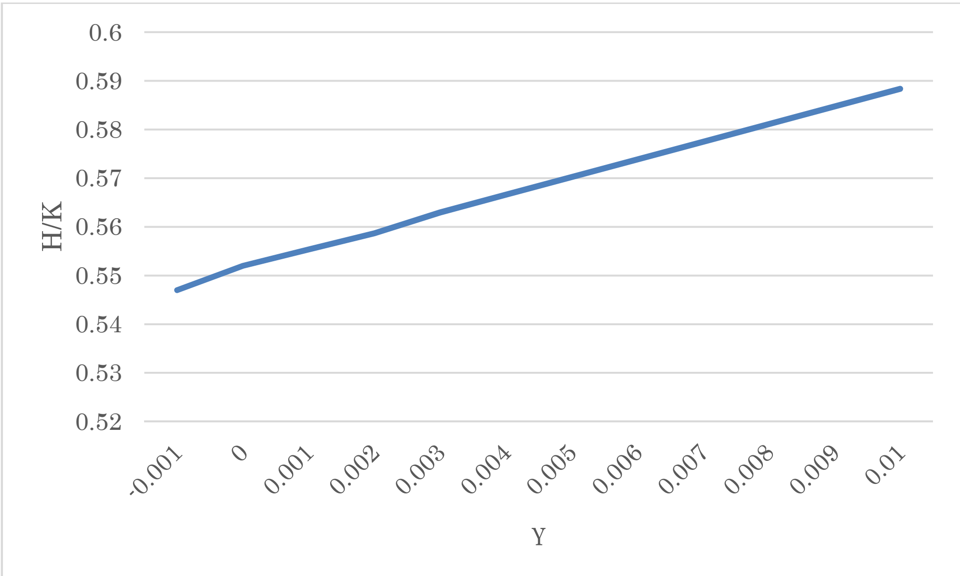

Note. $(\alpha, \beta, \gamma) = (0.5, 0.3, -0.001)$

Figure 2A. Simulation results: Saving-to-tangible capital ratio




Note. Median values of $B/K$ for each value of $\gamma$.

Figure 2B. Simulation results: Intangible-to-tangible capital ratio




Note. Median values of $H/K$ for each value of $\gamma$.

Figure 3. Simulation Results: Correlation coefficient of the intangible capital ratio and the saving ratio

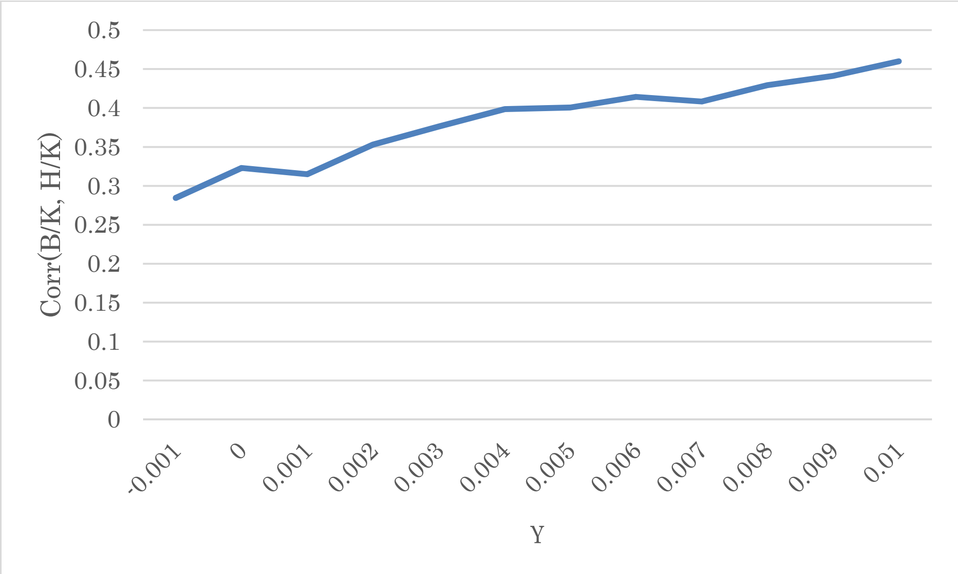


Figure 4. Industry-level liquid asset ratio and intangible asset ratio.

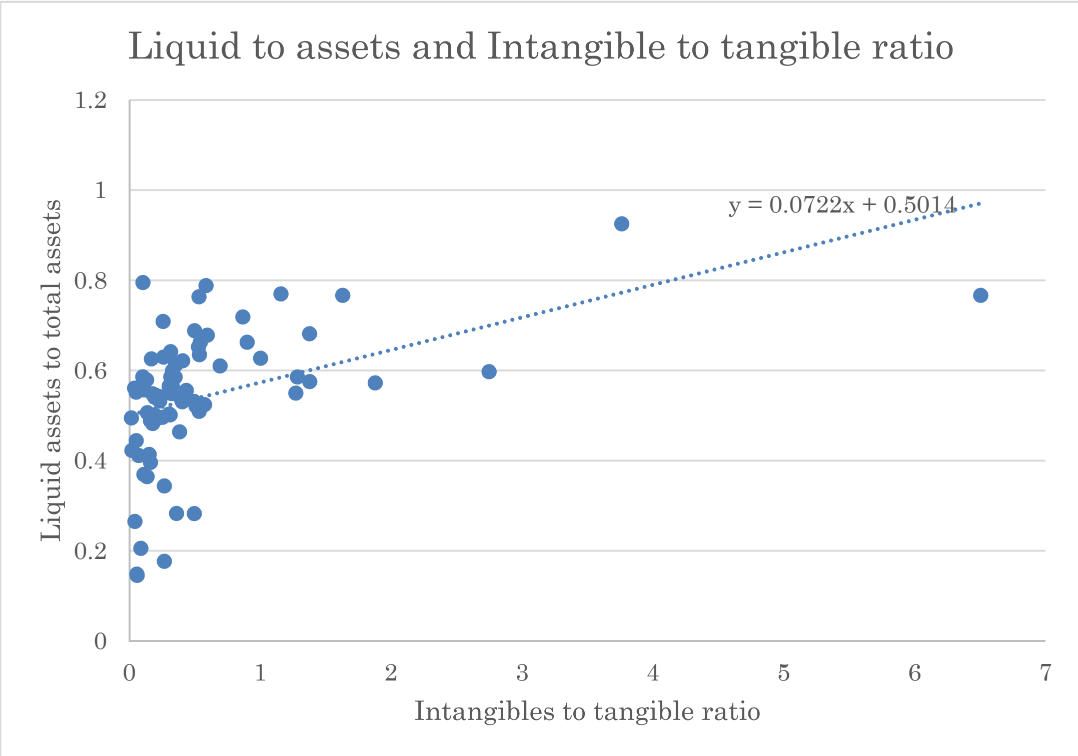


Table 1. Summary statistics

Panel a. All sample

| | LIQ_RATIO | INTAN_RATIO | SOFT_RATIO | AD_RATIO | RD_RATIO | LN_FASSETS | DEBT_RATIO | ROA | SALES_GROWTH |
|---|---|---|---|---|---|---|---|---|---|
| | Liquid assets to total assets | Intangible to tangible ratio | Software ratio to tangible ratio | advertisement ratio to tangible ratio | R&D ratio to tangible ratio | Ln assets | Debts to total assets | ROA (total assets) | Sales growth |
| mean | 0.58 | 6.20 | 4.65 | 0.78 | 0.77 | 8.40 | 0.67 | 0.04 | 0.00 |
| median | 0.58 | 0.35 | 0.14 | 0.02 | 0.00 | 8.23 | 0.69 | 0.03 | 0.00 |
| max | 1.03 | 11774.93 | 11579.98 | 8532.76 | 9750.75 | 16.53 | 360.00 | 12.90 | 5.96 |
| min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.39 | 0.00 | -36.17 | -4.76 |
| sd | 0.21 | 84.10 | 72.33 | 24.13 | 26.03 | 1.40 | 0.75 | 0.10 | 0.19 |
| N | 313511 | 312756 | 312756 | 312912 | 312912 | 313511 | 311409 | 313348 | 313511 |

Panel b. γ>median(γ)

| | LIQ_RATIO | INTAN_RATIO | SOFT_RATIO | AD_RATIO | RD_RATIO | LN_FASSETS | DEBT_RATIO | ROA | SALES_GROWTH |
|---|---|---|---|---|---|---|---|---|---|
| | Liquid assets to total assets | Intangible to tangible ratio | Software ratio to tangible ratio | advertisement ratio to tangible ratio | R&D ratio to tangible ratio | Ln assets | Debts to total assets | ROA (total assets) | Sales growth |
| mean | 0.56 | 9.85 | 8.11 | 0.98 | 0.77 | 8.24 | 0.67 | 0.04 | 0.00 |
| median | 0.56 | 0.42 | 0.16 | 0.04 | 0.00 | 8.06 | 0.67 | 0.03 | 0.00 |
| max | 1.03 | 11774.93 | 11579.98 | 8532.76 | 9750.75 | 15.59 | 360.00 | 12.90 | 3.93 |
| min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.39 | 0.00 | -36.17 | -4.75 |
| sd | 0.21 | 112.86 | 100.81 | 30.06 | 29.05 | 1.42 | 0.97 | 0.13 | 0.20 |
| N | 158914 | 158454 | 158454 | 158534 | 158534 | 158914 | 157739 | 158822 | 158914 |

Panel c. γ<=median(γ)

| | LIQ_RATIO | INTAN_RATIO | SOFT_RATIO | AD_RATIO | RD_RATIO | LN_FASSETS | DEBT_RATIO | ROA | SALES_GROWTH |
|---|---|---|---|---|---|---|---|---|---|
| | Liquid assets to total assets | Intangible to tangible ratio | Software ratio to tangible ratio | advertisement ratio to tangible ratio | R&D ratio to tangible ratio | Ln assets | Debts to total assets | ROA (total assets) | Sales growth |
| mean | 0.59 | 2.45 | 1.11 | 0.57 | 0.77 | 8.57 | 0.68 | 0.04 | 0.00 |
| median | 0.60 | 0.30 | 0.13 | 0.01 | 0.00 | 8.39 | 0.70 | 0.03 | 0.01 |
| max | 1.00 | 6237.89 | 1760.23 | 2715.57 | 5112.57 | 16.53 | 71.46 | 11.21 | 5.96 |
| min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.71 | 0.01 | -9.26 | -4.76 |
| sd | 0.20 | 35.02 | 11.87 | 15.89 | 22.51 | 1.36 | 0.41 | 0.08 | 0.19 |
| N | 154597 | 154302 | 154302 | 154378 | 154378 | 154597 | 153670 | 154526 | 154597 |

Note: The table shows the summary statistics of the variables used in our estimation. Panel a accounts for the summary statistics of all the observation while the panel b and c account for the two subsamples based on the complementarity and substitutability parameter (γ).

Table 2. Industry-level regression results of the liquidity ratio

| | (1) | (2) |
|---|---|---|
| INTANRATIO | 0.072*** | 0.067*** |
| | (0.017) | (0.019) |
| LN(ASSET) | | -0.025 |
| | | (0.025) |
| DEBTRATIO | | -0.166 |
| | | (0.219) |
| ROA | | 0.544 |
| | | (1.906) |
| SALESGROWTH | | 0.569 |
| | | (1.084) |
| CONSTANT | 0.501*** | 0.798* |
| | (0.018) | (0.320) |
| Adj. R2 | 0.185 | 0.191 |
| No. of Obs. | 78 | 78 |

Note: The dependent variable is the median value of the liquid asset ratio for each industry. The independent variables are the median values for each industry. *** and * denote significance at the 1% and 10% levels, respectively.

Table 3. Total intangibles

| Dependent var = LIQ_RATIO | All sample | | γ >median(0.0041177) | | γ <=median(0.0041177) | |
|---|---|---|---|---|---|---|
| | Coef. | Robust Std. Err. | Coef. | Robust Std. Err. | Coef. | Robust Std. Err. |
| <Independent Variables> | | | | | | |
| INTAN_RATIO | 4.6E-06 | 1.8E-06 ** | 7.7E-06 | 2.2E-06 *** | 5.8E-06 | 3.9E-06 |
| LN_FASSETS | -0.025 | 0.001 *** | -0.034 | 0.001 *** | -0.015 | 0.001 *** |
| DEBT_RATIO | -0.004 | 0.001 *** | -0.016 | 0.001 *** | 0.003 | 0.001 *** |
| ROA | 0.035 | 0.001 *** | 0.027 | 0.002 *** | 0.056 | 0.003 *** |
| SALES_GROWTH | 0.018 | 0.001 *** | 0.016 | 0.001 *** | 0.017 | 0.001 *** |
| Constant term | 0.800 | 0.005 *** | 0.866 | 0.007 *** | 0.732 | 0.007 *** |
| Firm-FE | yes | | yes | | yes | |
| Year-FE | yes | | yes | | yes | |
| No. Obs. | 313,511 | | 158,914 | | 154,597 | |
| No. Groups | 41,625 | | 24,738 | | 22,067 | |
| Obs per group | | | | | | |
| min | 1 | | 1 | | 1 | |
| avg | 7.5 | | 6.4 | | 7.0 | |
| max | 14 | | 14 | | 14 | |
| F | 315.29 | | 184.36 | | 152.48 | |
| Prob>F | 0 | | 0.0000 | | 0.0000 | |
| R-squared | | | | | | |
| within | 0.0204 | | 0.0241 | | 0.0203 | |
| between | 0.0191 | | 0.0445 | | 0.0061 | |
| overall | 0.0144 | | 0.0366 | | 0.006 | |
| F test (all U_i = 0) | 61.49 | | 46.16 | | 68.41 | |
| Prob>F | 0.0000 | | 0.0000 | | 0.0000 | |

Note: The table summarizes the estimation results of the equation (16). The first column summarizes the results based on the all observation while the second and third columns account for the two subsamples based on the complementarity and substitutability parameter (γ). ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table 4. Three intangibles

| Dependent var = LIQ_RATIO | All sample | | γ >median(0.0041177) | | γ <=median(0.0041177) | |
|---|---|---|---|---|---|---|
| | Coef. | Robust Std. Err. | Coef. | Robust Std. Err. | Coef. | Robust Std. Err. |
| <Independent Variables> | | | | | | |
| SOFT_RATIO | 6.5E-06 | 0.000 *** | 6.8E-06 | 2.4E-06 *** | 4.2E-06 | 4.5E-06 |
| AD_RATIO | -1.2E-05 | 0.000 * | 1.5E-05 | 8.4E-06 * | 2.8E-05 | 1.8E-05 |
| RD_RATIO | 6.7E-06 | 0.000 | 8.5E-06 | 8.5E-06 | 6.0E-06 | 1.2E-05 |
| LN_FASSETS | -0.025 | 0.001 *** | -0.034 | 0.001 *** | -0.015 | 0.001 *** |
| DEBT_RATIO | -0.004 | 0.001 *** | -0.016 | 0.001 *** | 0.003 | 0.001 *** |
| ROA | 0.035 | 0.001 *** | 0.027 | 0.002 *** | 0.056 | 0.003 *** |
| SALES_GROWTH | 0.018 | 0.001 *** | 0.015 | 0.001 *** | 0.017 | 0.001 *** |
| Constant term | 0.800 | 0.005 *** | 0.866 | 0.007 *** | 0.732 | 0.007 *** |
| Firm-FE | yes | | yes | | yes | |
| Year-FE | yes | | yes | | yes | |
| No. Obs. | 313,511 | | 158,914 | | 154,597 | |
| No. Groups | 41,625 | | 24,738 | | 22,067 | |
| Obs per group | | | | | | |
| min | 1 | | 1 | | 1 | |
| avg | 7.5 | | 6.4 | | 7.0 | |
| max | 14 | | 14 | | 14 | |
| F | 284.08 | | 165.97 | | 137.32 | |
| Prob>F | 0 | | 0.0000 | | 0.0000 | |
| R-squared | | | | | | |
| within | 0.0205 | | 0.0241 | | 0.0203 | |
| between | 0.019 | | 0.0445 | | 0.0063 | |
| overall | 0.0144 | | 0.0366 | | 0.0061 | |
| F test (all U_i = 0) | 61.47 | | 46.15 | | 68.37 | |
| Prob>F | 0.0000 | | 0.0000 | | 0.0000 | |

Note: The table summarizes the estimation results of the equation (17). The first column summarizes the results based on the all observation while the second and third columns account for the two subsamples based on the complementarity and substitutability parameter (γ). ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.