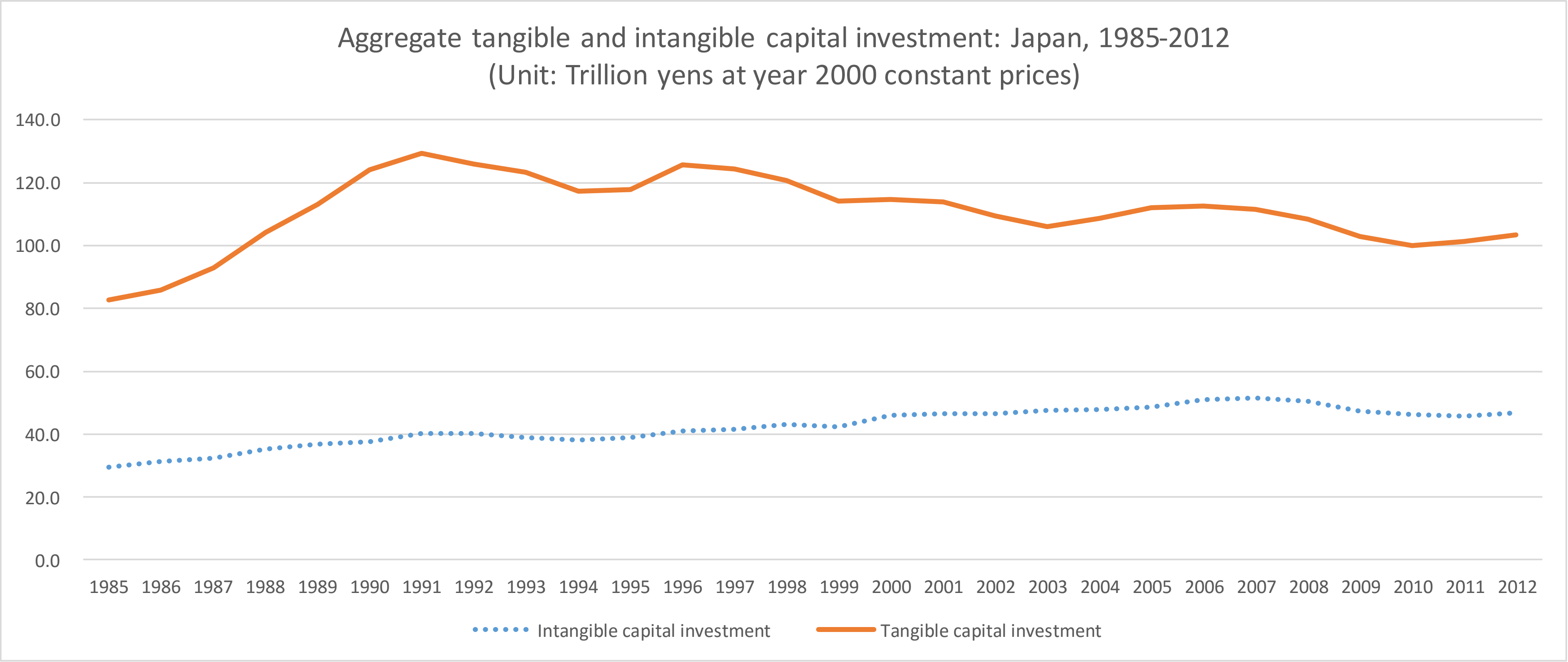
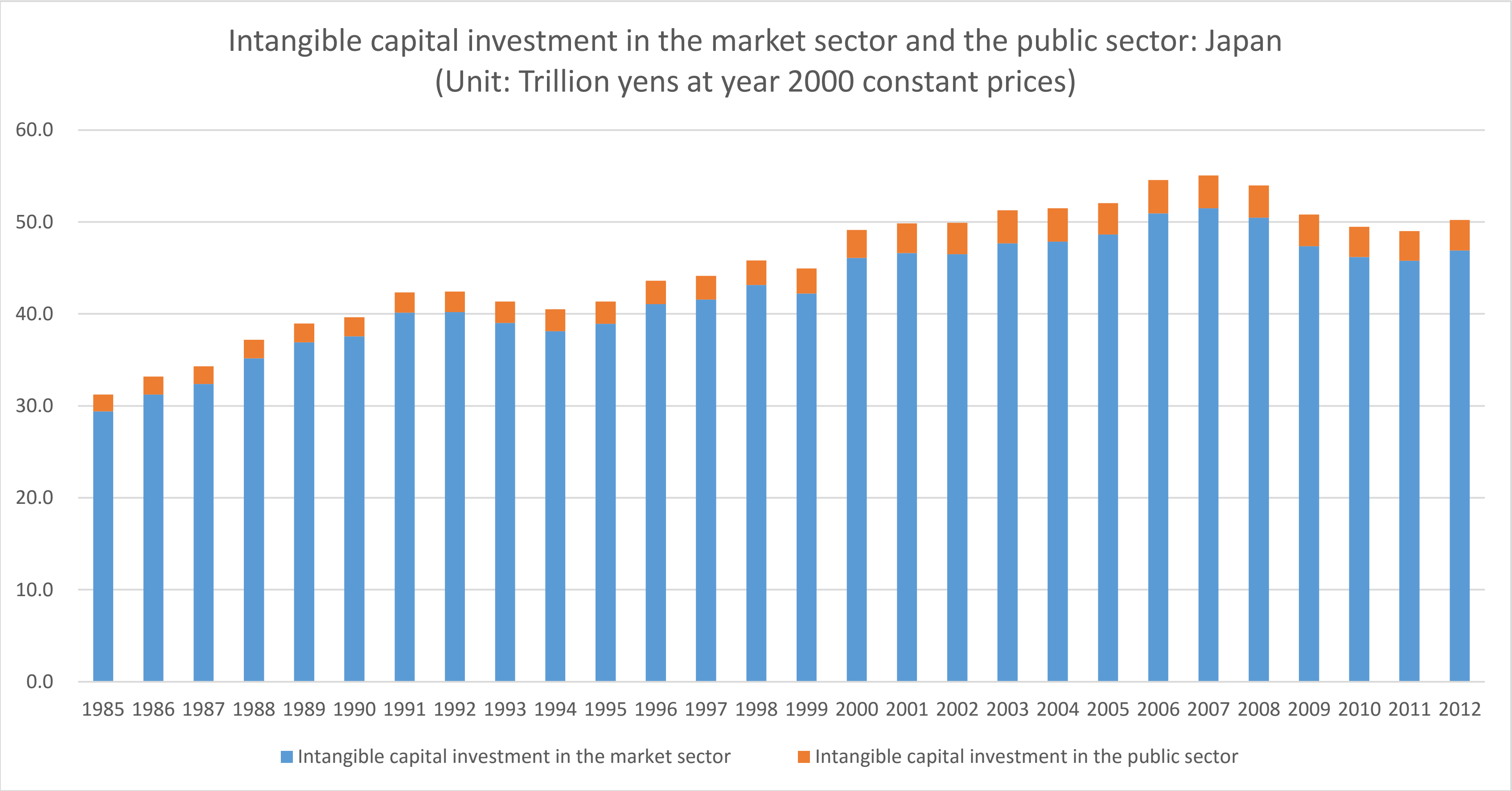
Complementarity and Substitutability between Tangible and Intangible Capital: Evidence from Japanese Firm-level Data

Kaoru Hosono (Gakushuin University/RIETI)
Daisuke Miyakawa (Hitotsubashi University)
Miho Takizawa (Toyo University)
Kenta Yamanouchi (Keio University/MERI)

Motivation: Intangible capital plays an important role in production and investment.



The market sector occupies a dominant share of intangible capital investment.



What we aim at:

- There seems a relation between tangible and intangible capital in production and investment.
- However, to our view, the literature does not fully explore the relation between tangible and intangible capital in production and investment.
- We analyze the complementarity and substitutability of tangible and intangible capital in production and investment in the market sector.
- The market sector includes private and non-profit organizations in medical, education, and waste disposal services.

Related literature: Theoretical models

(1) Growth and business cycles with intangible capital in general.
(McGrattan and Prescott, 2010a, b; Malik et al., 2014; De 2014).
⇒ Cobb-Douglas production function is often a priori assumed.

(2) Growth and business cycles with some specific intangible capital.
- ✓ Knowledge capital (Romer, 1990; Jones, 1995; Klette and Kortum, 2004).
- ✓ Organizational capital (Atkeson and Kehoe, 2005; Luttmer, 2007, 2011).
- ✓ Customer capital (Gourio and Rudanko, 2014a,b)

⇒ Intangible capital is only partially captured.

Related literature: Empirical analyses

(3) Empirical analyses of production functions with intangible capital

⇒ Firm-level analyses are scarce.

⇒ Cobb-Douglas functions

(De and Dutta, 2007; Verbič and Polanec, 2014).

Interaction between IT capital and organizational/human capital

(Breshnahan et al., 2002; Bugamelli and Pagano, 2003; Biagi and Parisi, 2012; Bloom et al., 2012)

⇒ Interaction (Complementarity/Substitutability) between tangible and intangible capitals has not been accounted for yet.

Although preceding studies focus on private sectors, interaction between tangible and intangible capitals has not been analyzed in the public sector as well.

Related literature: Empirical analyses (cnt'd)

(4) Empirical analyses of the relationship between tangible and intangible capital investment,

- ✓ Tobin's Q type of tangible capital investment (Bond and Cummins, 2000; Brynjolfsson et al., 2002; Takizawa, 2015)
- ✓ VAR with tangible capital and R&D investment

  (Lach and Schankerman, 1989; Lach and Rob, 1996; and Chiao, 2001)
- ✓ Intangible capital investment with both types of capital (Arrighetti et al., 2014)

⇒ They do not associate investment function with the production technology (i.e., complementarity/substitutability of tangible and intangible capital)

What we do:

- We analyze the complementarity and substitutability of tangible and intangible capital in production and investment.

- To this end, we
  - Construct a large dataset of Japanese firms including firm-level information on major intangible capitals: software, R&D, advertisement, spanning 2000-2013. (These three types account for about 70% of intangible capital: JIP 2015),
  - Estimate an industry-level production function taking into account the complementarity/substitutability of tangible and intangible capitals, and
  - Estimate an investment function to examine how the complementarity/substitutability in production accounts for the relation between tangible capital investment and intangible capital investment.

What we find:

1. Substantial heterogeneity among industries in terms of substitutability and complementarity between tangible and intangible capital.

2. For example, these two types of capital are complementary for medical sector, while they are substitute for waste disposal sector.

3. The estimated relation between tangible and intangible capital in production function accounts for the relation between tangible capital investment and intangible capital investment.

Composition

1. Introduction
2. Literature
3. Data
4. Methodology
5. Results: production
6. Results: investment
7. Conclusion

Data: source and coverage

- Source: The Basic Survey of Japanese Business Structure and Activities (BSJBSA) published by the METI.

- Sample:
  – BSJBSA covers the universe of enterprises in Japan with more than 50 employees and with paid-up capital of over 30 million yen.

  – Use data for 1994-2013 to construct intangible capital stock using the perpetual inventory (PI) method.

  – Use data for 2000-2013 to estimate production functions and data for 2000-2012 to estimate investment functions.

  – Drop firm-year observations with intangible capital=0 (0.6% of total number of observations).

Data: categories of intangible capital

Corrado et al. (2009)		This paper
• computerized information	--	software
• innovative property	--	R&D stock
• economic competencies	--	brand (advertisement)

- Software, R&D stock and brand accounts for about 70% of total intangible capital in Japan (JIP 2015).

Data: construction of intangible capital

- We follow Miyagawa et al. (2013).

- The following flow values are deflated and accumulated via PI method to construct stock values.

(1) Software (# of workers engaging in information processing/# of total workers) × total payroll + cost of information processing

(2) R&D (excluding capital expenditures for R&D)

(3) Advertisement

- Depreciation rates: 31.5%, 15% and 55% for software, R&D, and brand (advertisement):

  -- Sources: Corrado et al. (2009) and Miyagawa et al. (2013)

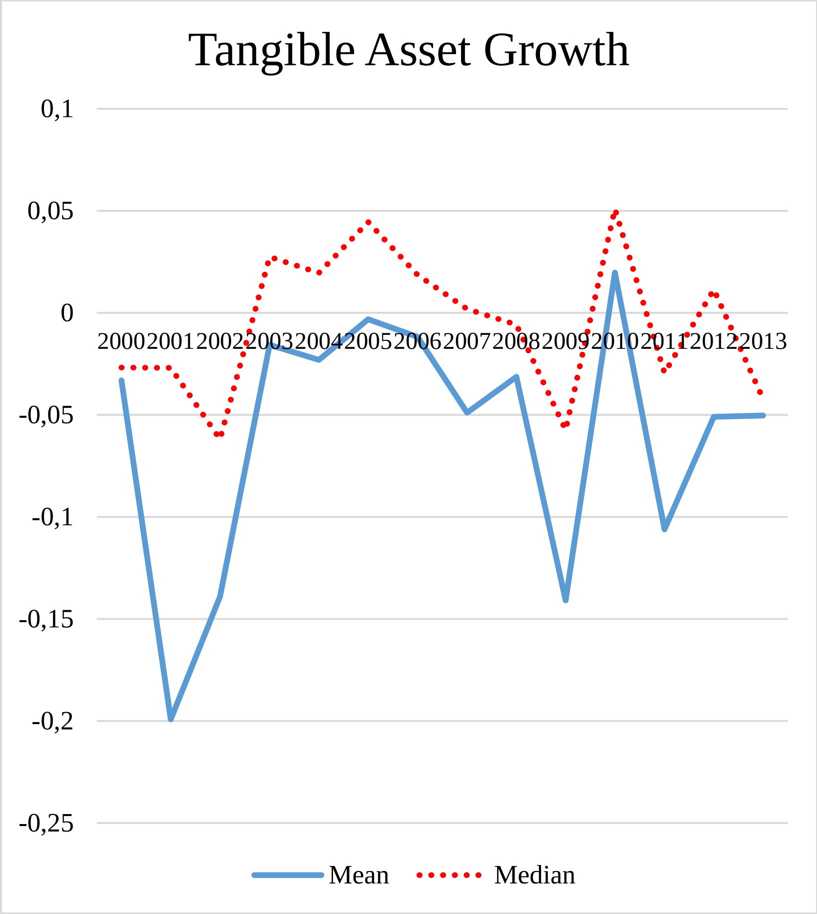
Industry classification (JIP 2015)

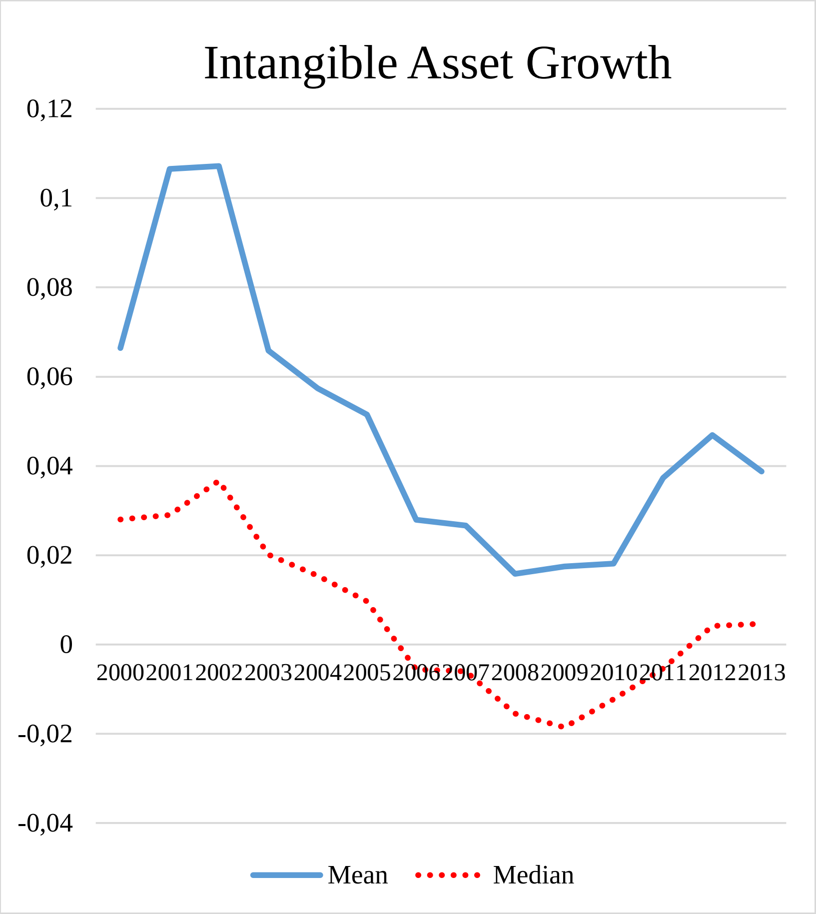
JIP Classif	Sector Name	JIP Classif	Sector Name
1	Rice, wheat production	50	Electronic equipment and electric measuring instruments
2	Miscellaneous crop farming	51	Semiconductor devices and integrated circuits
3	Livestock and sericulture farming	52	Electronic parts
4	Agricultural services	53	Miscellaneous electrical machinery equipment
5	Forestry	54	Motor vehicles
6	Fisheries	55	Motor vehicle parts and accessories
7	Mining	56	Other transportation equipment
8	Livestock products	57	Precision machinery & equipment
9	Seafood products	58	Plastic products
10	Flour and grain mill products	59	Miscellaneous manufacturing industries
11	Miscellaneous foods and related products	60	Construction
12	Prepared animal foods and organic fertilizers	61	Civil engineering
13	Beverages	62	Electricity
14	Tobacco	63	Gas, heat supply
15	Textile products	64	Waterworks
16	Lumber and wood products	65	Water supply for industrial use
17	Furniture and fixtures	66	Waste disposal
18	Pulp, paper, and coated and glazed paper	67	Wholesale
19	Paper products	68	Retail
20	Printing, plate making for printing and bookbinding	69	Finance
21	Leather and leather products	70	Insurance
22	Rubber products	71	Real estate
23	Chemical fertilizers	72	Housing
24	Basic inorganic chemicals	73	Railway
25	Basic organic chemicals	74	Road transportation
26	Organic chemicals	75	Water transportation
27	Chemical fibers	76	Air transportation
28	Miscellaneous chemical products	77	Other transportation and packing
29	Pharmaceutical products	78	Telegraph and telephone
30	Petroleum products	79	Mail
31	Coal products	80	Education (private and non-profit)
32	Glass and its products	81	Research (private)
33	Cement and its products	82	Medical (private)
34	Pottery	83	Hygiene (private and non-profit)
35	Miscellaneous ceramic, stone and clay products	84	Other public services
36	Pig iron and crude steel	85	Advertising
37	Miscellaneous iron and steel	86	Rental of office equipment and goods
38	Smelting and refining of non-ferrous metals	87	Automobile maintenance services
39	Non-ferrous metal products	88	Other services for businesses
40	Fabricated constructional and architectural metal products	89	Entertainment
41	Miscellaneous fabricated metal products	90	Broadcasting
42	General industry machinery	91	Information services and internet-based services
43	Special industry machinery	92	Publishing
44	Miscellaneous machinery	93	Video picture, sound information, character information production and distribution
45	Office and service industry machines	94	Eating and drinking places
46	Electrical generating, transmission, distribution and industrial apparatus	95	Accommodation
47	Household electric appliances	96	Laundry, beauty and bath services
48	Electronic data processing machines, digital and analog computer equipment and accessories	97	Other services for individuals
49	Communication equipment		

Sample statistics

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

Growth rates of tangible and intangible capitals





Method: production function

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

$$\omega_{i.t} = \rho\omega_{i.t-1} + \xi_{i,t}$$ (productivity shock)

- Cobb-Douglas production function augmented by the interaction of LN(Ktan) and LN(Kintan).
- Complementarity/substitutability is captured by $\beta_{tan\times intan}$.
- Firm fixed effects and year dummies

Estimation

Dynamic (common factor) presentation

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

or

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

Where $\pi_2 = -\pi_1\pi_9, \pi_4 = -\pi_3\pi_9, \pi_6 = -\pi_5\pi_9, \pi_8 = -\pi_7\pi_9.$

Estimation Procedure 1

1. We first obtain consistent estimates of the unrestricted parameter $\pi = (\pi_1, , , \pi_9)$ and $\mathrm{var}(\pi)$, using the system GMM (Blundell and Bond, 1998).

$$\mathrm{E}\left(x_{i,t-s}\Delta\omega_{i,t}\right) = 0 \qquad (6)$$

and

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

where

$x_{i,t} =$
$\left(LN(L)_{i,t}, LN(Ktan)_{i,t}, LN(Kintan)_{i,t}, LN(Ktan)_{i,t} \times LN(Kintan\right.$

and $s \geq 3$.

Estimation Procedure 2

2. Using consistent estimates of the unrestricted parameters and their variance-covariance matrix, we impose the above restrictions by minimum distance to obtain the restricted parameter vector $(\beta_l, \beta_{ktan}, \beta_{kintan}, \beta_{tan \times intan}, \rho)$.

Method: Definition of Complementarity /Substitutability

$$Ktan\ and\ Kintan\ are\ substitute\ if\ \delta(LN(Ktan))/\delta(Rintan) > 0$$
$$complemenatry\ if\ \delta(LN(Ktan))/\delta(Rintan) < 0$$

complementary if $\frac{\partial^2 F(Ktan, Kintan, L)}{\partial Ktan \partial Kintan}$>0

substitute if <0

- Complementary if $\beta_{tan\times intan}(IND)$ is either positive or negative with a sufficiently small absolute value.

- We call $\beta_{tan\times intan}(IND)$ the “complementarity coefficient” below.

Methodology: Investment function

- Simple form of structural equations

$$dK\tan_{i,t} = \frac{\partial K\tan}{\partial \omega} d\omega_{i,t-1} + \frac{\partial K\tan}{\partial R\tan} dR\tan_{i,t-1} + \frac{\partial K_{\tan}}{\partial R_{\text{int}\,an}} dR\,\text{int}\,an_{i,t-1}$$

$$dK\,\text{int}\,an_{i,t} = \frac{\partial K\,\text{int}\,an}{\partial \omega} d\omega_{i,t-1} + \frac{\partial K\tan}{\partial R\tan} dR\tan_{i,t-1} + \frac{\partial K\tan}{\partial R\,\text{int}\,an} dR\,\text{int}\,an_{i,t-1}$$

- Rental rates of intangible capital are difficult to observe and likely to vary across firms and over time.
- We substitute intangible capital investment into the rental rate of intangible capital of the tangible capital investment equation to obtain reduced form.
- The relationship between tangible capital investment and intangible capital investment should depend on the complementarity/substitutability captured by $\beta_{tan \times intan}$.

Method: Production and Investment

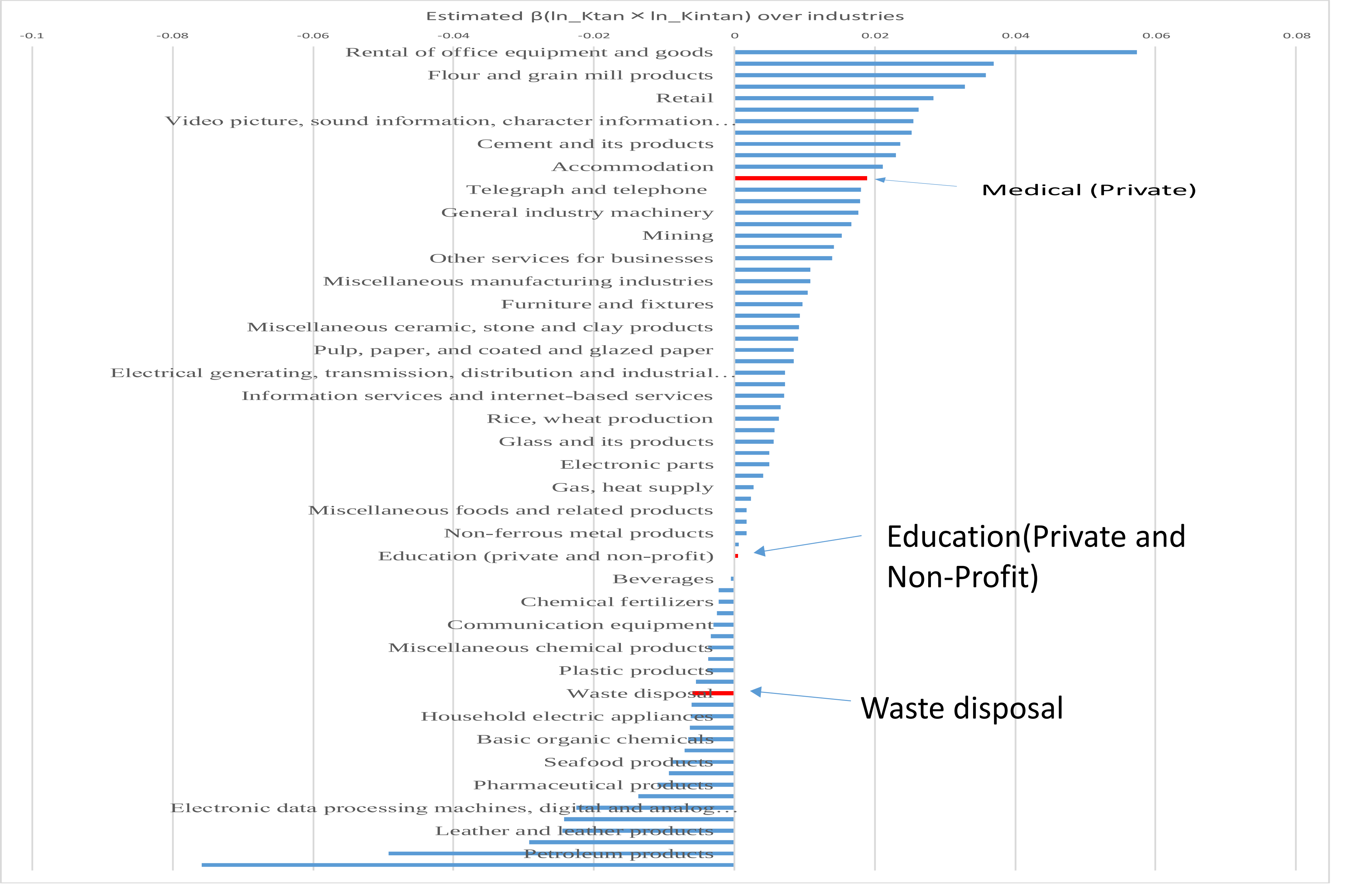
- $\Delta LN(Ktan)_{i,t} = \gamma_{intan}\Delta LN(Kintan)_{i,t}$
  $+\gamma_{intan\times\beta}\Delta LN(Kintan)_{i,t} \times \beta_{tan\times intan}(IND_i) + \delta\Delta LN(TFP)_{i,t}$
  $+ \eta_i + year_t + \varepsilon_{i,t}$

- TFP is measured either at the firm level or industry level.

- $\gamma_{intan\times\beta} > 0$ is expected.

- $Rintan\downarrow$ ⇒ Ktan ↑ if complementary
  Ktan ↓ if substitute
  ⇒ Kintan↑

Results from production functions: Estimated coefficients for $LN(Ktan)_{i,t} \times LN(Kintan)_{i,t}$ vary over industries



How are the complementarity/substitutability associated with industry characteristics?

- The degree of complementarity tends to be higher as the average firm size is smaller and the industry size is larger.

Dependent Variable: β(ln_Ktan×ln_Kintan)

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

Results: Investment function

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

$\beta_{tan\times intan}(IND_i)$ accounts for the joint dynamics of tangible and intangible capitals.

Quantitatively, however, even with relatively high $\beta_{tan\times intan}(IND_i)$ (e.g., around 0.045 for special industry machinery) the overall marginal effect associated with $\Delta LN(Kintan)_{i,t}$ is still negative.

Results: Investment function

- Replacing the industry-level TFP with firm-level TFP yields a similar result.

Dependent Variable: ΔLN(Ktan)

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

Why is tangible capital investment negatively associated with intangible capital investment? – Financial constraints?

Large firms

Dependent Variable: ΔLN(Ktan)

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

Small firms

Dependent Variable: ΔLN(Ktan)

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

Except for the industries with very high $\beta_{tan \times intan}(IND_i)$, increase in the intangible capital lead to larger reduction in tangible capital in the case of small firms, which is consistent with the financial constraint hypothesis.

Why is tangible capital investment negatively associated with intangible capital investment? – Financial constraints?

Large firms

Dependent Variable: ΔLN(Ktan)

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

Small firms

Dependent Variable: ΔLN(Ktan)

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

Replacing industry-level TFP with firm-level TFP yields a similar result.

Summary

Using a unique dataset of Japanese firms including firm-level information on major intangible capitals, we find

(1) Substantial heterogeneity among industries in terms of substitutability and complementarity between tangible and intangible capital.

(2) For example, these two types of capital are complementary for medical sector, while they are substitute for waste disposal sector.

(3) The estimated relation between tangible and intangible capital in production function accounts for the relation between tangible capital investment and intangible capital investment.

Policy implications

- The effects of such a policy as exclusively targeting one type of capital (e.g., tax credit for tangible capital investment or subsidy for R&D) vary over industries.

- Policies favoring one production factor might enhance the production if tangible and intangible capitals are complementary, while subsidies for intangible capital investment may severely reduce tangible capital investment in the case that these two inputs are substitute.

- It is necessary to take into account the detailed mechanism of production for disaggregated group (e.g., industry) for designing effective policy measures as well as evaluating the outcomes of policy measures.