Intangible Capital: Complement or Substitute in the Creation of Public Goods?

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Motivation

- growing awareness that intangible capital is an important component for economic success and subsequent social prosperity
- growing literature on intangible capital
  - method development and relevance in firms, industries and nations (*inter alia* Corrado et al., 2005; Inklaar, 2010; Piekkola, 2014; Görzig and Gornig, 2015; Bacchini et al., 2016)
  - contribution to growth, productivity, output elasticity (*inter alia* van Ark et al., 2009; Corrado et al., 2009; Edquist, 2011; Piekkola, 2011; Goodridge et al., 2013; Roth and Thum, 2013; Niebel et al., 2013; Chen et al., 2014; Corrado et al., 2014a,b)

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- substitutability between intangible and tangible capital is less studied
- knowing substitution elasticity is essential to avoid unintended consequences of stimulus packages or spending cuts

Research Question and Main results

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Contribution to the literature

- first analysis of the elasticity of substitution between intangible capital and other inputs for public sector in Europe
- adds evidence for significant contribution of intangible capital in the public sector

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- first analysis of the elasticity of substitution between intangible capital and other inputs for public sector in Europe
- adds evidence for significant contribution of intangible capital in the public sector

Main Results

- intangible capital is only weakly substitutable with other inputs; but also not fully complementary

Outline

Production Function

- along the line of previous literature, intangible capital is assumed to be an additional input
- implicit assumptions: intangible capital it is not in the law of motion for TFP
  Cobb-Douglas approach:

$$Y_{it} = C_{it}^{\alpha} L_{it}^{\beta} I_{it}^{\gamma} e^{\omega_{it}} e^{\epsilon_{it}} \quad (1)$$

- estimating Eq. (1) in logs by means of OLS with time, country and industry dummies
- problematic assumption: elasticity of substitution between any two inputs equals 1 at any point of the productions function $\rightarrow$ OLS provides first insights

Nested CES Production Functions

- nested CES production functions allows for deviating substitution elasticities
- two-level three input CES function for nesting structure CL-I:

$$\tilde{Y}_t = \gamma_{cl-i} e^{\lambda_{cl-i} t} \left[\underbrace{\delta_{cl-i} \left(\delta_{cl} \tilde{C_t}^{-\rho_{cl}} + (1-\delta_{cl}) \tilde{L_t}^{-\rho_{cl}} \right)^{\frac{\rho_{cl-i}}{\rho_{cl}}}}_{\text{CES prodcution function for C and L}} + (1-\delta_{cl-i}) \tilde{I_t}^{-\rho_{cl-i}} \right]^{-\frac{\nu_{cl-i}}{\rho_{cl-i}}} \tag{2}$$

- with L_t as labour, C_t as tangible capital, I_t as intangible capital and Y_t as gross value added
- with $\tilde{Y}_t = Y_t/\bar{Y}$, $\tilde{C}_t = C_t/\bar{C}$, $\tilde{L}_t = L_t/\bar{L}$ and $\tilde{I}_t = I_t/\bar{I}$
- with λ as rate of Hick-neutral technological change, t as time index, ρ_{ij} and ρ_{ij_k} are the substitution parameters, δ_{ij} and δ_{ij_k} determining the optimal distribution of inputs, γ as a productivity parameter and ν measures the elasticity of scale

Nested CES Production Functions

- the substitution elasticity is derived as

$$\sigma_{ij} = \frac{1}{1+\rho_{ij}} \tag{3}$$

- if $\rho_{ij} \to 0$, the substitution elasticity approaches 1. This is the special case of the Cobb-Douglas production function.
- if $\rho_{ij} \to -1$, the substitution elasticity approaches infinity. In this case, inputs are fully substitutable with each other (linear production function).
- if $\rho_{ij} \to \infty$, the substitution elasticity approaches 0. This is the case of complementarity of inputs (Leontief production function).

example

Estimation Procedure

- estimation of Eq. (2) for the nesting structures $CL - I$, $CI - L$ and $LI - C$
- estimation by industry to circumvent assumption of identical parameters across industries and countries
- normalization of all variables with geometric means in order to filter out country specific effects (Klump and Preissler, 2000; Klump et al., 2007a,b, 2011)
- non-linear estimation using optimization algorithms incorporated in the *micEconCES package* of R (see Henningsen and Henningsen 2011, 2014)
- issue of local minimums and implausible combinations overcome by applying grid search plus upper and lower bounds on parameters (apart from ρ_{ij} and ρ_{ij-k})

local minimums bounds

Data

- intangible capital data taken from SPINTAN database
- gross value added (GVA), gross fixed capital formation (GFCF), and the number of persons employed (EMP) taken from Eurostat
- first step: aggregation of different intangible assets into a single capital stock variable per one-digit industry and country
- second step: adjustment of GVA and GFCF
  - prevent double counting of R&D and software in both tangible and intangible capital by reducing GFCF by investments in R&D and software
  - GVA is adjusted upwards to capture investment in intangibles (Corrado et al., 2014b)
- third step: estimating initial tangible capital stocks using adjusted GFCF, industry specific depreciation rates and initial growth rates (both EU KLEMS) by means of PIM

Data

- final dataset contains 700 observations covering 14 countries, four one-digit public sectors over the period 1995-2010.

Table 1: Descriptive Statistics

Industry	Variable	N	Mean	Std. Dev.	Min	Max
	Value added (Mio)	191	47,970.57	50,037.68	1,171.64	151,237.40
O	Capital (Mio)	191	283,740.80	280,339.00	13,948.35	1,007,276.00
	Intangible capital (Mio)	191	12,141.88	15,029.33	138.44	55,322.82
	No. of employees (thousand)	191	849.48	925.03	35.25	3,109.00
	Value added (Mio)	191	35,847.19	35,919.32	3,783.15	111,163.20
P	Capital (Mio)	191	75,625.90	84,922.83	6,758.27	307,540.90
	Intangible capital (Mio)	191	6,587.53	7,391.15	516.69	41,497.20
	No. of employees (thousand)	191	730.61	682.51	136.10	2,292.00
	Value added (Mio)	159	54,400.03	47,519.78	6,961.59	164,169.50
Q	Capital (Mio)	159	108,353.20	128,964.80	13,073.00	528,802.10
	Intangible capital (Mio)	159	3,315.42	3,123.73	454.12	12,892.22
	No. of employees (thousand)	159	1,333.58	1,296.11	248.37	4,882.00
	Value added (Mio)	159	8,457.21	9,047.60	934.07	30,800.09
R	Capital (Mio)	159	27,455.76	30,027.18	2,858.21	109,553.60
	Intangible capital (Mio)	159	739.71	675.30	9.77	2,047.55
	No. of employees (thousand)	159	172.82	179.97	27.14	621.00

Source: SPINTAN, EUROSTAT, EU KLEMS; own calculations.

data availablitiy

OLS results

Table 2: OLS estimation results using number of employees

Variable	(1)	(2)	(3)	(4)	(5)
C	0.177***	0.242***	0.114***	0.0783***	0.0660***
	(0.0129)	(0.0179)	(0.00833)	(0.0125)	(0.0130)
L (EMP)	0.713***	0.617***	0.780***	0.595***	0.567***
	(0.0131)	(0.0180)	(0.00961)	(0.0236)	(0.0249)
I	0.143***	0.197***	0.0745***	0.0384***	0.0373***
	(0.00992)	(0.0109)	(0.00661)	(0.00815)	(0.00817)
Year	-	yes	yes	-	yes
Industry	-	yes	-	yes	yes
Country	-	-	yes	yes	yes
Constant	2.534***	1.830***	3.422***	5.161***	5.428***
	(0.0779)	(0.116)	(0.0639)	(0.183)	(0.199)
N	700	700	700	700	700
R^2	0.966	0.972	0.990	0.992	0.992

Source: SPINTAN, EUROSTAT, EU KLEMS; own calculations.

Results

Table 3: CES function parameter, estimated with lower and upper boundaries

industry	λ_{CL-I}	γ_{CL-I}	δ_{CL}	δ_{CL-I}	ν_{CL-I}	σ_{CL}	σ_{CL-I}	N
O	-0.004***	1.032***	0.447***	0.918***	1.57***	0.833	**0.400*** **	191
P	-0.002	1.015***	0.355***	0.95***	0.768***	10	**0.455**	191
Q	0.008***	0.942***	0.05	0.866***	0.599***	10	**0.333*** **	159
R	-0.003	1.022***	0.05	0.95***	0.811***	0.455	**2.5**	159
industry	λ_{CI-L}	γ_{CI-L}	δ_{CI}	δ_{CI-L}	ν_{CI-L}	σ_{CI}	σ_{CI-L}	N
O	-0.004***	1.031***	0.833***	0.492***	1.568***	**0.455*** **	0.769	191
P	-0.003**	1.019***	0.95***	0.371***	0.844***	**0.4**	10	191
Q	0.007***	0.95***	0.5	0.219**	0.628***	**0.333** **	0.333*	159
R	-0.006	1.052***	0.95**	0.06	0.953***	**10**	0.526	159
industry	λ_{LI-C}	γ_{LI-C}	δ_{LI}	δ_{LI-C}	ν_{LI-C}	σ_{LI}	σ_{LI-C}	N
O	-0.004***	1.031***	0.861***	0.592***	1.567***	**0.455** **	0.667	191
P	-0.002**	1.02***	0.95***	0.637***	0.816***	**0.385* **	10	191
Q	0.008***	0.942***	0.86***	0.95***	0.602***	**0.333*** **	10	159
R	-0.003	1.025***	0.95***	0.95***	0.823***	**2.5**	0.333	159

Source: SPINTAN, EUROSTAT, EU KLEMS; own calculations.
H0=1 for σ_k with $k = \{CL, CI, LI, CL-I, CI-L, LI-C\}$
*all other point estimates: H0=0; *** p<0.01, ** p<0.05, * p<0.1*

without bounds

Summarizing

- intangible capital is a significant input factor in the production of public goods
- intangible capital is just weakly substitutable with other inputs

Summarizing

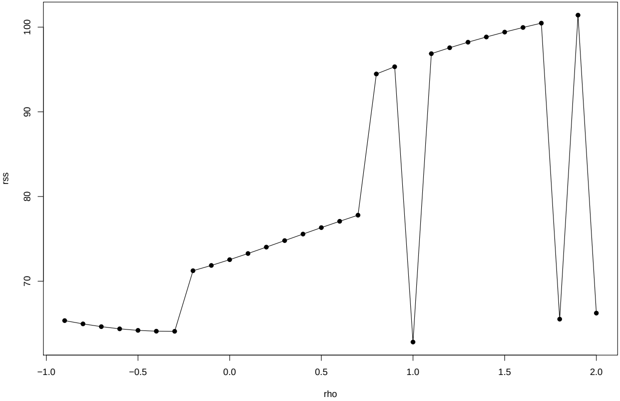
- intangible capital is a significant input factor in the production of public goods
- intangible capital is just weakly substitutable with other inputs
- implications:
  - investment programs require considering intangible capital alongside tangible capital
  - austerity programs that focus on one input category might have more severe effects than expected

example

Thank you for your attention!

Optimization routine

Figure 1: Example ρ outliers



Back to CES production functions

Bounds

Table 4: Boundaries of parameters in GRID SEARCH

variables	lower bound	upper bound
γ_k	-100	100
λ_k	-100	100
δ_{CL}	0.05	0.5
δ_{CI}	0.5	0.95
δ_{LI}	0.5	0.95
δ_{CL-I}	0.5	0.95
δ_{CI-L}	0.06	0.5
δ_{LI-C}	0.5	0.95
ν_k	0.5	1.5

Source: SPINTAN, EUROSTAT, EU KLEMS; own calculations.
with $k = \{CL - I, CI - L, LI - C\}$

Back to CES production functions

Data availability

Table 5: Data availability per country, industry and years

	Industry			
Country	O84	P85	Q	R
AT	1995-2010	1995-2010	1995-2010	1995-2010
BE	1995-2010	1995-2010	-	-
CZ	-	1995-2010	-	1995-2010
DE	1995-2010	1995-2010	1995-2010	1995-2010
DK	1995-2010	1995-2010	1995-2010	1995-2010
ES	1995-2010	1995-2010	1995-2010	-
FI	1995-2010	1995-2010	1995-2010	1995-2010
FR	1995-2010	1995-2010	1995-2010	1995-2010
HU	-	1995-2010	-	-
IT	1995-2010	1995-2010	1995-2010	1995-2010
NL	1995-2010	1995-2010	1995-2010	1995-2010
PT	1996-2010	1996-2010	1996-2010	1996-2010
SE	1995-2010	-	1995-2010	1995-2010
SI	1995-2010	-	-	-

Source: SPINTAN, EUROSTAT, EU KLEMS; own calculations.

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Results

Table 6: CES function parameter, estimated without boundaries

industry	λ_{CL-I}	γ_{CL-I}	δ_{CL}	δ_{CL-I}	ν_{CL-I}	σ_{CL}	σ_{CL-I}	N
O	-0.004***	1.032***	0.447***	0.918***	1.57***	0.833	**0.4*** **	191
P	-0.003***	1.023***	0.373***	1***	0.889***	10	**0.667**	191
Q	0.009***	0.94***	0	0.862***	0.6***	1.429	**0.333*** **	159
R	-0.005	1.04***	0	1***	0.901***	0.476	**1.25**	159
industry	λ_{CI-L}	γ_{CI-L}	δ_{CI}	δ_{CI-L}	ν_{CI-L}	σ_{CI}	σ_{CI-L}	N
O	-0.004***	1.031***	0.833***	0.492***	1.568***	**0.455*** **	0.769	191
P	-0.003***	1.023***	1***	0.373***	0.889***	**0.385**	10	191
Q	0.009***	0.94***	0	0.138	0.6***	**1.111**	0.333**	159
R	-0.003	1.019***	23.348	0	0.836***	**1**	1.25	159
industry	λ_{LI-C}	γ_{LI-C}	δ_{LI}	δ_{LI-C}	ν_{LI-C}	σ_{LI}	σ_{LI-C}	N
O	-0.004***	1.031***	0.861***	0.592***	1.567***	**0.455** **	0.667	191
P	-0.003***	1.023***	1***	0.627***	0.889***	**0.476**	10	191
Q	0.009***	0.94***	0.862***	1***	0.6***	**0.333*** **	0.625	159
R	-0.005	1.04***	1***	1***	0.901***	**0.476**	1.25	159

Source: SPINTAN, EUROSTAT, EU KLEMS; own calculations.
H0=1 for σ_k with $k = \{CL, CI, LI, CL-I, CI-L, LI-C\}$
*all other point estimates: H0=0; *** p<0.01, ** p<0.05, * p<0.1*

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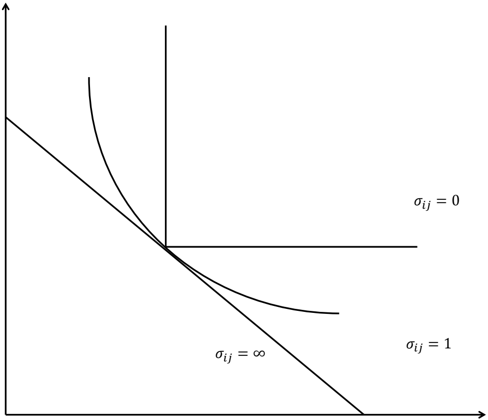
Substitution Elasticity

Elasticity of substitution

- shows "the ease with which the varying factor can be substituted for others" (Hicks, 1932: p.117), or,
- it "measures the degree to which the substitutability of one factor for another varies as the proportion between the factors varies" Lerner (1933, 68), or, in other words,
- it measures the percentage change in factor proportions due to a change in marginal rate of technical substitution, or,
- it is effectively a measure of the curvature of an isoquant (Lerner, 1933).

CD and Leontief Production Function

Figure 2: Production Functions and Elasticity



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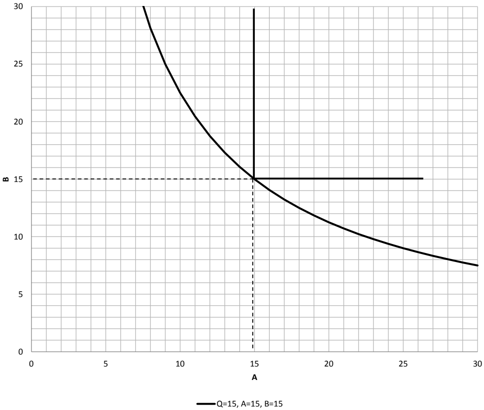
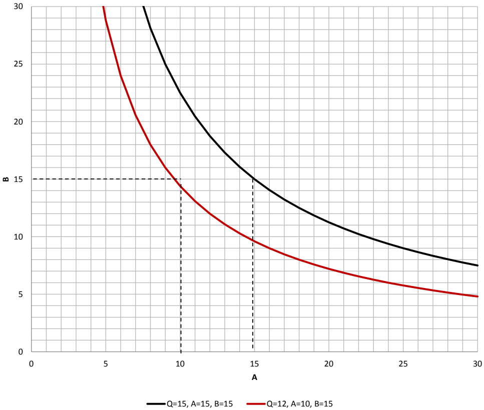
CD and Leontief Production Function

Figure 3: CD and Leontief



CD and Leontief Production Function

Figure 4: CD and Leontief



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CD and Leontief Production Function

Figure 5: CD and Leontief

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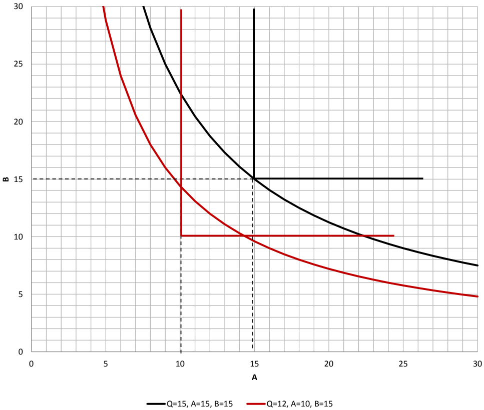
CD and Leontief Production Function

Figure 6: CD and Leontief



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