On the Elasticity of Substitution between Labor and ICT and IP Capital and Traditional Capital

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Abstract

I estimate a nested CES production function for 9 European countries over 1996-2020 using EU KLEMS data and distinguish between information and communication technologies (ICT), intellectual property (IP) capital, and traditional capital. I assume that aggregate output is produced using labor and these capital types, allowing for differences in the elasticities of substitution between labor, an aggregate of ICT and IP capital, and traditional capital. Results indicate that ICT and IP capital are gross complements, together they are gross substitutes for labor, whereas traditional capital is a gross complement. The results also imply that rapid technological progress and capital accumulation in ICT and IP capital explain most of the decline in labor income share. The imputed elasticity of substitution between labor and aggregate capital is below 1 but increases over time.

Keywords: CES Production Function; Elasticities of Substitution; System of Equations; ICT; IP Capital; Traditional Capital

JEL classification: E22; E25; J23; O33

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1 Introduction

Macroeconomic models typically incorporate explicit production technologies that combine labor and capital. The appropriateness of these models depends on the assumptions regarding the production technology including the elasticity of substitution between labor and capital and the direction of technological change.

I use data from the EU KLEMS database for a panel of 9 European countries and the 1996-2020 period and estimate a nested CES production function for total industrial value added together with the corresponding first order conditions. I assume that the production technology utilizes labor, an aggregate of information and communication technologies (ICT) and intellectual property (IP) capital, and the remainder of capital that I call traditional capital. IP capital includes software and patents and the assumption that ICT and IP capital enter into production jointly is motivated by, for example, that computers and software have a joint and complementary use. Moreover, the share of granted patents related to ICT in this period in sample countries was about 25% of the total, and patents related to ICT include methods of ICT applications, for example.

The estimate of the elasticity of substitution between labor and ICT and IP capital is greater than 1, implying that labor and ICT and IP capital are gross substitutes. The estimate of the elasticity of substitution between labor and traditional capital is below 1 implying that labor and traditional capital are gross complements. Similarly, the estimate of the elasticity of substitution between ICT and IP capital is below 1.

These results can help explain, for example, the dynamics of labor income share in sample countries. I consider a counter-factual scenario where there is no ICT- and IP-related technological progress and no ICT and IP capital accumulation in a simple accounting exercise that abstracts from potential equilibrium effects. I compare the predicted labor income share averaged across countries to the average labor income share. The results from this exercise imply that most of the fall in labor share can be attributed to the fast technological progress and extensive accumulation in ICT and IP capital. In turn, labor income share would have been much higher absent technological progress and accumulation in ICT.

Finally, I derive the elasticity of substitution between labor and aggregate capital from the nested CES production function with different types of capital and compute its values using the estimated values of the parameters of this function. The imputed elasticity of substitution between labor and aggregate capital is lower than 1, implying that labor and aggregate capital are gross complements, but it increases over the sample period. For comparison, I estimate the elasticity of substitution between labor and aggregate capital using data from the EU KLEMS database and following a similar methodology used for the estimation of the nested CES production function with several types of capital. The estimated value of the elasticity of substitution between labor and aggregate capital also appears to be below 1 but significantly higher than the imputed values of this parameter. This implies that the specification of the production function and aggregation of capital can play an important role in determining the value of the estimated elasticity of substitution between labor and aggregate capital.

The values of the elasticity of substitution and the direction of technological change are important for explaining, for example, movements in factor income shares (e.g., Caballero and Hammour, 1998, Karabarbounis and Neiman, 2014). A large number of studies that focus on labor share document that it has fallen. The literature offers competing explanations for this. Karabarbounis and Neiman (2014) use cross-country data and find that labor and capital are gross substitutes. They attribute the fall in labor income share to the rapid fall in prices of capital and capital deepening. Glover and Short (2020) use similar data and challenge these estimates showing that they can be upward biased because of omitted variables. Their estimates indicate that labor and capital are gross complements.[1] The estimates of Glover and Short (2020) suggest that alternative explanations might be in order for the fall in labor income share such as, for example, the rise in product-market concentration and import competition (Autor, Dorn, Katz, Patterson and van Reenen, 2017, Grossman, Helpman, Oberfield and Sampson, 2017).

A few recent studies provide an in-depth analysis of the fall in labor income share by

[1] Herrendorf, Herrington and Valentinyi (2015) also estimate a below one elasticity of substitution between labor and capital. Gechert, Havranek, Irsova and Kolcunova (2022) corroborate this evidence in their meta-analysis of 121 studies.

differentiating types of capital (Aum and Shin, 2024, Eden and Gaggl, 2018, 2019, Koh, Santaeulàlia-Llopis and Zheng, 2020). Eden and Gaggl (2018, 2019) attribute the fall in labor income share to the uptake of information and communication technologies (ICT) and the potential high substitutability of these technologies with labor because of, for example, the ease that routine tasks yield to automation (e.g., Acemoglu and Autor, 2011, Autor, Levy and Murnane, 2003, Jerbashian, 2019). ICT is a sum of ICT equipment and software in their study. They estimate the elasticity of substitution between labor and ICT using the first order conditions resulting from canonical firm's optimization problem similarly to, for example, Antràs (2004) and Karabarbounis and Neiman (2014).[2] In turn, Koh et al. (2020) perform an accounting exercise and show that the fall in labor income share can be attributed to the capitalization and the rise of compensation of intellectual property (IP) capital, R&D before 1980 and software after 1980.

A very recent and independent study by Aum and Shin (2024) differentiates between equipment and software capital and considers a CES production function that, in the first step, nests labor with equipment and, in the second step, nests this nest with software capital. Aum and Shin (2024) estimate first order conditions using firm-level data from South Korea. Their baseline estimation results suggest gross complementarity between equipment and labor and gross substitutability between software and labor, as well as gross substitutability between software and equipment. Moreover, falling software prices and increased use of software are largely responsible for the fall in labor income share in South Korea. According to Aum and Shin (2024), two equally important factors drive this result. First, software increasingly replaces labor. Second, production shifts toward firms that use software more intensively, as these firms become effectively more productive. These firms have higher markups and lower labor shares in their data. This reallocation further raises the aggregate markup and reduces the aggregate labor share.

This paper differs and contributes to these studies in multiple ways. First, I follow

[2] Krusell, Ohanian, Ríos-Rull and Violante (2000) and Ohanian, Orak and Shen (2023) estimate a nested CES production function with capital and labor inputs, and 2 levels of skills. They show that changes in factor inputs can account for most of the changes in skill premium in the US. Ohanian et al. (2023) also show that the incorporation of ICT capital in the production function can help to explain some of the movements in labor share. This study abstracts from levels of skills because of data limitations.

the approach developed and implemented by Grandville (1989), Klump, McAdam and Willman (2007), and León-Ledesma, McAdam and Willman (2010) and jointly estimate a normalized CES production function and first order conditions. The normalization is motivated by the observation that the elasticity of substitution is defined as a point elasticity and its identification needs benchmark values for the level of production and factor inputs and incomes. It represents the production function in a consistent indexed number form and facilitates the identification of parameters. León-Ledesma et al. (2010) use Monte Carlo simulations to provide comprehensive evidence regarding the superiority of this estimation method for identifying elasticities of substitution together with factor-biased technological change as compared to, for example, the estimation of first-order conditions only and a translog function. The use of this estimation method then can be especially relevant for this study because it attempts to identify these parameters for ICT that have been subject to exceptionally rapid technological progress. Motivated by the joint use of computers and software, I also assume that a CES aggregate between ICT equipment and IP capital, which includes software, is a separate capital input in the production function. I nest this aggregate with labor and then nest that with traditional capital. This allows me to estimate value added production function. Moreover, it allows me to compute the implied elasticity between labor and aggregate capital. The value of this elasticity is lower than 1 though the results suggest that the fall in labor income share can be entirely attributed to progress and accumulation in ICT and IP capital. This is consistent with the juxtaposition of the results of Aum and Shin (2024), Eden and Gaggl (2018, 2019), Karabarbounis and Neiman (2014), Glover and Short (2020), and Oberfield and Raval (2021). Finally, I draw on panel data from 9 European countries in the EU KLEMS database for my estimations. Computations based on EU KLEMS data for European Union countries (as well as the US) corroborate the findings of Koh et al. (2020), indicating that the share of capital (and labor) compensation would have remained constant if not for the increased compensation share of IP capital.

The next section describes the system of equations together with the method of estimation. Section 3 describes the data and its sources. Section 4 summarizes the results.

Section 5 concludes.

2 The Estimation Framework and Measurement

I consider a firm with an infinite lifespan that discounts its profits at the rate of return r and produces output Y using the following technology:

$$Y_t = \left[\varpi_{LIK}^{\frac{1}{\varepsilon_1}} LIK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{TK}^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_{TK} t} TK_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} \right]^{\frac{\varepsilon_1}{\varepsilon_1 - 1}}, \tag{1}$$

where

$$LIK_t = \left[\varpi_L^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + \varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} \right]^{\frac{\varepsilon_2}{\varepsilon_2 - 1}},$$

$$IK_t = \left[\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} \right]^{\frac{\varepsilon_3}{\varepsilon_3 - 1}},$$

and ϖ-s are share parameters, ε-s are Allen-Uzawa elasticity of susbstition parameters, γ-s are technological progress parameters, L is labor, K_{ICT} is ICT capital, K_{IP} is intellectual property capital, and TK is traditional capital.

The firm decides how much to invest in K_{ICT}, K_{IP} and TK taking the prices of investments p_{ICT}, p_{IP}, and p_{TK}, and interest rate r as given and solves the following problem:

$$\max_{\{L_t, I_{ICT,t}, I_{IP,t}, I_{TK,t}\}} \sum_{t=0}^{+\infty} \left(\frac{1}{1 + r_t} \right)^t \left(Y_t - w_t L_t - p_{ICT,t} I_{ICT,t} - p_{IP,t} I_{IP,t} - p_{TK,t} I_{TK,t} \right) \tag{2}$$

$s.t.$

$$I_{ICT,t} = K_{ICT,t+1} - (1 - \delta_{ICT}) K_{ICT,t},$$

$$I_{IP,t} = K_{IP,t+1} - (1 - \delta_{IP}) K_{IP,t},$$

$$I_{TK,t} = TK_{t+1} - (1 - \delta_{TK}) TK_t,$$

where $\delta_{ICT}, \delta_{IP}, \delta_{TK} \in (0, 1)$ are the rates of depreciation of ICT, IP, and traditional capital.

I denote by S_{LIK_t,Y_t} the share of labor, IP capital, and ICT capital compensation in value added and use S_{IK_t,LIK_t} and $S_{K_{ICT,t},IK_t}$ to denote the share of compensation of ICT and IP capital out of the compensation of labor and ICT and IP capital and the share of ICT capital compensation out of the compensation of ICT and IP capital:

$$
\begin{aligned}
S_{LIK_t,Y_t} &= \varpi_{LIK}^{\frac{1}{\varepsilon_1}} \left(\frac{LIK_t}{Y_t} \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}, \\
S_{IK_t,LIK_t} &= \varpi_{IK}^{\frac{1}{\varepsilon_2}} \left(\frac{IK_t}{LIK_t} \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}, \\
S_{K_{ICT,t},IK_t} &= \varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(\frac{e^{\gamma_{ICT} t} K_{ICT,t}}{IK_t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}.
\end{aligned}
$$

The first order conditions that follow from the firm's problem are given by

$$
\frac{r_{ICT,t} K_{ICT,t}}{Y_t} = S_{LIK_t,Y_t} S_{IK_t,LIK_t} S_{K_{ICT,t},IK_t}, \tag{3}
$$

$$
\frac{r_{IP,t} K_{IP,t}}{Y_t} = S_{LIK_t,Y_t} S_{IK_t,LIK_t} \left(1 - S_{K_{ICT,t},IK_t} \right), \tag{4}
$$

$$
\frac{w_t L_t}{Y_t} = S_{LIK_t,Y_t} \left(1 - S_{IK_t,LIK_t} \right), \tag{5}
$$

$$
\frac{r_{TK,t} TK_t}{Y_t} = \left(1 - S_{LIK_t,Y_t} \right), \tag{6}
$$

where

$$
r_{i,t} = \left[(1 + r_t)\, p_{i,t-1} - (1 - \delta_i)\, p_{i,t} \right], \tag{7}
$$

for $i \in \{ICT, IP, TK\}$. This equation is essentially a non-arbitrage condition that states that the rate of return on total capital (investment) is equal to the rate of return on a unit of capital of type $i \in \{ICT, IP, TK\}$, which was purchased at the price $p_{i,t-1}$, rented out for a period and resold.

The primary focus of this study is on the estimation of Allen-Uzawa elasticity of substitution parameters, ε, jointly with the technological change parameters, γ. I follow the approach developed by Grandville (1989), Klump et al. (2007) and León-Ledesma et al. (2010) in the estimation methodology. Specifically, this involves the joint estimation

of normalized versions of equations (1)-(6), where normalization is based on the sample averages of the variables (I use geometric averages as in Herrendorf et al., 2015).

I use α_1, α_2, and α_3 to denote the geometric averages of (1) the share of labor, IP capital, and ICT capital compensation in value added, (2) the share of labor compensation out of the compensation of labor and ICT and IP capital, and (3) the share of ICT capital compensation out of the compensation of ICT and IP capital:

$$\alpha_1 = \varpi_{LIK}^{\frac{1}{\varepsilon_1}} \overline{\left(\frac{LIK_t}{Y_t}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}}, \tag{8}$$

$$\alpha_2 = \varpi_{L}^{\frac{1}{\varepsilon_2}} \overline{\left(\frac{e^{\gamma_L t} L_t}{LIK_t}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}}, \tag{9}$$

$$\alpha_3 = \varpi_{ICT}^{\frac{1}{\varepsilon_3}} \overline{\left(\frac{e^{\gamma_{ICT} t} K_{ICT,t}}{IK_t}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}}}. \tag{10}$$

Using the expressions for α_1, α_2, and α_3, I write the logrithm of the normalized equation for output in the following way:

$$\ln \frac{Y_t}{\bar{Y}} = \frac{\varepsilon_1}{\varepsilon_1 - 1} \ln \left[\alpha_1 \left(\frac{LIK_t}{\overline{LIK_t}}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + (1-\alpha_1) \left(e^{\gamma_{TK}\hat{t}} \frac{TK_t}{\overline{TK_t}}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} \right], \tag{11}$$

where

$$\frac{LIK_t}{\overline{LIK_t}} = \left[\alpha_2 \left(e^{\gamma_L \hat{t}} \frac{L_t}{\overline{L_t}}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}} + (1-\alpha_2) \left(\frac{IK_t}{\overline{IK_t}}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}} \right]^{\frac{\varepsilon_2}{\varepsilon_2-1}},$$

$$\frac{IK_t}{\overline{IK_t}} = \left[\alpha_3 \left(e^{\gamma_{ICT}\hat{t}} \frac{K_{ICT,t}}{\overline{K_{ICT,t}}}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}} + (1-\alpha_3) \left(e^{\gamma_{IP}\hat{t}} \frac{K_{IP,t}}{\overline{K_{IPP,t}}}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}} \right]^{\frac{\varepsilon_3}{\varepsilon_3-1}},$$

and $\hat{t}$ is demeaned trend,

$$\hat{t} = t - \frac{1}{T}\sum t. \tag{12}$$

I further use the expressions for S_{LIK_t,Y_t} and S_{IK_t,LIK_t} and write the normalized first

order conditions in the following way:

$$\ln r_{ICT,t} - \ln \overline{r_{ICT,t}} = \left(1 - \frac{\varepsilon_3 - 1}{\varepsilon_3}\frac{\varepsilon_1}{\varepsilon_1 - 1}\right) \ln\left(\frac{S_{LIK_t,Y_t}}{\overline{S_{LIK_t,Y_t}}}\right) + \tag{13}$$
$$\left(1 - \frac{\varepsilon_3 - 1}{\varepsilon_1}\frac{\varepsilon_2}{\varepsilon_2 - 1}\right) \ln\left(\frac{S_{IK_t,LIK_t}}{\overline{S_{IK_t,LIK_t}}}\right) + \frac{\varepsilon_3 - 1}{\varepsilon_3}\gamma_{ICT}\hat{t} - \frac{1}{\varepsilon_3}\ln\left(\frac{K_{ICT,t}/\overline{K_{ICT,t}}}{Y_t/\overline{Y_t}}\right),$$

$$\ln r_{IP,t} - \ln \overline{r_{IP,t}} = \left(1 - \frac{\varepsilon_3 - 1}{\varepsilon_3}\frac{\varepsilon_1}{\varepsilon_1 - 1}\right) \ln\left(\frac{S_{LIK_t,Y_t}}{\overline{S_{LIK_t,Y_t}}}\right) + \tag{14}$$
$$\left(1 - \frac{\varepsilon_3 - 1}{\varepsilon_3}\frac{\varepsilon_2}{\varepsilon_2 - 1}\right) \ln\left(\frac{S_{IK_t,LIK_t}}{\overline{S_{IK_t,LIK_t}}}\right) + \frac{\varepsilon_3 - 1}{\varepsilon_3}\gamma_{IP}\hat{t} - \frac{1}{\varepsilon_3}\ln\left(\frac{K_{IP,t}/\overline{K_{IP,t}}}{Y_t/\overline{Y_t}}\right),$$

$$\ln w_t - \ln \overline{w_t} = \left(1 - \frac{\varepsilon_2 - 1}{\varepsilon_2}\frac{\varepsilon_1}{\varepsilon_1 - 1}\right) \ln\left(\frac{S_{LIK_t,Y_t}}{\overline{S_{LIK_t,Y_t}}}\right) + \frac{\varepsilon_2 - 1}{\varepsilon_2}\gamma_L\hat{t} - \frac{1}{\varepsilon_2}\ln\left(\frac{L_t/\overline{L_t}}{Y_t/\overline{Y_t}}\right), \tag{15}$$

$$\ln r_{TK,t} - \ln \overline{r_{TK,t}} = \frac{\varepsilon_1 - 1}{\varepsilon_1}\gamma_{TK}\hat{t} - \frac{1}{\varepsilon_1}\ln\left(\frac{TK_t/\overline{TK_t}}{Y_t/\overline{Y_t}}\right). \tag{16}$$

I use equations (11)-(16) in the empirical estimations. The value of r_t is needed for the estimations. The values of r_t can be obtained using the zero profit condition,

$$1 + r_t = \frac{Y_t - w_t L_t}{p_{ICT,t-1}K_{ICT,t} + p_{IP,t-1}K_{IP,t} + p_{TK,t-1}TK_t} + \tag{17}$$
$$\frac{(1 - \delta_{ICT})\, p_{ICT,t}K_{ICT,t} + (1 - \delta_{IP})\, p_{IP,t}K_{IP,t} + (1 - \delta_{TK})\, p_{TK,t}K_{TK,t}}{p_{ICT,t-1}K_{ICT,t} + p_{IP,t-1}K_{IP,t} + p_{TK,t-1}TK_t},$$

assuming the data contain information on real value added, labor compensation, and prices of investments, stocks and depreciation rates of ICT, IP, and traditional capital.

3 Data

The data are from the 2023 version of the EU KLEMS database for 9 European countries from the Euro Area (EA) and the 1996-2020 period for most of the countries. Panel A.1 of Table 1 offers the averages and initial and final sample values of the key variables used in the estimations. A few notable observations are in order. The prices of ICT investments relative to value added prices have fallen significantly during the study period. This contrasts with the prices of investments in IP and traditional capital and likely reflects the substantial technological advancements in ICT. Moreover, the stocks of ICT capital have increased at a much higher rate than the stocks of IP and traditional capital. As

reported in Table 2, the average yearly growth rate of ICT investment prices relative to value added prices in sample countries is -4.6%, whereas the corresponding growth rates for IP and traditional capital investments are -0.3% and 0.1%, respectively. The average yearly growth in real stock of ICT capital is 4.9% across sample countries, while the corresponding growth rates in real stocks of IP capital and traditional capital are 3.4% and 1.6%, respectively.

Table 1: Basic Statistics

Panel A.1

Variable	(1) Mean	(3) 1996	(4) 2020
Value Added, EUR, current, bn	839	627	804
Total Labor Income, EUR, current, bn	555	427	535
Total Hours Worked, bn	24	24	19
ICT Capital Stock, EUR, current, bn	27	25	24
IP Capital Stock, EUR, current, bn	131	83	150
TK Stock, EUR, current, bn	2876	2032	3025
Total Capital Stock (K), EUR, current, bn	3034	2139	3200
Value Added Price Index	0.902	0.739	1.080
ICT Investment Price Index	1.410	2.450	0.979
IP Investment Price Index	0.906	0.751	1.050
TK Investment Price Index	0.905	0.717	1.090
Total Capital (K) Investment Price Index	0.914	0.749	1.080

Panel A.2

Parameter	
δ_{ICT}	0.201
δ_{IP}	0.241
δ_{TK}	0.036

Panel B.1

Derived Variable	(1) Mean	(3) 1996	(4) 2020
r_{ICT}	0.518	1.310	0.237
r_{IP}	0.294	0.290	0.279
r_{TK}	0.085	0.081	0.075
w	25	24	27

Panel B.2

Derived Parameter	
α_1	0.709
α_2	0.923
α_3	0.212

Note: This table offers the averages and sample initial and final values of the variables used in estimations. Nominal variables are in national currency units (EUR). Price indices are normalized to 1 in 2015. Sample countries are Austria, Belgium, Finland, France, Germany, Italy, Netherlands, Portugal, and Spain and the period is from 1996-2020 except for Germany (1996-2019) and Portugal (2001-2020). Panel B.2 of Table 1 reports the computed values of α_1, α_2, and α_3 from equations (8), (9), and (10) averaged across countries. ICT capital includes information technologies (IT) and communication technologies (CT). IP capital includes software, organizational capital, and R&D capital. See Table A in the Data Description Appendix for complete descriptions and sources of variables.

Panel A.2 of Table 1 reports the computed annual rates of depreciation across the different types of capital. ICT and IP capital depreciate at very high rates of around 20% and 24%, respectively, whereas traditional capital depreciates at the rate of 3.6%. I use these figures and prices of investments in the types of capital to compute the rate of return on total capital and the rates of return on each type of capital from non-arbitrage

conditions (??)-(??) and the zero profit condition (17). Panel B.1 of Table 1 reports the results. The rate of return on traditional capital averaged across countries has fallen from 8.5% in 1996 to 8.1% in 2020. In turn, the rate of return on ICT capital was much higher in 1996 and fell much more sharply from 131% in 1996 to 24% in 2020. The computed rate of return on ICT capital is very large at the beginning of the sample period because of the observed sharp fall in ICT investment prices. Firms investing in ICT capital in a given year should have had high returns on it since they could have waited for a year and invested in it at much lower prices. The rate of return on ICT capital is comparable to the rate of return on IP capital in 2020 and these two are higher than the rate of return on traditional capital. However, the rates of return on these different types of capital are not that different in 2020 once the differences in depreciation rates are taken into account.

Table 2: Growth in Real Investment Prices and Capital Stocks

Variable	ICT	IP	TK	K
Investment Price Index	-0.046	-0.003	0.001	-0.001
Capital Stock	0.049	0.034	0.016	0.019

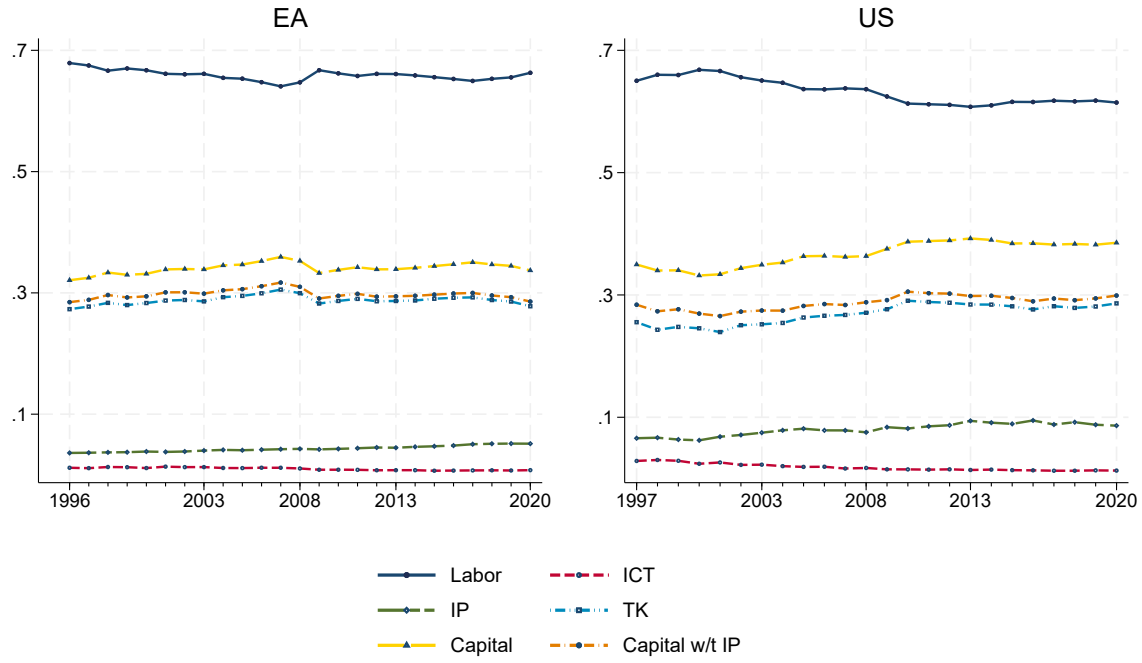
Note: This table offers the average annual growth rates in investment price indices for ICT, IP, and traditional capital (TK) as well as the average annual growth rates in (real) stocks of these types of capital. See Table A in the Data Description Appendix for complete descriptions and sources of variables.

Panel B.2 of Table 1 reports the computed values of α_1, α_2, and α_3 averaged across sample countries. The average share of labor, IP capital, and ICT capital compensation in value added is close to 71%. This value, together with the usual values of labor income share, suggests that labor compensation is much larger than the compensation of IP and ICT capital. The value of the average share of labor compensation out of the compensation of labor and ICT and IP capital α_2 reflects this as it is close to 92%. In turn, the average share of ICT capital compensation out of the compensation of ICT and IP capital is close to 21% implying that the compensation of ICT capital is much smaller than the compensation of IP capital.

Finally, Figure 1 illustrates labor income share and income shares of ICT, IP, and traditional capital in sample European countries (EA). I compute the latter using the

rates of return on ICT, IP, and traditional capital. Table 3 reports the values of these shares at the beginning of the sample period and the end. Figure 1 and Table 3 also offer these values for the US.[3]

Figure 1: The Shares of Compensation of Labor, ICT, IP Capital, and Traditional Capital



Note: This figure illustrates the shares of compensation of labor, ICT, IP capital, traditional capital, total capital, and capital without IP capital out of value added (Capital w/t IP) in sample countries European countries (EA) as well as in the US.

Labor income share has fallen during the sample period from about 68% to 66% in the sample European countries. This fall can be largely accounted for by the rise in the compensation share of IP capital. Labor income share would be virtually constant absent this raise, i.e., if either IP capital compensation or the raise in it could be attributed to labor income. A similar result holds for the US where labor income share has fallen by about 3.5 percentage points during the sample period and, absent the rise in intellectual property compensation share, it would have fallen by only 1.5 percentage points. These results corroborate the results of Koh et al. (2020) that the compensation share of labor/capital is virtually flat in the US absent the rise in the compensation of IP capital.

[3]Table I in the Data Appendix offers the basic statistics for each sample European country and the US.

Table 3: Sample Initial and Final Values of Income Shares

Panel A: European Countries (EA)

Year	Labor	ICT	IP	TK
1996	0.679	0.012	0.036	0.273
2020	0.663	0.008	0.051	0.278

Panel B: US

Year	Labor	ICT	IP	TK
1997	0.650	0.029	0.066	0.256
2020	0.615	0.013	0.086	0.286

Note: This table offers the average labor income share and income shares of ICT, IP, and traditional capital in sample European (EA) countries at the beginning of the sample period and the end. It also offers the values of labor income share and income shares of ICT, IP, and traditional capital in the US in 1997 and 2020 in Panel B. See Table A in the Data Description Appendix for complete descriptions and sources of variables.

Nevertheless, the share of joint compensation of ICT and IP does not increase as much as the compensation share of IP capital. Labor income share would still fall in European countries as well as in the US absent changes in these two, i.e., if either ICT and IP capital compensation or the raise in these two could be attributed to labor income.

4 Results

I employ the feasible generalized non-linear least-squares estimation method in all estimations, accounting for arbitrary heteroscedasticity and serial correlation in the residuals. I use the country-year-level shares of hours of employment out of the total hours of employment across sample countries as weights in these regressions. Further, I use multiple starting/initial points in estimations for the elasticity of substitution parameters and select the results that yield the best fit based on Log Likelihood, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and R-squared for each equation.[4]

Column 1 of Table 4 presents the results from the estimation of the system of equations (11), (13), (14), (15), and (16). The estimated elasticity of substitution between labor and traditional capital, ε_1, is 0.75 and it is statistically significantly below 1 implying

[4]In these estimations, I disregard results that produce excessively high values for the elasticities of substitution, as well as those with significantly negative values for γ_{ICT}.

that labor and traditional capital are gross complements. The estimated elasticity of substitution between labor and ICT and IP capital, ε_2, is 1.19 and it is statistically significantly above 1 implying that labor and ICT and IP capital are gross substitutes.[5] In turn, the estimate of the elasticity of substitution between ICT and IP capital, ε_3, is 0.96 and it is significantly below 1 implying that these two types of capital are gross complements.

The estimate of the labor augmenting technical change parameter γ_L is small and positive, 0.003. The estimate of the ICT capital augmenting technical change parameter γ_{ICT} is positive and γ_{ICT} is several orders of magnitude larger than γ_L. The high value of γ_{ICT} can possibly reflect the rapid technological progress in information and communication technologies. The estimate of IP capital augmenting technical change parameter γ_{IP} is negative and its absolute value is smaller than γ_{ICT}. In turn, the estimate of the traditional capital augmenting technical change parameter γ_{TK} is negative though small and statistically insignificant.

Several studies estimate a negative technical change parameter for (total) capital (e.g., Herrendorf et al., 2015, Mućk, 2017). Nevertheless, the negative values of γ_{IP} and γ_{TK} are not easily explained within a neoclassical framework. Such values suggest that the estimates of γ_{IP} and γ_{TK} might capture processes beyond technological progress. In this regard, a potential explanation can be that some parts of the accumulated IP and traditional capital may not be fully utilized in the near term, though the returns on these types of capital continue adhering to the non-arbitrage condition (7). Admittedly, equations (1) and (3)-(6) do not readily support this interpretation. Jiang and León-Ledesma (2018), drawing on data from De Loecker, Eeckhout and Unger (2020), incorporate variable markups into their estimation of value added function and first order conditions for labor and total capital. They show that this can reverse the negative sign of the estimate of (total) capital augmenting technological change. While promising, applying this strategy in the multi-country context of the current study is challenging due to data

[5] Eden and Gaggl (2018) have similar a finding for ICT capital that includes software using US data and single equation/first order condition with no biased technological progress parameters. Antràs (2004) shows that this can introduce an upward bias in the estimates of the elasticity of substitution.

Table 4: Estimation Results

A. Estimates

Parameter	(1) Main	(2) Eq. (18)	(3) Eq. (19)	(4) US
ε_1	0.745***	1.582***	1.212***	0.724***
	(0.009)	(0.142)	(0.045)	(0.024)
ε_2	1.187***	0.993***	1.127***	1.712***
	(0.010)	(0.004)	(0.015)	(0.133)
ε_3	0.961***	0.954***	0.969***	0.922***
	(0.003)	(0.004)	(0.003)	(0.017)
γ_L	0.003***	0.051***	0.009***	0.018***
	(0.001)	(0.003)	(0.001)	(0.001)
γ_{ICT}	0.725***	0.663***	0.880***	0.431***
	(0.065)	(0.045)	(0.099)	(0.119)
γ_{IP}	-0.111***	-0.167***	-0.101***	-0.113***
	(0.018)	(0.014)	(0.022)	(0.027)
γ_{TK}	-0.002	-0.103***	-0.021***	-0.020***
	(0.002)	(0.006)	(0.002)	(0.003)
Obs. (per eq.)	219	219	219	24

B. Measures of Fit

Log Likelihood	2262	2456	2177	301
AIC	-4510	-4898	-4341	-588
BIC	-4486	-4874	-4317	-580
R2				
$ln\left(Y_t/\overline{Y}\right)$	0.889	0.960	0.909	0.986
$ln\left(r_{ICT,t}/\overline{r_{ICT}}\right)$	0.864	0.872	0.861	0.987
$ln\left(r_{IP,t}/\overline{r_{IP}}\right)$	0.212	0.295	0.020	0.830
$ln\left(r_{TK,t}/\overline{r_{TK}}\right)$	0.638	0.617	0.968	-0.104
$ln\left(w_t/\overline{w}\right)$	0.968	0.873	0.867	0.935

Note: This table offers the results from the estimation of normalized and logarithmed production function together with the first order conditions. Panel *A* offers the estimates of the parameters and the corresponding number of observations in each equation. Sample years are given by the availability of data in the EU KLEMS database. Panel *B* offers various measures of fit including Log Likelihood, AIC, BIC, and R-squared of each equation. Column 1 offers the main results from the estimation of equations (11), (13), (14), (15), and (16). Columns 2 and 3 offer results from the estimation of other CES nests, (18) and (19) [see Technical Appendix for the first order conditions in these columns]. Column 4 offers results from the estimation of (11), (13), (14), (15), and (16) for the US. Negative R-squared in an equation means that the residual sum of squares is larger than the total sum of squares in that equation. Figure I shows the fit for the first equation in European countries and the US. All regressions use the feasible generalized non-linear least-squares estimation method and the country-year-level shares of hours of employment out of the total hours of employment across sample countries as weights. Initial/starting points for estimations are $\varepsilon_i = \{0.5, 1.5\}$ for $i = 1, 2, 3$ and $\gamma_j = 0.02$ for $j = L, ICT, IP, TK$ in columns 1-3 and the estimates from column 1 in column 4. Standard errors are in parentheses and are robust to arbitrary heteroscedasticity and serial correlation. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The Data Description Appendix offers further details about the data.

limitations. Moreover, the results of this study suggest the need to measure markups that vary across different types of capital, such as IP and traditional capital. A further potential drawback is that the data used in this study come from a single source

that ensures consistency across variables and introducing markup measures from external sources could raise additional measurement concerns.

4.1 The Elasticity of Substitution between Labor and ICT and IP Capital: Alternative Nests

I follow the literature on automation and labor demand and write the CES nests in equation (1) so that the production function permits a difference in the elasticities of substitution between labor and traditional capital and labor and ICT and IP capital (e.g., Acemoglu and Autor, 2011, Acemoglu and Restrepo, 2018, Aum, Lee and Shin, 2018). By construction, the elasticity of substitution between labor and traditional capital and the elasticity of substitution between ICT and IP capital and traditional capital are the same in equation (1). A rationale for this is that the aggregate of ICT and IP capital, being a substitute for labor, is used in tasks that can be performed by labor (e.g., routine tasks). I explore two alternative nests in this section to assess the elasticity of substitution between labor and ICT and IP capital. To save space, I will reuse the letters ε and γ and their indices albeit this involves an abuse of notation. In particular, ε_i for $i = 1, 2, 3$ will correspond to the i-th nest starting from the most outer nest, while γ_j for $j = L, ICT, IP, TK$ will pertain to the corresponding factor input.

First, I assume that the elasticity of substitution between labor and ICT and IP capital is equal to the elasticity of substitution between traditional capital and ICT and IP capital. Moreover, the aggregate of ICT and IP capital is either a complement or a substitute for the combination of labor and traditional capital. I further assume that the production function is given by

$$Y_t = \left(\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} \right)^{\frac{\varepsilon_1}{\varepsilon_1 - 1}}, \tag{18}$$

where

$$LTK_t = \left[\varpi_L^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_L t} L_t\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}\right]^{\frac{\varepsilon_2}{\varepsilon_2-1}},$$
$$IK_t = \left[\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}}\right]^{\frac{\varepsilon_3}{\varepsilon_3-1}}.$$

I estimate the parameters using normalized and logarithmed Y_t from equation (18) and the corresponding normalized and logarithmed first order conditions [see equations (35)-(39) in the Technical Appendix]. Column 2 of Table 4 reports the results. The estimated elasticity of substitution between labor, as well as traditional capital, and the CES aggregate of ICT and IP capital, ε_1, is large and significantly above 1. Similarly to the results from column 1, the estimates of ε_2 and ε_3 imply that the pairs of traditional capital and labor and ICT and IP capital are gross complements. The estimates of the parameters γ are also in line with the results from column 1 with a few notable differences. The estimate of γ_L is now 0.05 and the estimate of γ_{TK} is negative and large in absolute value, -0.1.

Another specification nests first the different types of capital and then nests these with labor. It is given by

$$Y_t = \left[\varpi_L^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_L t} L_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + \varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1-1}{\varepsilon_1}}\right]^{\frac{\varepsilon_1}{\varepsilon_1-1}}, \tag{19}$$

where

$$IKTK_t = \left[\varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2-1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}\right]^{\frac{\varepsilon_2}{\varepsilon_2-1}},$$
$$IK_t = \left[\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}}\right]^{\frac{\varepsilon_3}{\varepsilon_3-1}}.$$

This specification can be thought to be a generalization of a specification that combines total capital, K, with labor as it permits imperfect substitutability between different types of capital as well as well as technological change parameters specific to each type of capital.

Column 3 of Table 4 reports the results from the estimation of the normalized and logarithmed Y_t from equation (19) and the corresponding normalized and logarithmed first order conditions [see equations (45)-(49) in the Technical Appendix]. The estimated elasticity of substitution between labor and the CES aggregate of ICT, IP and traditional capital, ε_1, is large and significantly above 1. The estimates of ε_2 imply that traditional capital and the CES aggregate of ICT and IP capital are gross substitutes and that ICT and IP capital are gross complements. Similarly to the results in column 2, the estimates of the parameters γ are in line with the results from column 1.

The results from estimations of these two CES nests, similar to the main results, suggest that ICT and IP capital are gross substitutes for labor. Admittedly, these nests seem to be less appealing than the nest in (1) as they are not strongly in line with the literature on automation and labor demand and imply a gross substitutability between traditional capital and the aggregate of ICT and IP capital.

Taken together, these results can have important implications for the dynamics of labor income share. They can also have implications regarding the elasticity of substitution between labor and aggregate capital.

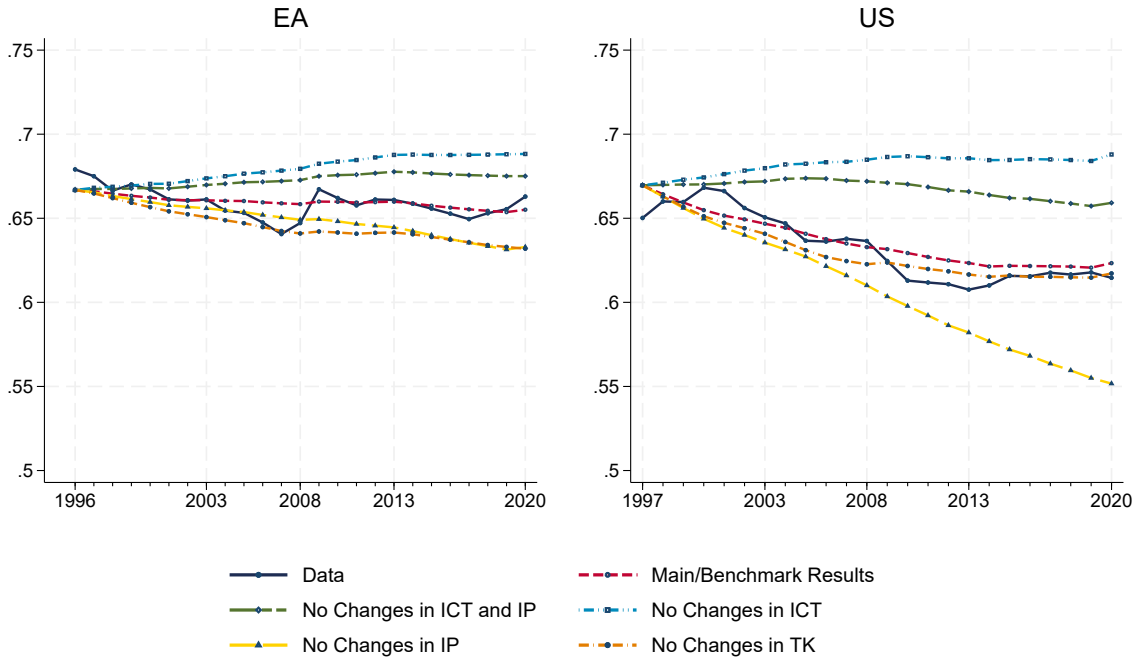
4.2 Labor Income Share

The labor income share has fallen during the sample years in European countries as well as in the US according to Table 3. This fall is visible in Figure 2 which offers the variation in labor income share in the EU KLEMS data as well as the predicted labor income share using equation (5) and parameter estimates from column 1 of Table 4 for European countries (EA). It also illustrates labor income share in the US and its predicted values using parameter estimates from column 5 of Table 4. In this column, I present the results from the estimation of equations (11), (13), (14), (15), and (16) using US data from the EU KLEMS database.[6] These results slightly under-predict the fall in labor share in European countries and over-predict it in the US but are very close to the data. Panel A of Table 3 provides the exact numbers.

[6]The results for the US are sensitive to the choice of initial values in the estimation, possibly due to the very limited sample size.

Figure 2 and Panel B of Table 3 also offer simple counterfactual predictions for cases when there is no technological progress and accumulation/changes in (1) ICT and IP capital, (2) ICT, (3) IP capital, and (4) traditional capital. I fix the corresponding trend index to its sample initial value to have no technological progress and set the value of capital stock equal to its sample initial value to have no changes in it. A rough interpretation of the counterfactual exercise, for example, for ICT is that it corresponds to fixing the number of computers and their productivity.[7]

Figure 2: Labor Income Share: Data, Predicted, and Counterfactual



Note: This figure illustrates the labor income share in European countries (EA) and in the US computed using the data from the EU KLEMS database. It also illustrates the predicted labor income share using equation (5) and parameter estimates from columns 1 and 5 of Table 4 for European countries and the US, correspondingly. The counterfactual predictions are for cases when there is no technological progress and changes in (1) ICT and IP capital, (2) ICT, (3) IP capital, and (4) traditional capital. The corresponding trend index is fixed to its sample initial value to have no technological progress in the type of capital and the value of capital stock is set equal to its sample initial value to have no changes in its level. The averages across European countries are weighted by the country-year-level shares of employment hours out of the total hours of employment across sample European countries.

These counterfactual exercises suggest that rapid technological progress and the accumulation of ICT and IP capital have been key factors in the decline of the labor income share according to column 1 of Panel B in Table 3. Absent these developments, the labor

[7]These counterfactual exercises do not accommodate potential adjustments in the supply of the free factors of production.

income share would have slightly increased in European countries and declined by about 75% less in the US over the sample period. This is consistent with the results of, for example, Aum and Shin (2024), Eden and Gaggl (2018), Ohanian et al. (2023), and Koh et al. (2020).

Columns 2-3 offer the results from counterfactual predictions for cases when there is no technological progress and changes in ICT, IP capital, and traditional capital separately. These results further suggest that the key factors in the decline in labor income share are rapid technological progress and changes/accumulation in ICT. Absent these advances, the labor income share would have significantly increased in European countries over the sample period.[8] It would have also increased in the US albeit less. In turn, labor income share would have declined substantially more absent trends corresponding to IP and traditional capital in European countries.

4.3 The Elasticity of Substitution between Labor and Aggregate Capital

What do the estimates of the elasticities of substitution in column 1 of Table 4 imply regarding the elasticity of substitution between labor and total/aggregate capital? In an attempt to answer this question, I write the level of aggregate capital in the following way

$$K = \frac{r_{K_{ICT}}}{r} K_{ICT} + \frac{r_{K_{IP}}}{r} K_{IP} + \frac{r_{TK}}{r} TK, \tag{20}$$

and assume that output with aggregate capital is represented as a function $f(L, K)$ with the following properties

$$f(L, K) = Y(L, K_{ICT}, K_{IP}, TK), \tag{21}$$

[8] A similar inference holds with the alternative nests as reported in Table II in the Data Appendix.

Table 5: Labor Income Share: Data, Predicted, and Counterfactual

A. Data and Main/Benchmark Prediction

European Countries (EA)

Year	(1) Data	(2) Main
1996	0.666	0.655
2020	0.647	0.642

US

Year	(1) Data	(2) Main
1997	0.650	0.670
2020	0.615	0.623

B. Counterfactual: No Technological Progress and Capital Accumulation

European Countries (EA)

Year	(1) ICT and IP	(2) ICT	(3) IP	(4) TK
2020	0.675	0.688	0.633	0.632
% of Predicted $\Delta_{2020-1996}$	-0.667	-1.750	2.833	2.917

US

Year	(1) ICT and IP	(2) ICT	(3) IP	(4) TK
2020	0.670	0.688	0.552	0.617
% of Predicted $\Delta_{2020-1997}$	0.000	-0.383	2.511	1.128

Note: Panel A of this table offers sample initial and final values of the labor income share in European countries (EA) and in the US computed using the data from the EU KLEMS database in. It also offers the predicted labor income share using equation (5) and parameter estimates from columns 1 and 5 of Table 4 for European countries and the US, correspondingly. Panel B of this table offers results from counterfactual prediction. The counterfactual predictions are for cases when there is no technological progress and changes in (1) ICT and IP capital, (2) ICT capital, (3) IP capital, and (4) traditional capital. The corresponding trend index is fixed to its sample initial value to have no technological progress in the type of capital and the value of capital stock is set equal to its sample initial value to have no changes in its level. The averages across European countries are weighted by the country-year-level shares of employment hours out of the total hours of employment across sample European countries.

where Y is given by equation (1), and

$$\frac{\partial f}{\partial L}L = \frac{\partial Y}{\partial L}L, \tag{22}$$

$$\frac{\partial f}{\partial K}K = \frac{\partial Y}{\partial K_{ICT}}K_{ICT} + \frac{\partial Y}{\partial K_{IP}}K_{IP} + \frac{\partial Y}{\partial TK}TK. \tag{23}$$

Given these assumptions, it is straightforward to show that the elasticity of substitution between labor and aggregate capital is given by

$$\varepsilon_{L,K} = \frac{1}{\tilde{S}\frac{1}{\varepsilon_2} + \left(1-\tilde{S}\right)\frac{1}{\varepsilon_1}} \tag{24}$$

where

$$\tilde{S} = \frac{S_{IKL}}{S_{IKL}S_{LIKTK} + (1 - S_{LIKTK})}, \tag{25}$$

$$S_{IKL} = \frac{(1-\alpha_2)\left(\frac{IK_t}{\overline{IK_t}}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}}{\alpha_2\left(e^{\gamma_L \hat{t}}\frac{L_t}{\overline{L_t}}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}} + (1-\alpha_2)\left(\frac{IK_t}{\overline{IK_t}}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}}, \tag{26}$$

$$S_{LIKTK} = \frac{\alpha_1\left(\frac{LIK_t}{\overline{LIK_t}}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}}{\alpha_1\left(\frac{LIK_t}{\overline{LIK_t}}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + (1-\alpha_1)\left(e^{\gamma_{TK}\hat{t}}\frac{TK_t}{\overline{TK_t}}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}}, \tag{27}$$

$\tilde{S} \in (0,1)$ and S_{IKL} is the share of IK in the compensation of IK and labor and S_{LIKTK} is the share compensation of labor and IK out of value added.

The equation for $\varepsilon_{L,K}$ (24) implies that if the elasticities of substitution between labor and capital are the same for the traditional capital and the aggregate of ICT and IP capital, $\varepsilon_1 = \varepsilon_2$, then the elasticity of substitution between aggregate capital is not different than these two, $\varepsilon_{L,K} = \varepsilon_1 = \varepsilon_2$. Moreover, it implies that $\partial\varepsilon_{L,K}/\partial\varepsilon_1 > 0$, $\partial\varepsilon_{L,K}/\partial\varepsilon_2 > 0$, and

$$\varepsilon_{L,K} \in \left(\min\left\{\varepsilon_1, \varepsilon_2\right\}, \max\left\{\varepsilon_1, \varepsilon_2\right\}\right), \tag{28}$$

so that, for example, when $\varepsilon_2 > \varepsilon_1$ then $\varepsilon_{L,K} > \varepsilon_1$.[9]

I use equations (24)-(27) and the estimated values of parameters from column 1 of

[9]It also implies that $\partial\varepsilon_{L,K}/\partial S_{IKL} > 0$ and $\partial\varepsilon_{L,K}/\partial S_{LIKTK} > 0$ iff $\varepsilon_2 > \varepsilon_1$ and $\lim_{S_{IKL}\to 1}\varepsilon_{L,K} = \lim_{S_{LIKTK}\to 1}\varepsilon_{L,K} = \varepsilon_2$.

Table 4 to compute the value of $\varepsilon_{L,K}$ for each sample year taking the (weighted) average across sample European countries. Column 1 of Table 6 offers the results. The values of the elasticity of substitution between labor and aggregate capital are considerably lower than 1 and are in line with the estimates reported by Herrendorf et al. (2015) and Oberfield and Raval (2021), for example. They are also considerably lower than the estimated ε_1 in column 3 of Table 4, which can be interpreted as the elasticity of substitution between labor and aggregate capital, where aggregate capital is a CES composite of traditional, ICT, and IP capital (these latter values align with the estimates reported by Karabarbounis and Neiman, 2014). The elasticity of substitution $\varepsilon_{L,K}$ also varies over time due to changes in compensation shares S_{LIKTK} and S_{IKL}. It has increased over the sample period in European countries.[10]

I have used the values of all the estimated parameters from column 1 of Table 4 to compute the values of compensation shares (26) and (27). I compute data counterparts of the compensation shares using the computed rates of return on different types of capital (7), recompute the elasticity of substitution between labor and aggregate capital using these shares and present the results in column 2 of Table 4. The values in column 2 are essentially the same as those in column 1 except for higher variability.

I also compute the elasticity of substitution between labor and aggregate capital for the US using equations (24)-(27) and parameter estimates from column 5 of Table 4 as well as the data counterparts of compensation shares for the US. I offer the results in columns 3 and 4 of Table 6. The values of $\varepsilon_{L,K}$ tend to be larger in the US than in the European countries similarly to the estimate of ε_2. Moreover, $\varepsilon_{L,K}$ increases from 1997 to 2010 in the US and falls afterward.

For comparison, I estimate a function that combines total capital K with labor and

[10]Similar computations yield an imputed elasticity of substitution between aggregate capital and labor slightly larger than 1 when using the production function in equation (18) and parameter estimates from column 2 of Table 4. Appendix - Imputed Elasticity of Substitution offers further results for the imputed elasticities of substitution.

Table 6: The Imputed Elasticity of Substitution between Labor and Aggregate Capital

	European Countries (EA)		US	
Year	(1) Main/Benchmark	(2) Data	(3) Main/Benchmark	(4) Data
1996	0.804	0.807		
1997	0.805	0.806	0.888	0.915
1998	0.806	0.809	0.893	0.925
1999	0.806	0.809	0.898	0.915
2000	0.807	0.808	0.902	0.904
2001	0.806	0.810	0.908	0.922
2002	0.807	0.810	0.912	0.915
2003	0.808	0.812	0.916	0.922
2004	0.809	0.810	0.920	0.924
2005	0.809	0.809	0.923	0.923
2006	0.810	0.810	0.925	0.918
2007	0.810	0.811	0.924	0.912
2008	0.811	0.810	0.926	0.907
2009	0.812	0.809	0.928	0.916
2010	0.813	0.810	0.929	0.908
2011	0.813	0.810	0.926	0.914
2012	0.814	0.812	0.923	0.919
2013	0.815	0.811	0.921	0.930
2014	0.815	0.813	0.918	0.926
2015	0.815	0.813	0.912	0.922
2016	0.815	0.814	0.910	0.933
2017	0.815	0.817	0.905	0.918
2018	0.816	0.819	0.901	0.926
2019	0.816	0.819	0.898	0.919
2020	0.813	0.821	0.900	0.914

Note: Column 1 of this table offers the values of $\varepsilon_{L,K}$ computed using equations (24)-(27) and estimated values of parameters from column 1 of Table 4. Column 2 computes the value of $\varepsilon_{L,K}$ using the data counterparts of S_{IKL} and S_{LIKTK}. Columns 3 and 4 present the results for the US. The averages across European countries are weighted by the country-year-level shares of employment hours out of the total hours of employment across sample European countries. Figure II in the Data Appendix illustrates these values. The Data Description Appendix offers further details about the data.

is given by

$$Y_t = \left[\varpi_L^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_K^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_K t} K_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} \right]^{\frac{\varepsilon_1}{\varepsilon_1 - 1}}, \tag{29}$$

where K includes all types of capital. I consider 3 cases for ε_1 in (29): (1) ε_1 is constant (CES); (2) it linearly depends on the shares S_{LIKTK} and S_{IKL}; and (3) it is a quadratic polynomial of time. I estimate the parameters in equation (29) for all sample countries using normalized and logarithmed Y_t from equation (29) and the corresponding normalized and logarithmed first order conditions [see equations (51), (52) and (53) in

the Technical Appendix].

Table 7: The Estimated Elasticity of Substitution and Aggregate Capital

A. Estimates

	European Countries (EA)			US		
Parameter	(1) CES	(2) Shares	(3) Polynomial	(4) CES	(5) Shares	(6) Polynomial
ε_1	0.984***	1.242***	0.988***	0.930***	3.195***	0.915***
	(-0.003)	(-0.078)	(-0.004)	(-0.015)	(-0.442)	(-0.013)
γ_L	0.052***	0.055***	0.054***	0.055***	0.066***	0.064***
	(-0.004)	(-0.004)	(-0.004)	(-0.010)	(-0.010)	(-0.008)
γ_K	-0.091***	-0.097***	-0.096***	-0.082***	-0.102***	-0.100***
	(-0.008)	(-0.008)	(-0.007)	(-0.018)	(-0.018)	(-0.014)
$\varepsilon_{1,S_{LIKTK}}$		-0.509***			-2.613***	
		(-0.118)			(-0.536)	
$\varepsilon_{1,S_{IKL}}$		1.417***			-2.813***	
		(-0.232)			(-0.659)	
$\varepsilon_{1,t}$			0.003**			-0.013***
			(-0.001)			(-0.003)
ε_{1,t^2}			0.0000			0.001***
			(0.0000)			(0.000)
Obs. (per eq.)	219	219	219	24	24	24

B. Measures of Fit

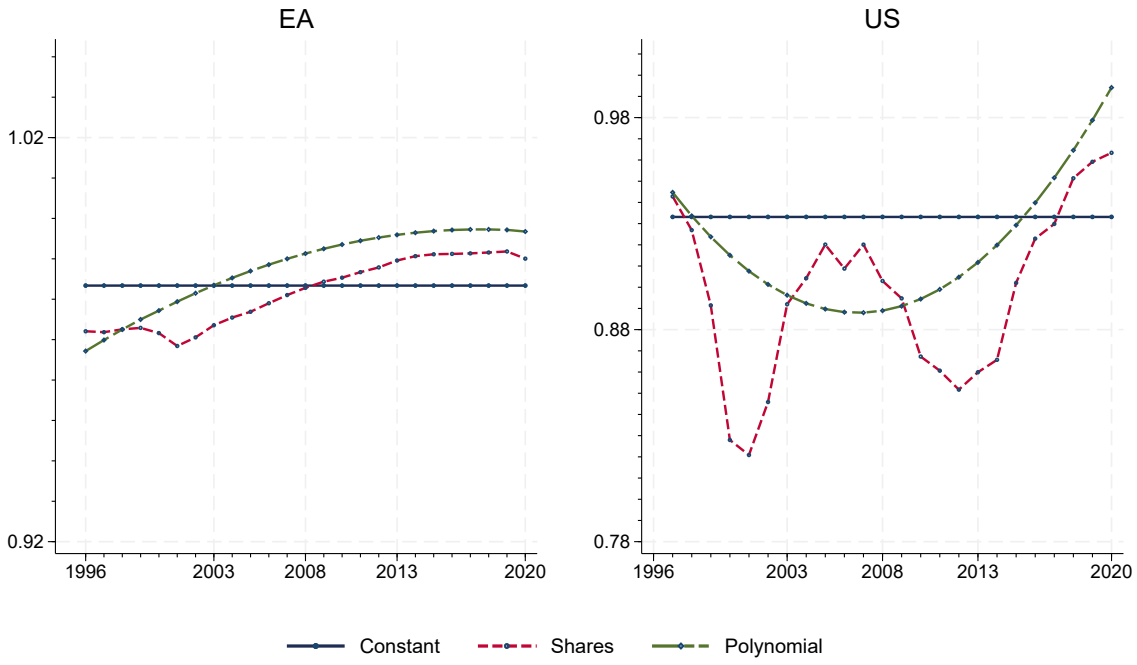
Log Likelihood	1977	1992	1990	256	265	268
AIC	-3948	-3974	-3970	-506	-520	-527
BIC	-3938	-3957	-3953	-502	-514	-521
R2						
$ln\left(Y_t/\overline{Y}\right)$	0.940	0.942	0.940	0.995	0.994	0.994
$ln\left(r_{K,t}/\overline{r_K}\right)$	0.860	0.862	0.867	0.954	0.973	0.972
$ln\left(w_t/\overline{w}\right)$	0.672	0.678	0.691	0.616	0.785	0.782

Note: This table offers the results from the estimation of normalized and logarithmed function (29) together with the corresponding first order conditions [see equations (51), (52) and (53) in the Technical Appendix] for European countries (EA) in columns 1-3 and the US in columns 4-6. Panel *A* offers the estimates of the parameters and the corresponding number of observations in each equation. Sample years are given by the availability of data in the EU KLEMS database. Panel *B* offers various measures of fit including Log Likelihood, AIC, BIC, and R-squared of each equation. Columns 1 and 4 offer the results when ε_1 is assumed to be constant (CES). In columns 2 and 5, ε_1 is assumed to linearly depend on S_{LIKTK} and S_{IKL}. Finally, it is assumed to be a quadratic polynomial of time in columns 3 and 6. I use a demeaned measure for the time index for estimations in these columns. All regressions use the feasible generalized non-linear least-squares estimation method and the country-year-level shares of hours of employment out of the total hours of employment across sample countries as weights. Initial/starting points for estimations are $\varepsilon_L = 0.5$ and $\gamma_L, \gamma_K = 0.02$. Standard errors are in parentheses and are robust to arbitrary heteroscedasticity and serial correlation. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The Data Description Appendix offers further details about the data.

Table 7 reports the results for European countries in columns 1-3 and for the US in columns 4-6. The estimation results in columns 1 and 4 are for the case when ε_1 is assumed to be constant. The estimates of ε_1 are significantly below 1 in both columns. The estimate for European countries is also significantly higher than $\varepsilon_{L,K}$ while the estimate

for the US is very close to it. Columns 2 and 5 report the estimation results for the case when the elasticity of substitution ε_1 is assumed to be a linear function of S_{LIKTK} and S_{IKL}. The estimates in these columns imply that time varying elasticity of substitution between labor and aggregate capital fits the data better albeit the estimation results for the US are not very precise potentially owning to the low number of observations. Columns 3 and 6 report the estimation results for the case when ε_1 is assumed to be a quadratic polynomial of time. The estimates in these columns once again imply that time varying elasticity of substitution between labor and aggregate capital fits the data better.[11]

Figure 3: The Estimated Elasticity of Substitution between Labor and Aggregate Capital



Note: This figure illustrates the labor income share in European countries (EA) and in the US computed using the data from the EU KLEMS database. It also illustrates the predicted labor income share using equation (5) and parameter estimates from columns 1 and 5 of Table 4 for European countries and the US, correspondingly. The counterfactual predictions are for cases when there is no technological progress and changes in (1) ICT and IP capital, (2) ICT, (3) IP capital, and (4) traditional capital. The corresponding trend index is fixed to its sample initial value to have no technological progress in the type of capital and the value of capital stock is set equal to its sample initial value to have no changes in its level. Prediction results for European countries use parameter estimates from column 1 of Table 4. The averages across European countries are weighted by the country-year-level shares of employment hours out of the total hours of employment across sample European countries.

[11] Koh and Santaeulàlia-Llopis (2022) estimate time-varying elasticity of substitution between labor and capital at business cycle frequencies and find that it is countercyclical.

Figure 3 plots the estimated values of ε_1 from Table 7 for European countries as well as the US. The estimated values of ε_1 are below 1. When the estimates for European countries imply that ε_1 has increased the estimates for the US imply a U shape pattern.[12] The increase in ε_1 in Figure 3 in European countries is in line with the imputed elasticity of substitution in Table 6 but ε_1 from Table 7 has a higher value.

Finally, I compute the aggregate capital-specific technological progress parameter from the production function in equation (1), using parameter estimates from column 1 of Table 4 [see Appendix - Additional Results and Robustness Checks for further details]. I then use this value, along with γ_L and $\varepsilon_{L,K}$, to impute labor income share. Labor income share counter-factually trends upward with these parameter values.

Taken together, these results imply that the elasticity of substitution between aggregate capital and labor is below 1 even though there are types of capital, specifically ICT and IP capital, that have a higher than 1 elasticity of substitution with labor. Most of the dynamics in labor income share can be attributed particularly to technical progress in ICT and the accumulation of IP capital. Moreover, the specification of production function and the assumed aggregation of capital can affect the estimated elasticity of substitution between aggregate capital and labor.

5 Conclusion

In this study, I explore the elasticities of substitution between labor, information and communication technologies (ICT) and intellectual property (IP) capital, and traditional capital. I use data from the EU KLEMS database for a panel of 9 European countries and the estimation methodology developed and applied by Grandville (1989), Klump et al. (2007) and León-Ledesma et al. (2010). In particular, I estimate a nested CES production technology that utilizes labor, an aggregate of ICT and IP capital, and traditional capital.

The estimate of the elasticity of substitution between labor and ICT and IP capital exceeds 1, implying that labor and ICT and IP capital are gross substitutes. The estimate of the elasticity of substitution between labor and traditional capital is below 1, implying

[12] This might be again because of the low number of observations.

that labor and traditional capital are gross complements. Similarly, the estimate of the elasticity of substitution between ICT and IP capital is below 1.

These findings offer insights into the decline in labor income share, suggesting that much of the fall in labor share across European countries can be attributed to rapid technological progress and the accumulation of ICT and IP capital. Moreover, labor income share would be significantly higher absent technological progress and the accumulation of ICT capital.

These results also have implications for the elasticity of substitution between labor and aggregate capital. I derive it from the nested CES production function with different types of capital and compute its values using the function's estimated parameters. The imputed elasticity of substitution between labor and aggregate capital is below 1 but increases over the sample period. This implies that labor and aggregate capital are gross complements. For comparison, I estimate the elasticity of substitution between labor and aggregate capital using data from the EU KLEMS database and following a similar methodology. The estimated value of the elasticity of substitution between labor and aggregate capital is lower than 1 but greater than the imputed values of this parameter. This implies that the specification of the production function and aggregation of capital can play an important role in determining the value of the estimated elasticity of substitution between labor and aggregate capital. In turn, the imputed elasticity of substitution, along with substitutability between ICT and IP capital and the implied labor share dynamics, aligns with the juxtaposition of findings by Aum and Shin (2024), Eden and Gaggl (2018, 2019), Karabarbounis and Neiman (2014) and Oberfield and Raval (2021). Finally, I show that all these results can also be extended to the US.

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A Data Description Appendix

Table A: Definitions and Sources of Variables

Variable Name	Definition and Source
ICT Capital Stock, NAC, current, bn	The nominal value of ICT capital stock in billions of national accounts currency (EUR in European/EA countries, USD in the US). ICT capital includes computers, communication devices, and peripheral equipment. Source: EU KLEMS database.
IP Capital Stock, NAC, current, bn	The nominal value of IP capital stock in billions of national accounts currency (EUR in European/EA countries, USD in the US). IP capital includes software, databases, patents, and other forms of intellectual property. Source: EU KLEMS database.
TK Stock, EUR, current, bn	The nominal value of traditional capital stock in billions of national accounts currency (EUR in European/EA countries, USD in the US). Traditional capital (TK) includes all types of capital but ICT and IP capital, such as machinery, transport, and construction equipment and structures. For example, it includes machinery and transport equipment. Source: EU KLEMS database.
ICT Investment Price Index	Price of investments in ICT capital. It is computed using a weighted average of prices of investments in information technology (IT) capital and communication technology (CT) capital. The weights are the averages of the shares of IT capital and CT capital out of the sum of IT and CT capital. The averages are taken over time within each country. Source: Authors' calculations using data from the EU KLEMS database.
IP Investment Price Index	Price of investments in IP capital. It is computed using a weighted average of prices of investments in R&D capital/patents and other types of intellectual property (IP) capital. The weights are the averages of the shares of different types of IP capital out of the total sum of IP capital types. The averages are taken over time within each country. Source: Authors' calculations using data from the EU KLEMS database.

Table A – (Continued)

Variable Name	Definition and Source
TK Investment Price Index	Price of investments in traditional capital, TK. It is computed using a weighted average of prices of investments in different types of traditional capital. The weights are the averages of the shares of different types of traditional capital out of the total sum of traditional capital types. The averages are taken over time within each country. Source: Authors' calculations using data from the EU KLEMS database.
δ_{ICT}	Annual depreciation rate of ICT capital. It is computed using a weighted average of depreciation rates of information technology (IT) capital and communication technology (CT) capital. The weights are the averages of the shares of IT capital and CT capital out of the sum of IT and CT capital. The averages are taken over time within each country. Source: Authors' calculations using data from the EU KLEMS database.
δ_{IP}	Annual depreciation rate of IP capital. It is computed using a weighted average of depreciation rates of R&D capital/patents and other types of intellectual property (IP) capital. The weights are the averages of the shares of different types of IP capital out of the total sum of IP capital types. The averages are taken over time within each country. Source: Authors' calculations using data from the EU KLEMS database.
δ_{TK}	Annual depreciation rate of traditional capital, TK. It is computed using a weighted average of depreciation rates of machinery, transport, and construction equipment and structures. The weights are the averages of the shares of different types of traditional capital (including machinery, transport, and construction equipment and structures) out of the total sum of traditional capital types. The averages are taken over time within each country. Source: Authors' calculations using data from the EU KLEMS database.
r_{ICT}	Returns on ICT capital. Source: Authors' calculations using data from the EU KLEMS database and equation (7).
r_{IP}	Returns on IP capital. Source: Authors' calculations using data from the EU KLEMS database and equation (7).

Table A – (Continued)

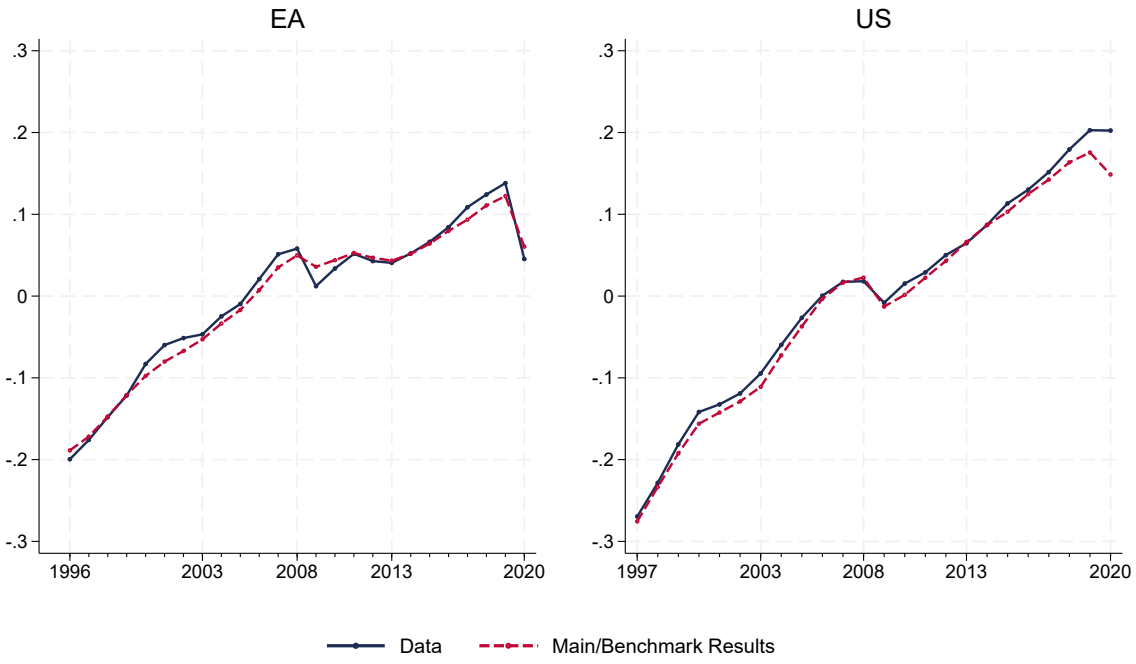
Variable Name	Definition and Source
r_{TK}	Returns on TK capital. Source: Authors' calculations using data from the EU KLEMS database and equation (7).
w	Hourly wages. It is computed from the ratio of labor compensation and hours of work. Source: Authors' calculations using data from the EU KLEMS database.

Data Sources: All data are from the 2023 release of the EU KLEMS database by the Luiss Lab of European Economics at Luiss University in Rome, Italy accessible at https://euklems-intanprod-llee.luiss.it/ (last accessed: 15.10.2024). This database includes information on investment in capital stocks across both tangible and intangible assets. It is often used to study productivity and output, employment, and labor income dynamics.

Countries: The main sample countries are Austria, Belgium, Finland, France, Germany, Italy, Netherlands, Portugal, and Spain, and the period is from 1996-2020 except for Germany (1996-2019) and Portugal (2001-2020). The sample also includes data for the US (1997-2020).

B Data Appendix

Figure I: Normalized and Logarithmed Real Value Added: Data and Prediction/Fit



Note: This figure illustrates the evolution of the normalized and logarithmed real value added in sample countries computed using data from the EU KLEMS database. It also illustrates the predicted values of this variable using equation (**??**) and parameter estimates from Table 4.

Table I: Country-Level Basic Statistics

Panel A	Austria			Belgium			Finland			France			Germany		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Variable	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1996	2019
Value Added, NAC, current, bn	250	163	342	302	192	413	153	89	206	1661	1117	2061	2271	1742	3130
Total Labor Income, NAC, current, bn	165	115	233	189	125	248	99	61	128	1134	772	1425	1526	1204	2122
Total Hours Worked, mn	7	7	7	7	6	7	4	4	4	41	38	40	59	58	62
ICT Capital Stock, NAC, current, bn	23	18	28	15	10	21	4	2	6	31	21	42	88	104	74
IP Capital Stock, NAC, current, bn	46	20	88	44	19	84	30	12	39	304	186	460	402	262	639
TK Stock, NAC, current, bn	1005	622	1540	930	597	1333	516	310	781	5437	3307	7389	7674	5965	10700
Total Capital Stock (K), NAC, current, bn	1074	659	1656	989	626	1438	549	324	826	5771	3513	7890	8164	6331	11400
Value Added Price Index	0.885	0.749	1.100	0.898	0.743	1.090	0.872	0.708	1.060	0.914	0.776	1.060	0.914	0.840	1.070
ICT Investment Price Index	1.030	1.110	0.999	1.110	1.390	0.941	1.770	3.910	1.020	1.420	2.040	1.010	1.750	3.380	0.991
IP Investment Price Index	0.910	0.795	1.060	0.890	0.754	1.070	0.839	0.628	1.070	0.943	0.825	1.020	0.921	0.843	1.060
TK Investment Price Index	0.864	0.700	1.100	0.893	0.711	1.080	0.885	0.675	1.110	0.885	0.721	1.070	0.896	0.808	1.110
Total Capital (K) Investment Price Index	0.880	0.735	1.090	0.901	0.747	1.070	0.883	0.688	1.110	0.901	0.750	1.060	0.924	0.881	1.090

Panel B	Austria			Belgium			Finland			France			Germany		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Derived Variable	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1996	2019
r_{ICT}	0.239	0.345	0.169	0.407	0.650	0.275	0.724	2.100	0.238	0.440	0.660	0.203	0.614	1.180	0.249
r_{IP}	0.289	0.286	0.255	0.294	0.285	0.270	0.265	0.224	0.274	0.321	0.318	0.284	0.276	0.253	0.282
r_{TK}	0.066	0.058	0.053	0.101	0.094	0.100	0.089	0.075	0.088	0.077	0.080	0.067	0.078	0.071	0.077
w	27	24	32	30	28	32	28	24	29	30	26	34	28	25	32

Note: This table offers the averages and sample initial and final values of the variables in each sample European country and the US. Nominal variables are in national currency units. EUR in the EU countries and USD in the US. See Table A in the **??** for complete descriptions and sources of variables.

Table I: Country-Level Basic Statistics — (Continued)

Panel A	Italy			Netherlands			Portugal			Spain			US		
	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)
Variable	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1997	2020
Value Added, NAC, current, bn	1332	948	1502	523	311	710	150	119	175	831	452	1020	13300	8000	20200
Total Labor Income, NAC, current, bn	851	621	949	355	217	514	96	83	113	529	299	673	8315	5201	12400
Total Hours Worked, mn	43	41	39	12	11	13	9	10	9	31	24	30	252	240	261
ICT Capital Stock, NAC, current, bn	32	20	39	13	8	16	7	6	7	28	18	36	668	506	909
IP Capital Stock, NAC, current, bn	149	88	208	98	48	164	11	5	16	81	27	144	4015	1919	6607
TK Stock, NAC, current, bn	4612	2871	5806	1628	991	2255	599	437	767	3229	1591	4327	37800	20700	60700
Total Capital Stock (K), NAC, current, bn	4793	2978	6054	1739	1047	2435	617	449	791	3339	1636	4507	42500	23200	68200
Value Added Price Index	0.890	0.700	1.060	0.911	0.724	1.090	0.945	0.783	1.090	0.900	0.673	1.060	0.914	0.726	1.140
ICT Investment Price Index	1.100	1.240	1.010	2.020	5.320	0.900	1.340	2.080	0.984	1.150	1.190	0.973	2.010	4.590	0.726
IP Investment Price Index	0.899	0.743	0.998	0.912	0.755	1.090	0.970	0.821	1.070	0.881	0.663	1.040	0.949	0.853	1.070
TK Investment Price Index	0.877	0.679	1.040	0.917	0.695	1.110	0.960	0.804	1.140	0.978	0.743	1.080	0.613	0.713	1.200
Total Capital (K) Investment Price Index	0.884	0.697	1.030	0.928	0.761	1.100	0.972	0.844	1.100	0.965	0.732	1.070	0.944	0.818	1.110

Panel B	Italy			Netherlands			Portugal			Spain			US		
	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(34)	(35)	(36)
Derived Variable	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1996	2020	Mean	1997	2020
r_{ICT}	0.380	0.565	0.244	1.090	4.520	0.309	0.414	0.846	0.223	0.338	0.484	0.234	0.903	2.860	0.181
r_{IP}	0.317	0.369	0.283	0.294	0.310	0.279	0.308	0.293	0.304	0.284	0.274	0.284	0.277	0.322	0.247
r_{TK}	0.092	0.098	0.082	0.083	0.073	0.065	0.082	0.077	0.075	0.092	0.097	0.070	0.065	0.097	0.100
w	22	22	23	31	27	35	11	11	12	19	18	21	35	30	42

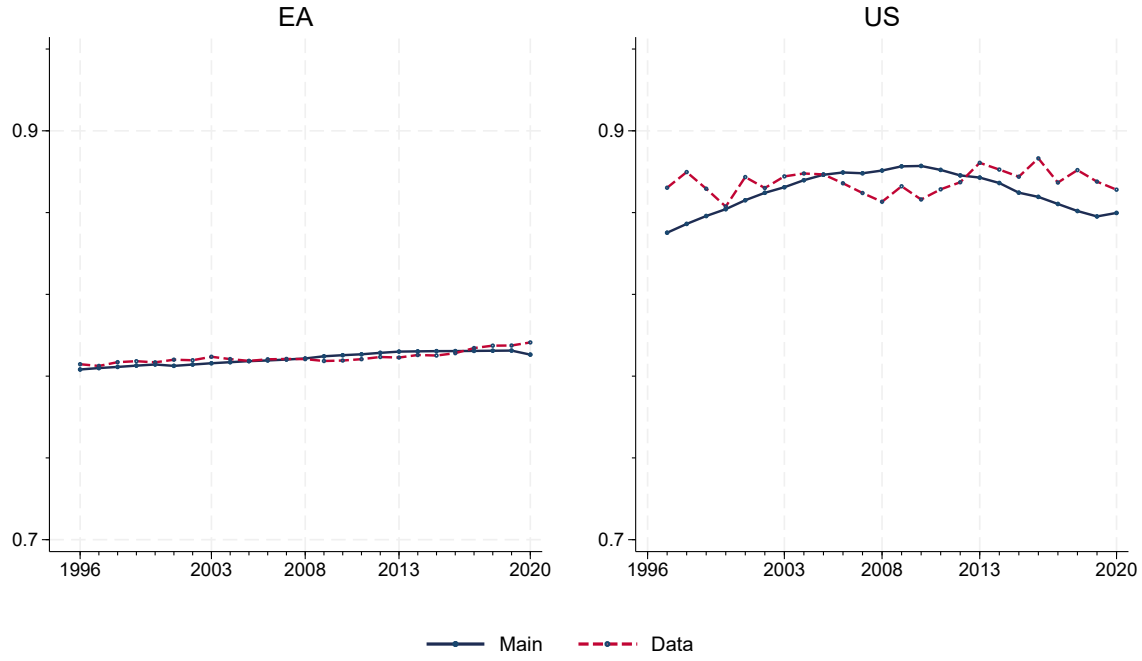
Note: This table offers the averages and sample initial and final values of the variables in each sample European country and the US. Nominal variables are in national currency units. EUR in the EU countries and USD in the US. See Table A in the **??** for complete descriptions and sources of variables.

Table II: Predicted Labor Income Share and Counterfactuals with Alternative Nests

Eq. (18)					
Year	(1) Prediction	(2) ICT and IP	(3) ICT	(4) IP	(5) TK
1996	0.700	0.700	0.700	0.700	0.700
2020	0.655	0.684	0.684	0.632	0.655
Eq. (19)					
Year	(1) Prediction	(2) ICT and IP	(3) ICT	(4) IP	(5) TK
1996	0.779	0.779	0.779	0.779	0.779
2020	0.623	0.777	0.625	0.623	0.619

Note: This table offers the predicted labor income share using alternative nests in equations (18) and (19) and parameter estimates from columns 2 and 3 of Table 4 for European countries. It also offers results from counterfactual predictions. The counterfactual predictions are for cases when there is no technological progress and changes in (1) ICT and IP capital, (2) ICT capital, (3) IP capital, and (4) traditional capital. The corresponding trend index is fixed to its sample initial value to have no technological progress in the type of capital and the value of capital stock is set equal to its sample initial value to have no changes in its level. The averages across European countries are weighted by the country-year-level shares of employment hours out of the total hours of employment across sample European countries.

Figure II: The Imputed Elasticity of Substitution and Counterfactuals



Note: This figure illustrates values of $\varepsilon_{L,K}$ computed using equations (??)-(??) and estimated values of parameters from column 1 of Table 4.

Table III: Shares and Ratios

	European Countries (EA)				US			
	Estimation		Data		Estimation		Data	
Year	(1) S_{IKL}	(2) S_{LIKTK}	(3) S_{IKL}	(4) S_{LIKTK}	(5) S_{IKL}	(6) S_{LIKTK}	(7) S_{IKL}	(8) S_{LIKTK}
1996	0.065	0.713	0.065	0.727				
1997	0.065	0.713	0.065	0.723	0.106	0.749	0.127	0.745
1998	0.066	0.712	0.069	0.716	0.110	0.747	0.128	0.757
1999	0.068	0.712	0.069	0.720	0.114	0.745	0.123	0.752
2000	0.068	0.711	0.069	0.717	0.118	0.743	0.114	0.755
2001	0.068	0.710	0.071	0.713	0.122	0.742	0.124	0.761
2002	0.069	0.710	0.071	0.712	0.125	0.743	0.125	0.749
2003	0.069	0.711	0.073	0.714	0.128	0.742	0.130	0.748
2004	0.070	0.711	0.074	0.707	0.131	0.742	0.133	0.746
2005	0.071	0.711	0.073	0.705	0.134	0.740	0.136	0.737
2006	0.071	0.711	0.075	0.701	0.136	0.738	0.133	0.734
2007	0.072	0.711	0.077	0.695	0.137	0.736	0.130	0.733
2008	0.073	0.711	0.076	0.701	0.139	0.735	0.127	0.729
2009	0.074	0.713	0.069	0.718	0.141	0.735	0.137	0.723
2010	0.075	0.714	0.071	0.713	0.142	0.733	0.136	0.709
2011	0.076	0.714	0.073	0.710	0.141	0.730	0.140	0.712
2012	0.077	0.715	0.073	0.714	0.140	0.727	0.143	0.713
2013	0.077	0.716	0.073	0.713	0.140	0.725	0.151	0.716
2014	0.078	0.715	0.075	0.713	0.139	0.722	0.148	0.716
2015	0.078	0.714	0.075	0.710	0.135	0.719	0.143	0.719
2016	0.078	0.713	0.078	0.708	0.134	0.718	0.149	0.724
2017	0.079	0.712	0.081	0.707	0.131	0.716	0.140	0.718
2018	0.079	0.711	0.082	0.712	0.129	0.713	0.145	0.721
2019	0.079	0.710	0.082	0.714	0.127	0.711	0.141	0.719
2020	0.077	0.710	0.081	0.722	0.128	0.715	0.139	0.714

Note: This table offers the values of the shares S_{IKL}, and S_{LIKTK} from equations (26)-(27) and the values of their data counterparts. The averages across European countries are weighted by the country-year-level shares of employment hours out of the total hours of employment across sample European countries.

Table IV: Growth Rate of Real Investment Prices in Aggregate Capital and Real Wages

	European Countries (EA)				US		
	(1) p_K	(2) p_K w/t Δ in p_{ICT}	(3) w		(4) p_K	(5) p_K w/t Δ in p_{ICT}	(6) w
$g_{1996-2020}$	-0.025	-0.011	0.132	$g_{1997-2020}$	-0.147	-0.035	0.332

Note: This table offers the growth rates of real prices of investments over the sample period in total/aggregate capital p_K in columns 1, 2, 4, and 5 and real wages w in columns 3 and 6. I compute p_K as $p_{K,t} = p_{ICT,t} \times K_{ICT,t}/K_t + p_{IP,t} \times K_{IP,t}/K_t + p_{TK,t} \times TK_t/K_t$ and set $p_{ICT,t}$ to its sample initial value for all countries and years in columns 2 and 5. The Data Description Appendix offers further details about the data.

C Technical Appendix

In this section, I offer the estimated equations for alternative specifications of the production function (18), (19), and (29).

C.A Separate Nests for Labor and Traditional Capital and for ICT and IP

The firm solves problem (2) where production function is now given by

$$Y_t = \left(\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} \right)^{\frac{\varepsilon_1}{\varepsilon_1 - 1}}, \tag{30}$$

where

$$LTK_t = \left[\varpi_L^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} \right]^{\frac{\varepsilon_2}{\varepsilon_2 - 1}},$$
$$IK_t = \left[\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} \right]^{\frac{\varepsilon_3}{\varepsilon_3 - 1}}.$$

The first order conditions that follow from this problem are given by

$$\frac{r_{ICT,t} K_{ICT,t}}{Y_t} = \frac{\varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}} \times \frac{\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}{\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}, \tag{31}$$

$$\frac{r_{IP,t} K_{IP,t}}{Y_t} = \frac{\varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}} \times \frac{\varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}{\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}, \tag{32}$$

$$\frac{w_t L_t}{Y_t} = \frac{\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}} \times \frac{\varpi_L^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}{\varpi_L^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}, \tag{33}$$

and

$$\frac{r_{TK,t}TK_t}{Y_t} = \frac{\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1-1}{\varepsilon_1}}}{\varpi_{LTK}^{\frac{1}{\varepsilon_1}} LTK_t^{\frac{\varepsilon_1-1}{\varepsilon_1}} + \varpi_{IK}^{\frac{1}{\varepsilon_1}} IK_t^{\frac{\varepsilon_1-1}{\varepsilon_1}}} \times \frac{\varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK}t}TK_t\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}}{\varpi_{L}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{L}t}L_t\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK}t}TK_t\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}}. \tag{34}$$

I denote by S_{LTK_t,Y_t} and S_{IK_t,Y_t} the shares of compensation of labor and traditional capital and ICT and IP capital in value added:

$$S_{LTK_t,Y_t} = \varpi_{LTK}^{\frac{1}{\varepsilon_1}} \left(\frac{LTK_t}{Y_t}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}},$$
$$S_{IK_t,Y_t} = \varpi_{IK}^{\frac{1}{\varepsilon_2}} \left(\frac{IK_t}{Y_t}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}.$$

I also use $\alpha_{1,R3}$, $\alpha_{2,R3}$, and $\alpha_{3,R3}$ to denote the following expressions:

$$\alpha_{1,R3} = \varpi_{LTK}^{\frac{1}{\varepsilon_1}} \overline{\left(\frac{LTK_t}{Y_t}\right)}^{\frac{\varepsilon_1-1}{\varepsilon_1}},$$
$$\alpha_{2,R3} = \varpi_{L}^{\frac{1}{\varepsilon_2}} \overline{\left(\frac{e^{\gamma_L t}L_t}{LTK_t}\right)}^{\frac{\varepsilon_2-1}{\varepsilon_2}},$$
$$\alpha_{3,R3} = \varpi_{ICT}^{\frac{1}{\varepsilon_3}} \overline{\left(\frac{e^{\gamma_{ICT}t}K_{ICT,t}}{IK_t}\right)}^{\frac{\varepsilon_3-1}{\varepsilon_3}}.$$

I use $\alpha_{1,R3}$, $\alpha_{2,R3}$, and $\alpha_{3,R3}$ and write the logrithm of the normalized equation for output in the following way:

$$\ln \frac{Y_t}{\overline{Y_t}} = \frac{\varepsilon_1}{\varepsilon_1 - 1} \ln \left[\alpha_{1,R3} \left(\frac{LTK_t}{\overline{LTK_t}}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + (1-\alpha_{1,R3}) \left(\frac{IK_t}{\overline{IK_t}}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} \right], \tag{35}$$

where

$$\frac{LTK_t}{\overline{LTK_t}} = \left[\alpha_{2,R3}\left(e^{\gamma_L \hat{t}}\frac{L_t}{\overline{L_t}}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}} + (1-\alpha_{2,R3})\left(\frac{TK_t}{\overline{TK_t}}\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}\right]^{\frac{\varepsilon_2}{\varepsilon_2-1}},$$

$$\frac{IK_t}{\overline{IK_t}} = \left[\alpha_{3,R3}\left(e^{\gamma_{ICT}\hat{t}}\frac{K_{ICT,t}}{\overline{K_{ICT,t}}}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}} + (1-\alpha_{3,R3})\left(e^{\gamma_{IP}\hat{t}}\frac{K_{IP,t}}{\overline{K_{IPP,t}}}\right)^{\frac{\varepsilon_3-1}{\varepsilon_3}}\right]^{\frac{\varepsilon_3}{\varepsilon_3-1}},$$

and $\hat{t}$ is demeaned trend.

I write the normalized equations corresponding to the first order conditions in the following way:

$$\ln r_{ICT,t} - \ln \overline{r_{ICT,t}} = \left(1 - \frac{\varepsilon_3 - 1}{\varepsilon_3}\frac{\varepsilon_1}{\varepsilon_1 - 1}\right)\ln\left(\frac{S_{IK_t,Y_t}}{\overline{S_{IK_t,Y_t}}}\right) + \frac{\varepsilon_3 - 1}{\varepsilon_3}\gamma_{ICT}\hat{t} - \frac{1}{\varepsilon_3}\ln\left(\frac{K_{ICT,t}/\overline{K_{ICT,t}}}{Y_t/\overline{Y_t}}\right), \tag{36}$$

$$\ln r_{IP,t} - \ln \overline{r_{IP,t}} = \left(1 - \frac{\varepsilon_3 - 1}{\varepsilon_3}\frac{\varepsilon_1}{\varepsilon_1 - 1}\right)\ln\left(\frac{S_{IK_t,Y_t}}{\overline{S_{IK_t,Y_t}}}\right) + \frac{\varepsilon_3 - 1}{\varepsilon_3}\gamma_{IP}\hat{t} - \frac{1}{\varepsilon_3}\ln\left(\frac{K_{IP,t}/\overline{K_{IP,t}}}{Y_t/\overline{Y_t}}\right), \tag{37}$$

$$\ln w_t - \ln \overline{w_t} = \left(1 - \frac{\varepsilon_2 - 1}{\varepsilon_2}\frac{\varepsilon_1}{\varepsilon_1 - 1}\right)\ln\left(\frac{S_{LTK_t,Y_t}}{\overline{S_{LTK_t,Y_t}}}\right) + \frac{\varepsilon_2 - 1}{\varepsilon_2}\gamma_L\hat{t} - \frac{1}{\varepsilon_2}\ln\left(\frac{L_t/\overline{L_t}}{Y_t/\overline{Y_t}}\right) \tag{38}$$

$$\ln r_{TK,t} - \ln \overline{r_{TK,t}} = \left(1 - \frac{\varepsilon_2 - 1}{\varepsilon_2}\frac{\varepsilon_1}{\varepsilon_1 - 1}\right)\ln\left(\frac{S_{LTK_t,Y_t}}{\overline{S_{LTK_t,Y_t}}}\right) + \frac{\varepsilon_2 - 1}{\varepsilon_2}\gamma_{TK}\hat{t} - \frac{1}{\varepsilon_2}\ln\left(\frac{TK_t/\overline{TK_t}}{Y_t/\overline{Y_t}}\right). \tag{39}$$

C.B One Nest for Capital Types

The firm solves problem (2) where production function is now given by

$$Y_t = \left[\varpi_L^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_L t}L_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + \varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1-1}{\varepsilon_1}}\right]^{\frac{\varepsilon_1}{\varepsilon_1-1}}, \tag{40}$$

where

$$IKTK_t = \left[\varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2-1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}}\left(e^{\gamma_{TK}t}TK_t\right)^{\frac{\varepsilon_2-1}{\varepsilon_2}}\right]^{\frac{\varepsilon_2}{\varepsilon_2-1}},$$

and

$$IK_t = \left[\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} \right]^{\frac{\varepsilon_3}{\varepsilon_3 - 1}}.$$

The first order conditions that follow from this problem are given by

$$\begin{aligned} \frac{r_{ICT,t} K_{ICT,t}}{Y_t} = & \frac{\varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\varpi_L^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}} \times \\ & \frac{\varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}{\varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}} \times \\ & \frac{\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}{\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}, \end{aligned} \tag{41}$$

$$\begin{aligned} \frac{r_{IP,t} K_{IP,t}}{Y_t} = & \frac{\varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\varpi_L^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}} \times \\ & \frac{\varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}{\varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}} \times \\ & \frac{\varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}{\varpi_{ICT}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{ICT} t} K_{ICT,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + \varpi_{IP}^{\frac{1}{\varepsilon_3}} \left(e^{\gamma_{IP} t} K_{IP,t} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}, \end{aligned} \tag{42}$$

$$\frac{w_t L_t}{Y_t} = \frac{\varpi_L^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\varpi_L^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}, \tag{43}$$

$$\begin{aligned} \frac{r_{TK,t} TK_t}{Y_t} = & \frac{\varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\varpi_L^{\frac{1}{\varepsilon_1}} \left(e^{\gamma_L t} L_t \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + \varpi_{TKIK}^{\frac{1}{\varepsilon_1}} IKTK_t^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}} \times \\ & \frac{\varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}{\varpi_{IK}^{\frac{1}{\varepsilon_2}} IK_t^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + \varpi_{TK}^{\frac{1}{\varepsilon_2}} \left(e^{\gamma_{TK} t} TK_t \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}. \end{aligned} \tag{44}$$

I denote by S_{IKTK_t,Y_t} and $S_{IK_t,IKTK_t}$ the following expressions:

$$S_{IKTK_t,Y_t} = \varpi_{TKIK}^{\frac{1}{\varepsilon_1}} \left(\frac{IKTK_t}{Y_t} \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}},$$

$$S_{IK_t,IKTK_t} = \varpi_{IK}^{\frac{1}{\varepsilon_2}} \left(\frac{IK_t}{IKTK_t} \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}.$$

I also use $\alpha_{1,R4}$, $\alpha_{2,R4}$, and $\alpha_{3,R4}$ to denote the following expressions:

$$\alpha_{1,R4} = \varpi_L^{\frac{1}{\varepsilon_1}} \overline{\left(\frac{e^{\gamma_L t} L_t}{Y_t}\right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}},$$
$$\alpha_{2,R4} = \varpi_{IK}^{\frac{1}{\varepsilon_2}} \overline{\left(\frac{IK_t}{IKTK_t}\right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}},$$
$$\alpha_{3,R4} = \varpi_{ICT}^{\frac{1}{\varepsilon_3}} \overline{\left(\frac{e^{\gamma_{ICT} t} K_{ICT,t}}{IK_t}\right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}}}.$$

I use $\alpha_{1,R4}$, $\alpha_{2,R4}$, and $\alpha_{3,R4}$ and write the logarithm of the normalized equation for output in the following way:

$$\ln \frac{Y_t}{\overline{Y_t}} = \frac{\varepsilon_1}{\varepsilon_1 - 1} \ln \left[\alpha_{1,R4} \left(e^{\gamma_L \hat{t}} \frac{L_t}{\overline{L_t}} \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + (1 - \alpha_{1,R4}) \left(\frac{IKTK_t}{\overline{IKTK_t}} \right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} \right], \tag{45}$$

where

$$\frac{IKTK_t}{\overline{IKTK_t}} = \left[\alpha_{2,R4} \left(\frac{IK_t}{\overline{IK_t}} \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + (1 - \alpha_{2,R4}) \left(e^{\gamma_{TK} \hat{t}} \frac{TK_t}{\overline{TK_t}} \right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} \right]^{\frac{\varepsilon_2}{\varepsilon_2 - 1}},$$
$$\frac{IK_t}{\overline{IK_t}} = \left[\alpha_{3,R4} \left(e^{\gamma_{ICT} \hat{t}} \frac{K_{ICT,t}}{\overline{K_{ICT,t}}} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} + (1 - \alpha_{3,R4}) \left(e^{\gamma_{IP} \hat{t}} \frac{K_{IP,t}}{\overline{K_{IP,t}}} \right)^{\frac{\varepsilon_3 - 1}{\varepsilon_3}} \right]^{\frac{\varepsilon_3}{\varepsilon_3 - 1}}.$$

I write the normalized equations corresponding to the first order conditions in the following way:

$$\begin{aligned} \ln r_{ICT,t} - \ln \overline{r_{ICT,t}} = & \left(1 - \frac{\varepsilon_1}{\varepsilon_1 - 1} \frac{\varepsilon_3 - 1}{\varepsilon_3}\right) \ln \left(\frac{S_{IKTK_t, Y_t}}{\overline{S_{IKTK_t, Y_t}}} \right) + \\ & \left(1 - \frac{\varepsilon_2}{\varepsilon_2 - 1} \frac{\varepsilon_3 - 1}{\varepsilon_3}\right) \ln \left(\frac{S_{IK_t, IKTK_t}}{\overline{S_{IK_t, IKTK_t}}} \right) + \\ & \frac{\varepsilon_3 - 1}{\varepsilon_3} \gamma_{ICT} \hat{t} - \frac{1}{\varepsilon_3} \ln \left(\frac{K_{ICT,t} / \overline{K_{ICT,t}}}{Y_t / \overline{Y_t}} \right), \end{aligned} \tag{46}$$

$$\ln r_{IP,t} - \ln \overline{r_{IP,t}} = \left(1 - \frac{\varepsilon_1}{\varepsilon_1 - 1}\frac{\varepsilon_3 - 1}{\varepsilon_3}\right) \ln\left(\frac{S_{IKTK_t,Y_t}}{\overline{S_{IKTK_t,Y_t}}}\right) + \tag{47}$$
$$\left(1 - \frac{\varepsilon_2}{\varepsilon_2 - 1}\frac{\varepsilon_3 - 1}{\varepsilon_3}\right) \ln\left(\frac{S_{IK_t,IKTK_t}}{\overline{S_{IK_t,IKTK_t}}}\right) +$$
$$\frac{\varepsilon_3 - 1}{\varepsilon_3}\gamma_{IP}\hat{t} - \frac{1}{\varepsilon_3}\ln\left(\frac{K_{IP,t}/\overline{K_{IP,t}}}{Y_t/\overline{Y_t}}\right),$$
$$\ln w_t - \ln \overline{w_t} = \frac{\varepsilon_1 - 1}{\varepsilon_1}\gamma_L\hat{t} - \frac{1}{\varepsilon_1}\ln\left(\frac{L_t/\overline{L_t}}{Y_t/\overline{Y_t}}\right), \tag{48}$$
$$\ln r_{TK,t} - \ln \overline{r_{TK,t}} = \left(1 - \frac{\varepsilon_1}{\varepsilon_1 - 1}\frac{\varepsilon_3 - 1}{\varepsilon_3}\right) \ln\left(\frac{S_{IKTK_t,Y_t}}{\overline{S_{IKTK_t,Y_t}}}\right) + \tag{49}$$
$$\frac{\varepsilon_2 - 1}{\varepsilon_2}\gamma_{TK}\hat{t} - \frac{1}{\varepsilon_2}\ln\left(\frac{TK_t/\overline{TK_t}}{Y_t/\overline{Y_t}}\right).$$

C.C One Type of Capital

I consider an infinitely lived firm that has the following production technology

$$Y_t = \left[\varpi_L^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_L t}L_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + \varpi_K^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_K t}K_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}\right]^{\frac{\varepsilon_1}{\varepsilon_1-1}}. \tag{50}$$

where K is total capital stock.

The firm discounts its profits at the rate of return r and solves the following problem:

$$\max_{\{L_t,I_t\}_{t=0}^{+\infty}} \sum_{t=0}^{+\infty}\left(\frac{1}{1+r_t}\right)^t (Y_t - w_t L_t - p_t I_t)$$
$$s.t.$$
$$I_t = K_{t+1} - (1-\delta)K_t.$$

The first order conditions that follow from this problem are given by

$$\frac{w_t L_t}{Y_t} = \frac{\varpi_L^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_L t}L_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}}{\varpi_L^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_L t}L_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + \varpi_K^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_K t}K_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}},$$
$$\frac{r_{K,t}K_t}{Y_t} = \frac{\varpi_K^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_K t}K_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}}{\varpi_L^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_L t}L_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + \varpi_K^{\frac{1}{\varepsilon_1}}\left(e^{\gamma_K t}K_t\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}}.$$

I use $\alpha_{1,R1}$ to denote

$$\alpha_{1,R1} = \varpi_L^{\frac{1}{\varepsilon_1}} \overline{\left(\frac{A_{L,t}L_t}{Y_t}\right)^{\frac{\varepsilon_1-1}{\varepsilon_1}}} = \overline{\frac{w_t L_t}{Y_t}},$$

and the estimations use the following system of normalized equations:

$$\ln \frac{Y_t}{\overline{Y}} = \frac{\varepsilon_1}{\varepsilon_1 - 1} \ln \left[\alpha_{1,R1} \left(e^{\gamma_L \hat{t}} \frac{L_t}{\overline{L_t}} \right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} + (1 - \alpha_{1,R1}) \left(e^{\gamma_K \hat{t}} \frac{K_t}{\overline{K_t}} \right)^{\frac{\varepsilon_1-1}{\varepsilon_1}} \right], \tag{51}$$

$$\ln w_t - \ln \overline{w_t} = \frac{\varepsilon_1 - 1}{\varepsilon_1} \gamma_L \hat{t} - \frac{1}{\varepsilon_1} \ln \left(\frac{L_t/\overline{L_t}}{Y_t/\overline{Y_t}} \right), \tag{52}$$

$$\ln r_{K,t} - \ln \overline{r_{K,t}} = \frac{\varepsilon_1 - 1}{\varepsilon_1} \gamma_K \hat{t} - \frac{1}{\varepsilon_1} \ln \left(\frac{K_t/\overline{K_t}}{Y_t/\overline{Y_t}} \right). \tag{53}$$

The values of r are determined using $r_t = (Y_t - w_t L_t)/K_t$.

D Appendix - Imputed Elasticity of Substitution

The elasticity of substation between labor L and aggregate capital K is given by

$$\varepsilon_{L,K} = \frac{\frac{\partial f}{\partial L}\frac{\partial f}{\partial K}\left(L\frac{\partial f}{\partial L} + K\frac{\partial f}{\partial K}\right)}{LK\left[-\frac{\partial^2 f}{\partial L^2}\left(\frac{\partial f}{\partial K}\right)^2 + 2\frac{\partial^2 f}{\partial L \partial K}\frac{\partial f}{\partial L}\frac{\partial f}{\partial K} - \frac{\partial^2 f}{\partial K^2}\left(\frac{\partial f}{\partial L}\right)^2\right]}. \tag{54}$$

It follows from the definition of K (20) and equations (22) and (23) that

$$f = \frac{\partial f}{\partial L} L + \frac{\partial f}{\partial K} K \tag{55}$$

since Y in equation (1) has constant returns to scale. This, in turn, implies that

$$\frac{\partial^2 f}{\partial L^2} L + \frac{\partial^2 f}{\partial K \partial L} K = 0, \tag{56}$$

$$\frac{\partial^2 f}{\partial L \partial K} L + \frac{\partial^2 f}{\partial K^2} K = 0. \tag{57}$$

Therefore, $\varepsilon_{L,K}$ in equation (54) can be rewritten as

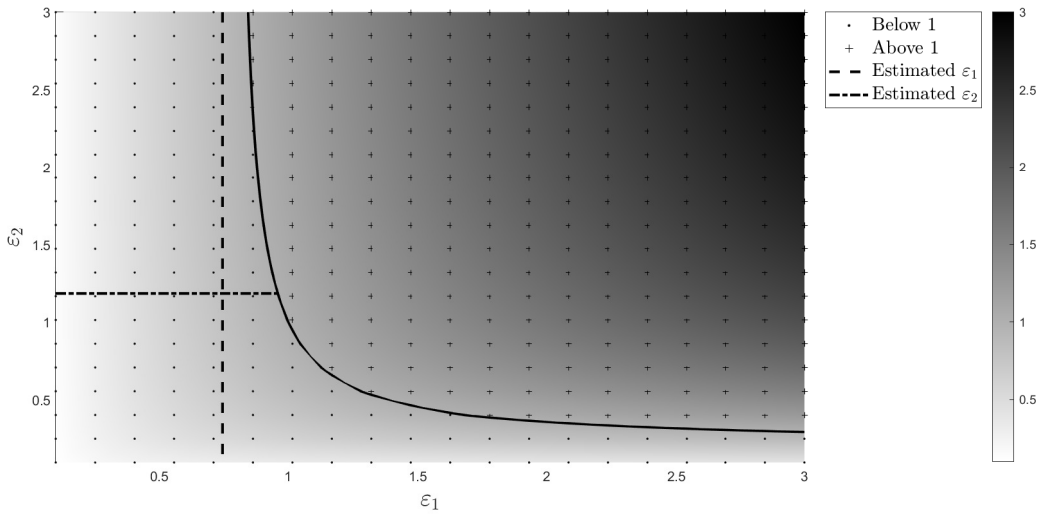
$$\varepsilon_{L,K} = \frac{\frac{\partial f}{\partial L}\frac{\partial f}{\partial K}}{\frac{\partial^2 f}{\partial K \partial L} f}.$$

The equation for the elasticity of substitution between labor and aggregate capital (24) can be easily derived using this expression and the partial derivatives of the function $f(L, K)$ from equations (22) and (23).

I compute the values of $\varepsilon_{L,K}$ from equation (24) for a range of values of ε_1 and ε_2 from $(0.1, 3)$ interval taking the averages of S_{IKL} and S_{LIKTK} from equations (26) and (27). Figure III illustrates the results. For a wide range of values of ε_1 and ε_2, the value of $\varepsilon_{L,K}$ is higher than 1. However, $\varepsilon_{L,K}$ is lower than 1 for all values of ε_2 at the estimated value of ε_1.

I also compute the values of $\varepsilon_{L,K}$ from equation (24) for a range of values of S_{IKL} and S_{LIKTK} from $(0.01, 0.99)$ interval using the estimated values of ε_1 and ε_2 from from column 1 of Table 4. Figure 3 illustrates the results. For a wide range of values of S_{IKL} and S_{LIKTK}, the value of $\varepsilon_{L,K}$ is below 1.

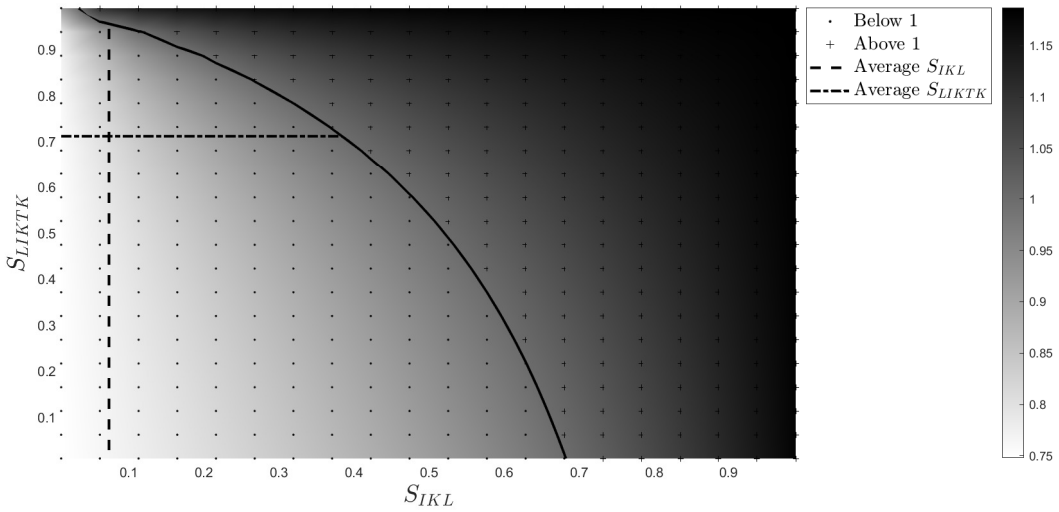
Figure III: The Values of $\varepsilon_{L,K}$ for Different ε_1 and ε_2



Note: This figure illustrates the values of $\varepsilon_{L,K}$ from equation (24) for a range of values of ε_1 and ε_2 from $(0.1, 3)$ interval using the averages of S_{IKL} and S_{LIKTK} from equations (26) and (27).

The elasticity of substitution between labor and aggregate capital can be derived from

Figure IV: The Values of $\varepsilon_{L,K}$ for Different S_{IKL} and S_{LIKTK}



Note: This figure illustrates the values of $\varepsilon_{L,K}$ from equation (24) for a range of values of ε_1 and ε_2 from $(0.01, 0.99)$ interval using the estimated values of ε_1 and ε_2 from equations column 1 of Table 4.

the production function in equation (18) using similar assumptions as for the properties of the function $f(L, K)$ in equation (21) and aggregation of capital in equation (20). It is straightforward to show that when the production function given by equation (18) the elasticity of substitution between labor and aggregate capital is

$$\varepsilon_{L,K,1} = \frac{1}{\tilde{S}_1 \frac{1}{\varepsilon_2} + \left(1 - \tilde{S}_1\right) \frac{1}{\varepsilon_1}}, \tag{58}$$

where

$$\tilde{S}_1 = \frac{\left(1 - S_{L_t,LTK_t}\right)}{\left(1 - S_{L_t,LTK_t}\right) + \left(1 - S_{LTK_t,Y_t}\right) S_{L_t,LTK_t}} \in (0, 1),$$

and

$$S_{LTK_t,Y_t} = \frac{\alpha_{1,R3} \left(\frac{LTK_t}{\overline{LTK_t}}\right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}}{\alpha_{1,R3} \left(\frac{LTK_t}{\overline{LTK_t}}\right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}} + (1 - \alpha_{1,R3}) \left(\frac{IK_t}{\overline{IK_t}}\right)^{\frac{\varepsilon_1 - 1}{\varepsilon_1}}},$$

$$S_{L_t,LTK_t} = \frac{\alpha_{2,R3} \left(e^{\gamma_L \hat{t}} \frac{L_t}{\overline{L_t}}\right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}{\alpha_{2,R3} \left(e^{\gamma_L \hat{t}} \frac{L_t}{\overline{L_t}}\right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}} + (1 - \alpha_{2,R3}) \left(e^{\gamma_{TK} \hat{t}} \frac{TK_t}{\overline{TK_t}}\right)^{\frac{\varepsilon_2 - 1}{\varepsilon_2}}}.$$

Table V offers the values of $\tilde{\varepsilon}_{L,K}$ together with the values of the corresponding share

variables.

Table V: The Values of $\varepsilon_{L,K,1}$ and the Corresponding Data

	Estimation			Data		
Year	(1) $\varepsilon_{L,K,1}$	(2) $S_{LTK,Y}$	(3) $S_{L,LTK}$	(4) $\varepsilon_{L,K,1}$	(5) $S_{LTK,Y}$	(6) $S_{L,LTK}$
1996	0.996	0.997	0.702	1.035	0.952	0.713
1997	0.997	0.996	0.701	1.034	0.953	0.709
1998	0.998	0.995	0.701	1.035	0.950	0.702
1999	1.000	0.992	0.700	1.036	0.950	0.706
2000	1.003	0.989	0.700	1.035	0.951	0.702
2001	1.007	0.985	0.698	1.035	0.949	0.697
2002	1.011	0.979	0.697	1.035	0.949	0.697
2003	1.016	0.973	0.697	1.037	0.947	0.699
2004	1.021	0.967	0.696	1.035	0.948	0.691
2005	1.026	0.960	0.696	1.034	0.948	0.689
2006	1.030	0.955	0.695	1.033	0.947	0.684
2007	1.033	0.951	0.695	1.033	0.946	0.677
2008	1.035	0.948	0.695	1.033	0.947	0.684
2009	1.037	0.946	0.695	1.035	0.950	0.703
2010	1.037	0.945	0.695	1.035	0.949	0.698
2011	1.037	0.945	0.695	1.035	0.948	0.694
2012	1.037	0.946	0.695	1.036	0.947	0.698
2013	1.036	0.946	0.695	1.036	0.948	0.698
2014	1.036	0.947	0.695	1.037	0.946	0.696
2015	1.035	0.948	0.694	1.036	0.946	0.693
2016	1.034	0.949	0.694	1.037	0.945	0.691
2017	1.033	0.950	0.693	1.039	0.942	0.690
2018	1.032	0.951	0.693	1.040	0.941	0.694
2019	1.031	0.952	0.693	1.041	0.941	0.697
2020	1.028	0.955	0.686	1.043	0.941	0.705

Note: This table offers the values of the imputed elasticity of substitution from equation (58) and the corresponding share variables. The averages across European countries are weighted by the country-year-level shares of employment hours out of the total hours of employment across sample European countries.

E Appendix - Additional Results and Robustness Checks

I compute the aggregate capital-specific technological progress parameter in two ways. First, I consider the production function in equation (1) and use the values of γ_{ICT}, γ_{IP},

and γ_{TK} from column 1 of Table 4 and compute it as

$$\gamma_{L,K} = \overline{\left(\frac{r_{ICT}K_{ICT}}{Y}\right)}\gamma_{ICT} + \overline{\left(\frac{r_{IP}K_{IP}}{Y}\right)}\gamma_{IP} + \overline{\left(\frac{r_{TK}TK}{Y}\right)}\gamma_{TK}.$$

Next, I assume that the production function is given by (29), where ε_1 is equal to $\varepsilon_{L,K}$ as given by equation (24) and attains the average value of $\varepsilon_{L,K}$ from column 1 of Table 6, the value of γ_L is from column 1 of Table 4, and K is given by equation (20). I compute the aggregate capital-specific technological progress parameter as

$$\gamma_{L,K} = \gamma_L + \frac{\varepsilon_1}{\varepsilon_1 - 1}\frac{1}{T}\sum_{t=1}^{T} g\left(\frac{\frac{r_t K_t}{Y_t}}{\frac{w_t L_t}{Y_t}}\right) + \frac{1}{T}\sum_{t=1}^{T} g\left(\frac{L_t}{K_t}\right),$$

where $g(x)$ is the growth rate of x.

Both these computations provide negative values of $\gamma_{L,K}$. However, these values are small in absolute value, and labor income share computed using production functions from equation (1) and (29) counter-factually trends upward with these parameter values.

E.A Rates of Return and Sample Exclusions

The computation of rates of return on different types of capital in equation (7) assumes perfect foresight. This tends to be a common assumption after seminal works by Jorgenson and Siebert (1968a,b). An alternative approach assumes that producers anticipate no capital gains (Jorgenson, 1963). The returns on different types of capital $i \in \{ICT, IP, TK\}$ are expressed as follows in such a case:

$$r_{i,t} = r_t p_{i,t} + \delta_i p_{i,t-1}.$$

The main results are robust to this alternative specification of returns on different types of capital.

There is considerable variation in returns across different types of capital, primarily driven by fluctuations in corresponding investment prices. As part of a robustness check, I rescale the investment prices for ICT and IP capital by a constant factor such that the

average returns, computed using equation (7), are equalized across these capital types and with the returns on traditional capital. I perform this rescaling in two ways: (i) using the average returns across years and countries, and (ii) using the average returns over years. The main results remain largely unaffected by these adjustments.

Additionally, the findings are robust to the exclusion of years associated with economic crises in European countries. The parameter estimates are also qualitatively similar to the estimates in column 1 of Table 4 within each country except for Germany and Spain.