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SPINTAN Project: Smart Public intangibles. This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no: 612774.

Version: July 2016

Published by:

Instituto Valenciano de Investigaciones Económicas, S.A.
C/ Guardia Civil, 22 esc. 2 1º - 46020 Valencia (Spain)

DOI: http://dx.medra.org/10.12842/SPINTAN-WP-15

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Abstract

This paper tests whether intangible capital is a substitute or, to some degree, a complement to standard inputs in the production process. The analysis is conducted for public sectors in which governmental institutions are directly responsible for both, efficiently producing public goods as well as for the investment in new production factors. Knowing the substitutability of inputs is important for achieving the best possible result for the invested money, *inter alia*, when designing stimulus programs. The analysis is carried out using three-input two-level nested value added CES production functions. The analysis reveals that intangible capital is just weakly substitutable with other inputs. This result implies that any investment plan or any stimulus program should not just focus on tangible assets, but also needs to include investments in intangibles in order to achieve the maximum output and to efficiently use public money. It also follows that investment programs for tangible assets should not be undermined by austerity programs focused on intangible assets.

* This paper is deliverable 5.4 of the SPINTAN project. The project is funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities, Grant Agreement no 612774. Further details can be found here: www.spintan.net.
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1 Introduction

Starting with the knowledge production function of Griliches (1979), intangible capital, in the form of R&D in Griliches approach, is increasingly the focus of economic research and policy. Since the millennium, research on intangible capital accelerated with new forms of intangible assets coming into focus, and the economic literature on it grew significantly.

Part of that literature is dedicated to evolving the techniques for measuring the different intangible assets, as well as on estimating its importance in firms, industries, and nations. (see *inter alia* Kendrick, 1972; Corrado et al., 2005; Inklaar, 2010; Lipsey, 2010; Nakamura, 2010; Martin-Oliver and Salas-Fumás, 2011; Corrado et al., 2013; Piekkola, 2014; Haan et al., 2010; Görzig and Gornig, 2015; Bacchini et al., 2016). Another strand of the literature focus on the relationship between intangible capital and productivity growth, and finds a mixed picture. While most find an acceleration of labour productivity growth if intangibles are included in the growth accounting framework (see *inter alia* Marrano et al., 2009; van Ark et al., 2009; Fukao et al., 2009; Ackerberg et al., 2006; Corrado et al., 2009; Goodridge et al., 2013), others find that TFP growth is lower when investments in intangibles are included in growth accounting (see *inter alia* Fukao et al., 2009; Edquist, 2011; Piekkola, ed, 2011). In these latter cases, conventional TFP growth captures that part of output growth that actually has to be assigned to intangible capital deepening. In other words, TFP, which is measured as a residual within growth accounting, captures the effect of intangibles if they are not explicitly included in the production function. But once included, the upward bias of TFP growth is reduced. Finally, a number of studies focus on output elasticity of intangibles within an augmented Cobb-Douglas production framework. These mostly find a positive and significant effect of intangible capital or intangible investments (see *inter alia* Roth and Thum, 2013; Niebel et al., 2013; Chen et al., 2014; Corrado et al., 2014a,b). As a result of the growing research in this field, there is a increasing awareness that these assets are an important component that fuels economic growth (OECD, 2013, 2015). Consequently, policy makers are trying to encourage investment in these assets. This is most obvious with respect to R&D investments which are subsidized, directly or indirectly, by all European governments. In addition, policy makers are now aware that training, software, and other intangible assets are also important factors underlying economic success and societal prosperity.

The above mentioned literature, however, always implicitly assumes a specific substitutability between intangibles and other inputs. This is due to the fact that these studies rely on the Cobb-Douglas production function framework. Specifically, it is assumed that the substitution elasticity is equal to 1 between all inputs at any point on the production function.[1] This has important consequences for economic policy. If tangible capital and intangible capital were really such substitutes, it would not matter much in which assets the public sector invests. In other words, it would be sufficient if stimulus programs focus on investments in concrete, without also investing in intangibles. If, instead, intangibles and tangible capital are just weakly substitutable or even complements to each other, economic policy should support investments in both types of capital. The same reasoning holds for the substitutability between the various types of capital and labour. After all, what is an additional new school or hospital without staff?

The question of substitutability is not only relevant for general economic policy. It is particularly important for the non-market sector, because the state is the dominant actor in these industries, whether as the main employer, the main investor, or in providing crucial social services. Thus, this study focuses on the non-market sector and addresses the following research questions:

Is intangible capital a substitute or, to some degree, a complement for other inputs? Or in other words, what is the elasticity of substitution between intangible capital, tangible capital and labour?

The study contributes to existing literature on intangibles by being, as far as it can be determined, the first to analyse the elasticity of substitution of intangibles to other inputs. Thereby, it also tests the implicit assumption of the existing literature that the substitution elasticity between intangibles and tangibles is 1. It uses data from the SPINTAN database on intangible assets in non-market sectors and Eurostat data on tangible capital, labour and output. Output and tangible capital are adjusted for investment in intangibles. The estimations are conducted by means of nested CES production functions. The analysis reveals that intangible capital is just weakly substitutable with other inputs and that the substitution elasticity is significantly below 1. Thus, the assumption of the Cobb-Douglas approach is not supported.

The remainder of this paper is organized as follows. Section 2 describes the method and the estimation strategy, while Section 3 describes the database. The estimation results are presented in Section 4 and Section 5 concludes.

[1] Hence, a one percentage change in the ratio of input i and input j resulting from a one percentage change in the marginal rate of technical substitution at every point of the isoquant.

2 Method and Estimation Procedure

2.1 Nested CES-Production Functions

The starting point of the analysis is a production function that includes intangible capital as an additional input. This is based on the approach proposed by Griliches (1979), according to which knowledge capital is included as an additional input factor alongside labour and capital. Hence, we include intangible capital as a third input in the subsequent analysis, as Griliches (1979) did with R&D. In fact, all previous studies addressing the effect of intangible capital on growth or productivity growth, use intangibles as an additional input. However, when estimating the effects of intangibles, these studies rely on some form of an augmented Cobb-Douglas production function. We deviate from this literature for the following reason: The Cobb-Douglas function imposes an elasticity of substitution of 1 between any two inputs. Using an augmented Cobb-Douglas function is, therefore, inappropriate for the research question of this study. Instead, the production function has to be such that any substitution elasticities between any two inputs are possible.

Consequently, the analysis applies so-called Constant Elasticity of Substitution (CES) functions. The CES production function for labour and capital with Hick-neutral technological change is defined as follows:

$$Y_t = \gamma e^{\lambda t} \left(\delta_C C_t^{-\rho_{CL}} + (1 - \delta_C) L_t^{-\rho_{CL}} \right)^{-\frac{\nu}{\rho_{CL}}} \tag{1}$$

where L_t is labour input, C_t is tangible capital input, Y_t is gross value added, λ is the rate of Hick-neutral technological change over time, t is the time index, ρ_{CL} is the substitution parameter, δ_C determined the optimal distribution of the inputs, γ can be understood as a productivity parameter and ν measures the elasticity of scale. The elasticity parameter ρ can take any value between -1 and ∞. Based on these values, the elasticity of substitution between any two inputs i and j is derived as $\sigma_{ij} = 1/(1 + \rho_{ij})$. Hence, the elasticity of substitution in a CES production function can take any value between (approaching) zero and infinity.

There are three special cases: First, if $\rho \to 0$, the substitution elasticity approaches 1. This is the special case of the Cobb-Douglas production function. Second, if $\rho \to -1$, the substitution elasticity approaches infinity. In this case the production function tends to become linear, meaning that it is an additive production function; given that $\nu = 1$. Consequently, all inputs would be perfect substitutes for each other. Finally, in case that $\rho \rightarrow \infty$, the substitution elasticity approaches 0. This is the case if the production process is best described by a Leontief production function. This limitational production function is characterized by the fact that inputs are not substitutable for each other and that there is exactly one efficient input combination for a given level of output. It also follows that any increase of a factor input has no effect on the output as long as the other inputs are not increased accordingly.

Eq. (1) refers to a simple value added production function with labour and capital. The CES function for n-inputs, as described in Eq. (2), has the disadvantage that it assumes the elasticity of substitution between all inputs to be identical. This, however, is unlikely.

$$Y_t = \gamma e^{\lambda t} \left(\sum_{i=1}^{n} \delta_i X_{i,t}^{-\rho} \right)^{-\frac{\nu}{\rho}} \tag{2}$$

Sato (1967) proposes using a nested structure to construct CES functions with more than two inputs. Essentially, a nested CES function approach uses at least one additional CES function within an upper-level CES function. This, however, requires that the scale elasticity of the lower-level CES function and its productivity parameter is normalized to one. Additionally, the assumption that the inputs aggregated within the lower-level CES function share the identical substitution elasticity toward the other lower-level CES function or the third input is imposed. Finally, it must be kept in mind that the parameters of nested CES functions are not invariant to the chosen nesting structure.

Another issue are industry and county fixed effects. As seen in Eq. (1), industry or country dummies cannot be easily included in CES functions. To circumvent the assumption that all industries across all countries work under the same production function, sharing the same distribution parameters and substitution parameters, the estimation is conducted separately for each industry. Unfortunately, given the low number of observations per industry and country, it is not possible to do the estimations separately at the industry-country level. In order to tackle this issue, we follow a recent strand of literature and use geometric means to normalize each variable at country and industry level (de La Grandville, 1989; Klump and Preissler, 2000; Klump et al., 2007a,b, 2011). Eq. (3) shows the resulting three-input two-level nested CES function, for the combination $LC - I$ with I being intangible capital. Additional combinations are $CI - L$ (Eq. (4)) and $LI - C$ (Eq. (5)).

$$\tilde{Y}_t = \gamma_{CL-I} e^{\lambda_{CL-I} t} \left[\delta_{CL-I} \left(\delta_{CL} \tilde{C}_t^{-\rho_{CL}} + (1-\delta_{CL}) \tilde{L}_t^{-\rho_{CL}} \right)^{\frac{\rho_{CL-I}}{\rho_{CL}}} + (1-\delta_{CL-I}) \tilde{I}_t^{-\rho_{CL-I}} \right]^{-\frac{\nu_{CL-I}}{\rho_{CL-I}}} \tag{3}$$

$$\tilde{Y}_t = \gamma_{CI-L} e^{\lambda_{CI-L} t} \left[\delta_{CI-L} \left(\delta_{CI} \tilde{C}_t^{-\rho_{CI}} + (1-\delta_{CI}) \tilde{I}_t^{-\rho_{CI}} \right)^{\frac{\rho_{CI-L}}{\rho_{CI}}} + (1-\delta_{CI-L}) \tilde{L}_t^{-\rho_{CI-L}} \right]^{-\frac{\nu_{CI-L}}{\rho_{CI-L}}} \tag{4}$$

$$\tilde{Y}_t = \gamma_{LI-C} e^{\lambda_{LI-C} t} \left[\delta_{LI-C} \left(\delta_{LI} \tilde{L}_t^{-\rho_{LI}} + (1-\delta_{LI}) \tilde{I}_t^{-\rho_{LI}} \right)^{\frac{\rho_{LI-C}}{\rho_{LI}}} + (1-\delta_{LI-C}) \tilde{C}_t^{-\rho_{LI-C}} \right]^{-\frac{\nu_{LI-C}}{\rho_{LI-C}}} \tag{5}$$

with $\tilde{Y}_t = Y_t/\bar{Y}$, $\tilde{C}_t = C_t/\bar{C}$, $\tilde{L}_t = L_t/\bar{L}$ and $\tilde{I}_t = I_t/\bar{I}$. From these equations we will obtain the substitution elasticities for intangible capital with labour, with capital and with the CES function for labour and capital, i.e. σ_{CL-I}, σ_{CI}, σ_{LI}.

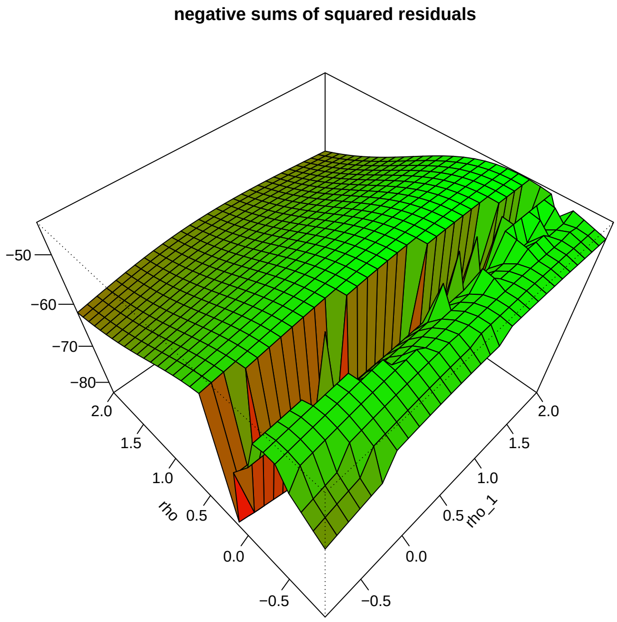
2.2 Estimation Procedure

The estimation procedure starts with a simple OLS estimation of Eq. (6) in order to gain an initial impression of whether intangible capital has any measurable influence within the production process. Hence, we start the analysis using an augmented Cobb-Douglas production function along the lines of Griliches (1979). Nevertheless we must keep in mind that this goes along with the restrictive assumption of a constant substitution elasticity of 1 between all inputs. In addition, using OLS requires the restrictive assumptions that TFP is unobservable to the firms and that the firms decide about their inputs without taking productivity into consideration. Without these assumptions, the well known simultaneity and endogeneity issue comes into play and any estimation of Eq. (6) by mean of OLS is biased (cf. Olley and Pakes, 1996; Levinsohn and Petrin, 2003; Ackerberg et al., 2006, 2007). However, we are only interested in gaining an initial impression of the importance of intangible capital and the OLS estimations serve as a form of an enhanced correlation analysis.

$$Y_{it} = C_{it}^{\alpha} L_{it}^{\beta} I_{it}^{\gamma} e^{\omega_{it}} e^{\epsilon_{it}} \tag{6}$$

After the initial estimation of Eq. (6), we start estimating Eq. (3) – Eq. (5). Due to the fact that the CES functions is non-linear in parameters, we cannot simply apply linear estimation techniques. Until the early 2000s the so-called Kmenta approximation was used to linearise CES functions and estimate its parameters. But this method is not without drawbacks. Thus, we follow a newer strand of the literature and estimate the parameters of the CES function directly by using optimization algorithms. The actual estimation is conducted using the micEconCES package developed by Henningsen and Henningsen (2011).

Figure 1: Example grid search

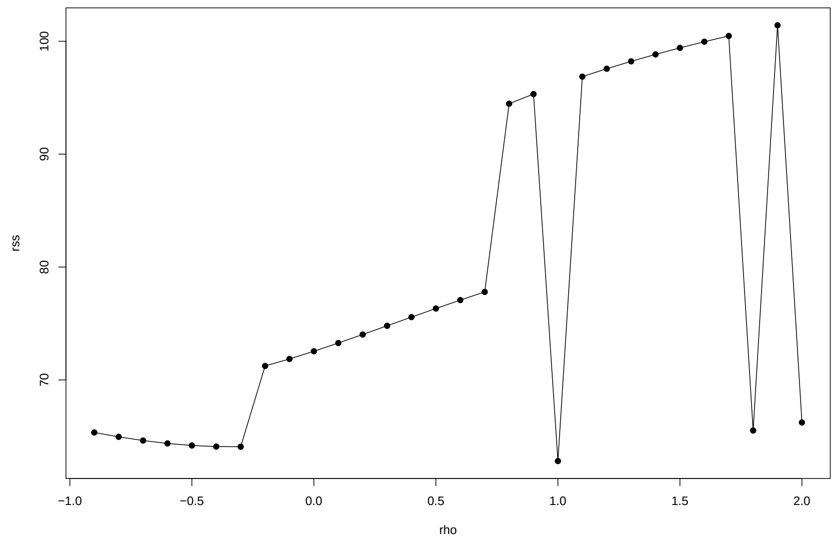


The optimization routines used by the *micEconCES* package and applied within our analysis are *Levenberg-Marquardt*, *PORT*, *BFGS*, and *L-BFGS-B*.[2] These routines aim at reducing the residual sum of square. Given that all parameters are estimated within one step, there are a multitude of possible solutions to the optimization problem. Depending on the starting point

[2] For details see Henningsen and Henningsen (2014) and Henningsen and Henningsen (2011). Other available routines are *Conjugate Gradients*, *Newton*, *Nelder-Mead*, *Simulated Annealing* and *Differential Evolution*. However, we run several tests showing that these methods do not perform as well as the methods mentioned above. Moreover, only *PORT* and *L-BFGS-B* allow setting upper and lower limits for parameters when conducting grid searches.

of the calculation, which is defined by a set of starting values – either the default starting values of the routines, or by self defined starting values – the routines potentially stop at local minimums. Therefore, we apply a grid search. Within a grid search, the routines runs across a set of predefined substitution parameters – i.e. ρ_{ij} and ρ_k for a CES function with three inputs – estimating the remaining parameters such that the residual sum of square is minimized. The corresponding minimum reveals where the global minimum can be found. Figure 1 shows an example in which the global minimum can be found in the area of around $\rho = -0.25$ and $\rho_1 = 1.5$.

Figure 2: Example ρ outliers



This approach also helps overcome the problem that a certain combination of parameter values might result in minimal sum of squares, but that such result is most likely an awkward outlier. Such an example is shown in Figure 2, where the algorithm finds that the substitution elasticity between two inputs is 0.5, given that the minimal sum of squared residuals is found for a set of parameters that include a ρ of 1. However, $\rho = 1$ rather looks like an outlier. As the figure shows, the robust CES production function has a substitution parameter of approximately -0.4.

But even the grid search cannot prevent economically unreasonable parameters. E.g. the optimal parameter combination might imply that the output is produced without using any labour input. This is clearly implausible. The estimation strategy therefore contains an additional step, in which a set of upper and lower values is defined for every parameter. These values are partly derived from the results of the OLS estimation.

Summing up, the estimation procedure contains three steps: (i) estimating Eq. (6) by means of OLS; (ii) estimating Eq. (3) to Eq. (5) without any restriction on the parameters but applying grid search; and (iii) estimating of Eq. (3) to Eq. (5) using grid search and economically meaningful boundaries for all parameters.

3 Data

3.1 Intangible Capital

The study uses data for intangible capital from the *SPINTAN* project. The project aims at providing a data set for intangible investment and intangible capital in public sectors. This comprises the industries *scientific research and development (ISIC4 code M72); public administration and defence, compulsory social security (ISIC4 code O); education (ISIC4 code P); human health and social work activities (ISIC4 code Q); human health activities (ISIC4 code Q86); residential care activities* plus *social work activities without accommodation (ISIC4 code Q87-Q88); creative, arts and entertainment activities* plus *libraries, archives, museums and other cultural activities* plus *gambling and betting activities (ISIC4 code R90-R92)*; and *arts, entertainment and recreation (ISIC4 code R)*. The data set contains information on the intangible assets *organizational capital, design, advertising, market research, training, R&D*, and *software*. R&D and software are available only at the one-digit industry level. The remaining intangible assets are available only at the two-digit sub-industries (except for industries O and P). The data set covers the 1995-2011 period. For a detailed description of the data collection, data production, measurement issues, and other issues see Bacchini et al. (2016) and Mas (2015). The data is downloadable at `http://http://www.spintan.net/`.

As we aim to analyze the substitution elasticity between intangible capital and other independent variables by means of a two-level nested CES function, we need to construct an aggregated intangible capital variable per industry and country in the first stage. However, because a considerable number of cells are not filled, a simple aggregation is not an option. Instead, we proceed industry by industry, excluding those observations for which one or more of the intangible assets is missing. In most cases, observations are dropped due to lack of observations for R&D. The calculation is conducted using the deflated capital stocks. After this initial step, the data set contain the full intangible capital stock for a set of 5 industries covering 16 countries. Table A.5 in the Appendix provides an overview per industry and country.

3.2 Labour, Tangible Capital and Gross Value Added

The SPINTAN database contains no data on labour, tangible capital, or output. We construct these variables using gross value added (GVA), gross fixed capital formation (GFCF), and the number of persons employed (EMP) at the one-digit industry level from Eurostat.[3] These data need to be modified for three reasons: First, R&D and software is included in both GFCF and intangible capital; thus the GFCF data must be adjusted. Second, the calculation of CES production functions requires a tangible capital stock, not just the GFCF. We approximate the capital stocks using the adjusted GFCF, the Perpetual Inventory Method (PIM), and depreciation rates from the EU KLEMS database. Third, the output needs to be adjusted for those intangible assets that are not included in national accounts.

In a first step, we reduce the GFCF by investments in R&D and software. The data on R&D and software investments are taken from the SPINTAN database. Subsequently, we follow Berlemann and Wesselhöft (2014) and Görzig and Gornig (2015) and use the investment level in t_0 for the calculation of the initial tangible capital stock by means of PIM. Industry specific depreciation rates and growth rates are taken from the EU KLEMS database (`http://www.euklems.net/`).[4] The initial capital stocks, the industry depreciation rates obtained from EU KLEMS, and the adjusted GFCF are then used to calculate the capital stock for the years following 1995.

Eventually, output needs to be adjusted upward if some of the expenditures are considered as intangible investments (Corrado et al., 2014b). This comes from the fact that the respective expenditures are no longer intermediates but capital expenditures. In this case, "they are not subtracted from gross output to obtain value added and they lead to the creation of new capital input. Moreover the own-account production leads to new output and newly owned capital with a (possibly implicit) rental payment. Thus the nominal value added has risen both because

[3] Because the number of observations for hours worked (HEMP) is considerably smaller than for number of persons employed, we refrain from using HEMP.

[4] For those countries not included in the latest EU KLEMS database, the industry mean of growth rates from all available countries in the EU KLEMS database is applied.

intermediate inputs are lower and because gross output is higher. The overall increase in nominal value added of industry j is equal to the additional nominal investment." (Corrado et al., 2014b, pp. 4) We follow Corrado et al. (2014b) and add deflated investment in intangibles, other than R&D and software, to deflated gross value added.[5,6]

The final data set with all required variables, i.e. intangible capital stock, labour, tangible capital stock and gross value added, contain 700 observations for 14 countries and four public industries. However, it is not a balanced panel and does not contain observations for all industries and years as shown in Table A.6. The descriptive statistics for each industry and variable are shown in Table 1.

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.

4 Estimation Results

Following the procedure outlined in Section 2.2, we start the analysis by estimating Eq. (6) in logs by means of OLS. The results in Table 2 are in line with expectations. Column (1)

[5] $P_V V_j = P_G G_J + P_N N_j^{OA} - (P_M M_j - P_N N_j^{PURCH})$, with $P_V V_j$ as value added of industry j, $P_G G_J$ as the value of gross output, $P_N N_j^{OA}$ as the value of own account intangible assets, $P_M M_j$ as value of intermediate input as reported by national accounts and $P_N N_j^{PURCH}$ as value of purchased intangible assets (Corrado et al., 2014b, pp. 4). Due to a lack of data, we have to ignore $P_N N_j^{OA}$ in the the adjustment of value added in this study.

[6] Due to the changes in national accounts following the implementation of SNA2008 and ESA2010, R&D and software are accounted as investments. Consequently, national accounts gross value added does not need to be adjusted for these two intangible assets.

contains the output elasticities without controlling for year, country or industry effects. In this specification, the coefficient for labour is 0.71, that of capital is 0.18, and the coefficient of intangible capital is 0.14. All coefficients are significant. This significance persists if we include year and industry dummies (2), although the output elasticities of tangible and intangible capital increases while that of labour decreases.. Apart from this deviation, the coefficients of tangible and intangible capital continuously decrease as we include year and country dummies (3), industry and country dummies (4), and all dummies (5). However, the coefficients remain significant in all specifications. This result is in line with previous findings in the literature in market sectors. However, this study is the first that confirms a positive elasticity for intangible capital in public sectors.

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.

Eq. (3) to Eq. (5) are estimated in the next step of the analysis. Although we do not impose restriction on the main production function parameters, such as the δ's, we restrict the range of possible substitution parameters from -0.9 to 2 with interval steps of 0.1. Consequently, the substitution elasticities can range from 10, indicating strong substitutability between two inputs, and $0.\overline{3}$, indicating weak substitutability; almost complementarity. This procedure is applied in order to limit computational time.

The results are shown in Table 3, where we present the substitution elasticity (σ_k) instead of the substitution parameter (ρ_k) due to lack of space.[7] Labour and tangible capital are found to be strong substitutes for each other (σ_{CL}) in industry P (row 2), but weak substitutes in

[7] The full result table is provided in Table A.8.

Table 3: 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	est. no.
O84	-0.004***	1.032***	0.447***	0.918***	1.57***	0.833	**0.4*** **	191	(1)
	(0.001)	(0.007)	(0.025)	(0.007)	(0.039)	(0.696)	(0.163)		
P85	-0.003***	1.023***	0.373***	1***	0.889***	10	**0.667**	191	(2)
	(0.001)	(0.009)	(0.037)	(0.016)	(0.067)	(148.04)	(6.0E+12)		
Q	0.009***	0.94***	0	0.862***	0.6***	1.429	**0.333*** **	159	(3)
	(0.002)	(0.013)	(0.124)	(0.041)	(0.06)	(1.7E+13)	(0.15)		
R	-0.005	1.04***	0	1***	0.901***	0.476	**1.25**	159	(4)
	(0.004)	(0.032)	(0.099)	(0.024)	(0.149)	(3.1E+13)	(6.2E+12)		
industry	λ_{CI-L}	γ_{CI-L}	δ_{CI}	δ_{CI-L}	ν_{CI-L}	σ_{CI}	σ_{CI-L}	N	
O84	-0.004***	1.031***	0.833***	0.492***	1.568***	**0.455*** **	0.769	191	(5)
	(0.001)	(0.007)	(0.013)	(0.024)	(0.039)	(0.171)	(0.55)		
P85	-0.003***	1.023***	1***	0.373***	0.889***	**0.385**	10	191	(6)
	(0.001)	(0.009)	(0.042)	(0.038)	(0.067)	(5.2E+13)	(147.563)		
Q	0.009***	0.94***	0	0.138	0.6***	**1.111**	0.333**	159	(7)
	(0.002)	(0.013)	(0.692)	(0.089)	(0.062)	(7.7E+12)	(0.3)		
R	-0.003	1.019***	23.348	0	0.836***	**1**	1.25	159	(8)
	(0.003)	(0.023)	(798.663)	(0.017)	(0.113)	(0.138)	(11.72)		
industry	λ_{LI-C}	γ_{LI-C}	δ_{LI}	δ_{LI-C}	ν_{LI-C}	σ_{LI}	σ_{LI-C}	N	
O84	-0.004***	1.031***	0.861***	0.592***	1.567***	**0.455** **	0.667	191	(9)
	(0.001)	(0.007)	(0.013)	(0.022)	(0.039)	(0.254)	(0.463)		
P85	-0.003***	1.023***	1***	0.627***	0.889***	**0.476**	10	191	(10)
	(0.001)	(0.009)	(0.025)	(0.038)	(0.067)	(2.5E+13)	(147.751)		
Q	0.009***	0.94***	0.862***	1***	0.6***	**0.333*** **	0.625	159	(11)
	(0.002)	(0.013)	(0.035)	(0.114)	(0.061)	(0.149)	(1.2E+13)		
R	-0.005	1.04***	1***	1***	0.901***	**0.476**	1.25	159	(12)
	(0.004)	(0.031)	(0.017)	(0.096)	(0.147)	(3.1E+13)	(6.2E+12)		

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*

industries O (row 1) and R (row 4). The results are mixed when considering the substitutability between intangible capital and the CES function for labour and capital (σ_{CL-I}), as well as between intangible capital and tangible capital (σ_{CI}), and between intangible capital and labour (σ_{LI}). We find a substitution elasticity close to 1 between intangible capital and the CES function for labour and capital in industry R (row 4) as well as between tangible capital and intangible capital in industries Q and R (row 7, 8). In the remaining 9 out of the 12 estimations, however, the substitution elasticities between intangible capital and the respective other inputs are below 1, indicating weak substitutability. Or in other words, the substitution elasticities deviate in most estimations from the Cobb-Douglas assumption of a substitution elasticity of 1, whereby it deviates mostly such that intangibles and the other respective inputs are weak substitutes for each other. This is a hint that the assumption of the Cobb-Douglas approach does not apply. However, it must be noted that only 6 of the total 24 substitution elasticities are significantly different from 1. In the remaining cases, we cannot rule out with statistical certainty that the elasticity of substitution is actually 1.

Table 4: 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	est. no.
O84	-0.004***	1.032***	0.447***	0.918***	1.57***	0.833	**0.400*****	191	(1)
	(0.001)	(0.007)	(0.025)	(0.007)	(0.039)	(0.696)	(0.163)		
P85	-0.002	1.015***	0.355***	0.95***	0.768***	10	**0.455**	191	(2)
	(0.001)	(0.009)	(0.047)	(0.023)	(0.07)	(191.961)	(0.371)		
Q	0.008***	0.942***	0.05	0.866***	0.599***	10	**0.333*****	159	(3)
	(0.002)	(0.014)	(0.152)	(0.041)	(0.065)	(2950.261)	(0.153)		
R	-0.003	1.022***	0.05	0.95***	0.811***	0.455	**2.5**	159	(4)
	(0.004)	(0.033)	(0.12)	(0.033)	(0.156)	(5.027)	(11.091)		
industry	λ_{CI-L}	γ_{CI-L}	δ_{CI}	δ_{CI-L}	ν_{CI-L}	σ_{CI}	σ_{CI-L}	N	
O84	-0.004***	1.031***	0.833***	0.492***	1.568***	**0.455*****	0.769	191	(5)
	(0.001)	(0.007)	(0.013)	(0.024)	(0.039)	(0.171)	(0.55)		
P85	-0.003**	1.019***	0.95***	0.371***	0.844***	**0.4**	10	191	(6)
	(0.001)	(0.009)	(0.05)	(0.04)	(0.068)	(0.89)	(176.338)		
Q	0.007***	0.95***	0.5	0.219**	0.628***	**0.333****	0.333*	159	(7)
	(0.002)	(0.014)	(0.319)	(0.103)	(0.064)	(0.315)	(0.381)		
R	-0.006	1.052***	0.95**	0.06	0.953***	**10**	0.526	159	(8)
	(0.004)	(0.033)	(0.416)	(0.081)	(0.148)	(3294.7)	(3.927)		
industry	λ_{LI-C}	γ_{LI-C}	δ_{LI}	δ_{LI-C}	ν_{LI-C}	σ_{LI}	σ_{LI-C}	N	
O84	-0.004***	1.031***	0.861***	0.592***	1.567***	**0.455****	0.667	191	(9)
	(0.001)	(0.007)	(0.013)	(0.022)	(0.039)	(0.254)	(0.463)		
P85	-0.002**	1.02***	0.95***	0.637***	0.816***	**0.385***	10	191	(10)
	(0.001)	(0.009)	(0.032)	(0.042)	(0.069)	(0.34)	(170.259)		
Q	0.008***	0.942***	0.86***	0.95***	0.602***	**0.333*****	10	159	(11)
	(0.002)	(0.014)	(0.037)	(0.13)	(0.062)	(0.211)	(3668.819)		
R	-0.003	1.025***	0.95***	0.95***	0.823***	**2.5**	0.333	159	(12)
	(0.004)	(0.033)	(0.03)	(0.115)	(0.156)	(10.481)	(2.675)		

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*

Unfortunately, some of the results in Table 3 lack economic credibility. This is apparent looking over the δ's: It would follow from $\delta_{CL} = 0$ in industries Q and R (row 3, 4) that the output is generated without any contribution of tangible capital. Similarly implausible coefficients can be found for δ_{CI} (row 7, 8), δ_{CI-L} (row 8), and for for δ_{LI-C} (row 11, 12). In addition, the standard deviation for many substitution elasticities, e.g. for tangible capital and labour in industries Q and R (row 3, 4), are outside normal ranges.

Because of these unsatisfying results we define upper and lower boundaries for all coefficients.

These boundaries are partly derived from the OLS results. *Inter alia*, the minimal coefficient for tangible capital in Table 2 is 0.066. Although the OLS results are potentially biased, we expect the coefficient for capital to not be below 0.05. Consequently, the maximum coefficient for labour should not exceed 0.95. Likewise, the maximal sum of the coefficients of intangible and tangible capital in Table 2 is 0.44 (column 2). Again, the coefficients might be potentially biased, but we do not expect them to exceed 0.5, thus defining the upper limit of δ_{CI} as being 0.5. We further proceed along this line of reasoning in defining upper and lower boundaries. The full set of boundaries is provided in Table A.7. Using these boundaries, Eq. (3) to Eq. (5) are again estimated using grid search.

Applying boundaries for all parameters improves the estimation considerably, as shown in Table 4. Not only are the δ's within economically reasonable boundaries, but the number of significant δ's also increases to 20. The effect on the substitution elasticities is also favourable. We can state that intangible capital is just weakly substitutable with labour, capital, or the respective nested CES function in 9 of the 12 estimations. In addition, in 7 of the 9 estimations elasticities are significantly smaller than 1. Admittedly though, only 8 out of all 24 substitution elasticities in Table 4 are significantly different from 1. This is due to the high standard deviation. Thus, other tests, like for H0=0, i.e. implying a Leontief production function, would also fail. However, the standard deviations are now, compared to the results in Table 3, mostly in reasonable ranges.

Summing up, our findings indicate weak substitutability between intangible capital and other inputs.

5 Conclusions

Stimulus programs were heavily used during the economic crisis of 2009. Policymakers are also discussing stimulation programs as a part of both the Growth Pact and the Investment Plan for Europe. It is important to understand the mechanisms of stimulus programs, but it is equally important to rethink the composition of such programs. This study tries to evaluate whether investments in intangible capital should be considered in any public investment program. To do so, we have to answer the following research questions: Is intangible capital a substitute or, to some degree, a complement for other inputs?

In order to answer this question, we create a data set of inputs and outputs in public sectors.

For this purpose, the newly developed SPINTAN database is used as it contains various types of intangible assets at the one-digit and two-digit industry levels. As the study makes use of nested CES production functions, the data are merged to create a single intangible capital variable per industry, which later can be applied in a three-input two-level nested CES function. The complete database is built with these SPINTAN data and data on value added, labour and gross fixed capital formation that are obtained from Eurostat. The tangible capital stock is derived by reducing official gross fixed capital formation by investments in R&D and software, two intangibles that are considered as intangibles but also captured within gross fixed capital formation, and applying the Perpetual Inventory Method. Additionally, value added is adjusted for investments in intangibles, because these investments are treated as intermediates in national accounting and are, therefore, not included in national accounts value added. The derived data set on intangible capital, tangible capital, labour, and value added serves as base for the analysis.

The econometric analysis starts with estimating an augmented Cobb-Douglas production function with intangible capital as additional input. Cyclical effects are controlled for by a time dummy, while additional dummies capture the industry specific and country specific fixed-effects. In these estimations, intangible capital is found to have a positive and significant output elasticity. Hence, investing in intangible capital increase the value added in public sectors. These estimates, like the entire econometric literature on the effects of intangibles, are based on the rigid assumptions of the Cobb-Douglas production function, *inter alia*, that any two inputs have a substitution elasticity of 1 at any point of the production function. In other words, the assumption of the Cobb-Douglas approach is that intangibles are rather easily substitutable with tangible capital or labour.

In order to test that assumption and to address the research question, we estimate three-input two-level nested CES production functions. This explicitly allows for any substitution elasticity. By normalizing and estimating the CES functions separately for each industry, it is ensured that industry specific or country specific effects that otherwise might distort the analysis are eliminated.

The analysis reveals that intangible capital is just weakly substitutable with tangible capital, labour, or the nested CES function for capital and labour. In other words, the substitution elasticity is noticeably below 1. This rejects the assumption of the Cobb-Douglas approach. This result is found in 9 of the 12 different estimations. The respective elasticities are significantly different from the assumed substitution elasticity of 1 in 7 of the 9 estimations. Thus, we can conclude that intangible capital is just weakly substitutable with other inputs, *inter alia*, tangible capital and intangible capital are weak substitutes for each other.

The implication of this finding for economic policy is straightforward. Public investment in the public sectors should not focus only on classical tangible assets, but part of the investment should go into intangible capital. That not only increases the output through the positive effect of intangible capital, but it is also required because intangibles and tangibles are weakly substitutable. An excessive focus on one input category will not lead to the expected results because the other inputs are also required, such as intangibles, in order to achieve the maximum output possible. From this finding it also follows that investment programs for tangible assets should not be undermined by austerity programs for intangible assets.

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Appendix

Table A.5: Intangible capital availability per country and industry

	Industry				
Country	M72	O	P	Q	R
AT	1995-2010	1995-2010	1995-2010	1995-2010	1995-2010
BE	1995-2010	1995-2010	1995-2010	-	-
CZ	1995-2010	-	1995-2010	-	1995-2010
DE	-	1995-2010	1995-2010	1995-2010	1995-2010
DK	1995-2010	1995-2010	1995-2010	1995-2010	1995-2010
ES	-	1995-2010	1995-2010	1995-2010	-
FI	1995-2010	1995-2010	1995-2010	1995-2010	1995-2010
FR	1995-2010	1995-2010	1995-2010	1995-2010	1995-2010
HU	1995-2010	-	1995-2010	-	-
IT	1995-2010	1995-2010	1995-2010	1995-2010	1995-2010
NL	1995-2010	1995-2010	1995-2010	1995-2010	1995-2010
PL	1995-2010	1995-2010	1995-2010	1995-2010	-
PT	1995-2010	1995-2010	1995-2010	1995-2010	1995-2010
SE	1995-2010	1995-2010	-	1995-2010	1995-2010
SI	-	1995-2010	-	-	-
UK	-	1995-2010	1995-2010	-	-

Source: SPINTAN database; own calculations.

Table A.6: 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.

Table A.7: 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 $k = \{CL - I, CI - L, LI - C\}$

Table A.8: Estimation results using GRID search without boundaries

industry	λ_{CL-I}	γ_{CL-I}	δ_{CL}	δ_{CL-I}	ρ_{CL}	ρ_{CL-I}	ν_{CL-I}	σ_{CL}	σ_{CL-I}	N	est. no.
O84	-0.004***	1.032***	0.447***	0.918***	0.2	1.5	1.57***	0.833	**0.4*** **	191	(1)
	(0.001)	(0.007)	(0.025)	(0.007)	(1.002)	(1.017)	(0.039)	(0.696)	(0.163)		
P85	-0.003***	1.023***	0.373***	1***	-0.9	0.5	0.889***	10	**0.667**	191	(2)
	(0.001)	(0.009)	(0.037)	(0.016)	(1.48)	(1.3E+13)	(0.067)	(148.042)	(6.0E+12)		
Q	0.009***	0.94***	0	0.862***	-0.3	2	0.6***	1.429	**0.333*** **	159	(3)
	(0.002)	(0.013)	(0.124)	(0.041)	(8.2E+12)	(1.347)	(0.06)	(1.7E+13)	(0.15)		
R	-0.005	1.04***	0	1***	1.1	-0.2	0.901***	0.476	**1.25**	159	(4)
	(0.004)	(0.032)	(0.099)	(0.024)	(1.3E+14)	(4.0E+12)	(0.149)	(3.1E+13)	(6.2E+12)		
sector	λ_{CI-L}	γ_{CI-L}	δ_{CI}	δ_{CI-L}	ρ_{CI}	ρ_{CI-L}	ν_{CI-L}	σ_{CI}	σ_{CI-L}	N	
O84	-0.004***	1.031***	0.833***	0.492***	1.2	0.3	1.568***	**0.455*** **	0.769	191	(5)
	(0.001)	(0.007)	(0.013)	(0.024)	(0.825)	(0.93)	(0.039)	(0.171)	(0.55)		
P85	-0.003***	1.023***	1***	0.373***	1.6	-0.9	0.889***	**0.385**	10	191	(6)
	(0.001)	(0.009)	(0.042)	(0.038)	(3.5E+14)	(1.476)	(0.067)	(5.2E+13)	(147.563)		
Q	0.009***	0.94***	0	0.138	-0.1	2	0.6***	**1.111**	0.333**	159	(7)
	(0.002)	(0.013)	(0.692)	(0.089)	(6.2E+12)	(2.697)	(0.062)	(7.7E+12)	(0.3)		
R	-0.003	1.019***	23.348	0	0	-0.2	0.836***	**1**	1.25	159	(8)
	(0.003)	(0.023)	(798.663)	(0.017)	(0.138)	(7.501)	(0.113)	(0.138)	(11.72)		
sector	λ_{LI-C}	γ_{LI-C}	δ_{LI}	δ_{LI-C}	ρ_{LI}	ρ_{LI-C}	ν_{LI-C}	σ_{LI}	σ_{LI-C}	N	
O84	-0.004***	1.031***	0.861***	0.592***	1.2	0.5	1.567***	**0.455** **	0.667	191	(9)
	(0.001)	(0.007)	(0.013)	(0.022)	(1.229)	(1.042)	(0.039)	(0.254)	(0.463)		
P85	-0.003***	1.023***	1***	0.627***	1.1	-0.9	0.889***	**0.476**	10	191	(10)
	(0.001)	(0.009)	(0.025)	(0.038)	(1.1E+14)	(1.478)	(0.067)	(2.5E+13)	(147.751)		
Q	0.009***	0.94***	0.862***	1***	2	0.6	0.6***	**0.333*** **	0.625	159	(11)
	(0.002)	(0.013)	(0.035)	(0.114)	(1.339)	(3.1E+13)	(0.061)	(0.149)	(1.2E+13)		
R	-0.005	1.04***	1***	1***	1.1	-0.2	0.901***	**0.476**	1.25	159	(12)
	(0.004)	(0.031)	(0.017)	(0.096)	(1.3E+14)	(4.0E+12)	(0.147)	(3.1E+13)	(6.2E+12)		

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*

Table A.9: Estimation results using GRID search with lower and upper boundaries

industry	λ_{CL-I}	γ_{CL-I}	δ_{CL}	δ_{CL-I}	ρ_{CL}	ρ_{CL-I}	ν_{CL-I}	σ_{CL}	σ_{CL-I}	N	est. no.
O84	-0.004***	1.032***	0.447***	0.918***	0.2	1.5	1.57***	0.833	**0.4*** **	191	(1)
	(0.001)	(0.007)	(0.025)	(0.007)	(1.002)	(1.017)	(0.039)	(0.696)	(0.163)		
P85	-0.002	1.015***	0.355***	0.95***	-0.9	1.2	0.768***	10	**0.455**	191	(2)
	(0.001)	(0.009)	(0.047)	(0.023)	(1.92)	(1.796)	(0.07)	(191.961)	(0.371)		
Q	0.008***	0.942***	0.05	0.866***	-0.9	2	0.599***	10	**0.333*** **	159	(3)
	(0.002)	(0.014)	(0.152)	(0.041)	(29.503)	(1.374)	(0.065)	(2950.261)	(0.153)		
R	-0.003	1.022***	0.05	0.95***	1.2	-0.6	0.811***	0.455	**2.5**	159	(4)
	(0.004)	(0.033)	(0.12)	(0.033)	(24.332)	(1.775)	(0.156)	(5.027)	(11.091)		
industry	λ_{CI-L}	γ_{CI-L}	δ_{CI}	δ_{CI-L}	ρ_{CI}	ρ_{CI-L}	ν_{CI-L}	σ_{CI}	σ_{CI-L}	N	
O84	-0.004***	1.031***	0.833***	0.492***	1.2	0.3	1.568***	**0.455*** **	0.769	191	(5)
	(0.001)	(0.007)	(0.013)	(0.024)	(0.825)	(0.93)	(0.039)	(0.171)	(0.55)		
P85	-0.003**	1.019***	0.95***	0.371***	1.5	-0.9	0.844***	**0.4**	10	191	(6)
	(0.001)	(0.009)	(0.05)	(0.04)	(5.564)	(1.763)	(0.068)	(0.89)	(176.338)		
Q	0.007***	0.95***	0.5	0.219**	2	2	0.628***	**0.333** **	0.333*	159	(7)
	(0.002)	(0.014)	(0.319)	(0.103)	(2.833)	(3.432)	(0.064)	(0.315)	(0.381)		
R	-0.006	1.052***	0.95**	0.06	-0.9	0.9	0.953***	**10**	0.526	159	(8)
	(0.004)	(0.033)	(0.416)	(0.081)	(32.947)	(14.177)	(0.148)	(3294.7)	(3.927)		
industry	λ_{LI-C}	γ_{LI-C}	δ_{LI}	δ_{LI-C}	ρ_{LI}	ρ_{LI-C}	ν_{LI-C}	σ_{LI}	σ_{LI-C}	N	
O84	-0.004***	1.031***	0.861***	0.592***	1.2	0.5	1.567***	**0.455** **	0.667	191	(9)
	(0.001)	(0.007)	(0.013)	(0.022)	(1.229)	(1.042)	(0.039)	(0.254)	(0.463)		
P85	-0.002**	1.02***	0.95***	0.637***	1.6	-0.9	0.816***	**0.385* **	10	191	(10)
	(0.001)	(0.009)	(0.032)	(0.042)	(2.298)	(1.703)	(0.069)	(0.34)	(170.259)		
Q	0.008***	0.942***	0.86***	0.95***	2	-0.9	0.602***	**0.333*** **	10	159	(11)
	(0.002)	(0.014)	(0.037)	(0.13)	(1.899)	(36.688)	(0.062)	(0.211)	(3668.819)		
R	-0.003	1.025***	0.95***	0.95***	-0.6	2	0.823***	**2.5**	0.333	159	(12)
	(0.004)	(0.033)	(0.03)	(0.115)	(1.677)	(24.079)	(0.156)	(10.481)	(2.675)		

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*