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Labour-augmenting technical change data for alternative elasticities of substitution, growth, slowdown, and distribution dynamics

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Labour-augmenting technical change data for alternative elasticities of substitution, growth, slowdown, and distribution dynamics

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Abstract. We solve the standard production function with constant elasticity of substitution (CES) for its labour augmenting technology term. We make capital stock data and insert them together with data from Penn World Tables (PWT9.1). This provides labour augmenting technology levels and growth rates for alternative elasticities of substitution for 70 countries, 1950-2017. The percentage growth rates of labour-augmenting technical change (LATC) are shown to fall over time (productivity slowdown) for all elasticity values in a panel data analysis. They converge to a panel average of 2.67% and 1% depending on the inclusion of human capital and the elasticity of substitution assumed. The standard growth result of a GDP growth rate equal to that of LATC and labour input holds only for LATC based on low elasticities of substitution indicating that the economies are not in steady-states. The correlation of LATC growth rates with total factor productivity growth from PWT9.1 is strongest (0.893) for LATC data based on an elasticity of substitution of 0.8. Matching the labour/capital share ratios from CES functions with those of PWT9.1 reveals a range of elasticities of substitution for each country, mostly between 0.8 and 1.2 or somewhat lower for developing countries. If the MPL-to-wage ratio is 1.6, the elasticities of substitution vary around 0.8. Using the human-capital corrected LATC growth with CES = 0.8, 13 of 69 countries have a productivity slowdown defined as growth rate below mean in the long run; the USA is not among them indicating that the US productivity slowdown is mainly one of human capital. Dynamics of coefficient of variation and kernel density distributions for LATC growth rates shows that there is neither technological convergence nor divergence.

Keywords: technical change, growth, productivity slowdown, convergence. JEL code: O47.

1. Introduction

Tinbergen (1942), Solow (1957) and Denison (1962) and many others later[1] calculated total factor productivity (TFP) residuals using the Cobb-Douglas function with unitary elasticity of substitution. Feenstra et al. (2015) and Inklaar et al. (2019) calculate TFP as the geometric average of two relative revenue functions of the translog type.

Estimates of elasticities of substitution assuming a CES function, invented by Solow (1956), have found lower values of the elasticity of substitution than unity. Arrow et al. (1961) found an elasticity of 0.57. Rowthorn (1996) averaged the result of 33 later studies and found a median value of 0.58.[2] Antras (2004) suggests a range of 0.3-0.9 for the private sector of the USA. Ziesemer (2005) estimates 0.35 for the USA. Klump et al. (2007) suggest a range of 0.5-0.6 for the USA.[3] Chirinko (2008) suggests an interval of 0.4-0.6 surveying literature regarding USA, UK and Mexico. Knoblach et al. (2020) suggest an interval of 0.45-0.87 from 77 studies. There are a few suggestions for higher

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[1] See Fagerberg 1994, Griliches 1996, Inklaar and Timmer 2013, Bergeaud et al. 2017.

[2] He also shows that elasticities are below 0.3 when household substitution of goods is taken into account.

[3] Considering total output minus indirect tax revenues, public-sector output, and housing-sector.

values such as Piketty's (2014) value of 1.3. Because of this evidence, Cobb-Douglas functions have served mainly as simplifying assumption in growth theory but seem inadequate for empirical work.

Elasticities of substitution lower than unity lead to CES functions other than Cobb-Douglas. For these, to the best of our knowledge, factor productivities have not yet been derived as data.[4] We do so in this paper making some simplifying assumptions. In particular, with no agreement on the value of the elasticity of substitution, we calculate labour-augmenting productivities and their growth rates for alternative values of constant elasticities of substitution. We then use these new data for an analysis of trends such as the productivity slowdown, steady-state growth regressions, and correlation with TFP growth rates from PWT9.1. Finally, we calculate labour/capital share ratios from a CES function for alternative elasticities of substitution (without and with Pigovian exploitation) and compare them to those from PWT9.1. Similar values indicate which elasticities of substitution are most plausible because they have a strong impact on these shares. Section 2 explains the methodologies of these steps. Section 3 briefly describes the data. Section 4 presents the results for the LATC slowdown, its long-run panel value per elasticity of substitution, labour/capital share ratios and slowdown per country. Section 5 briefly summarises and concludes with some remarks of caution related to policy.

2. Methodology

The CES function with constant returns to scale[5] is assumed to be as follows.

$$Y = [\alpha K^{\rho} + (1-\alpha)(AH^{\delta}L)^{\rho}]^{\frac{1}{\rho}}, \qquad \rho <(>)\ 0 \text{ as } \sigma = 1/(1-\rho) <(>) 1 \qquad (1)$$

Y denotes the GDP, *K* the capital stock, and *L* labour hours, *H* human capital per worker, and *A* labour-augmenting productivity; ρ is called CES parameter and the constant elasticity of substitution is $\sigma = 1/(1-\rho)$. δ = 1 for a model including human capital or zero for a model without human capital. We treat both cases. We assume absence of capital-augmenting technical change. Antras (2004) and Steenkamp (2018) and several earlier studies (see León-Ledesma et al. 2010) find negative constant growth rates for it, which are hard to explain as they may reflect negative unmeasured quality growth or be the mirror image of too high capital growth in the generated capital data.[6] Klump et al. (2007) and Schubert and Neuhäusler (2018) show that it vanishes.

Solving (1) for A yields[7] the level of labour-augmenting productivity as

$$A = \left[\frac{Y^{\rho} - \alpha K^{\rho}}{1-\alpha}\right]^{1/\rho} \frac{1}{H^{\delta}L}. \qquad (2)$$

We use data from PWT9.1 to calculate *A* from (2) for 70 countries 1950-2017 and also calculate growth rates of *A,* labour-augmenting technical change (LATC), as differences of natural logarithms between two periods.

[4] Russel (2018) discusses other alternatives to the CD approach, which mostly are developed from the perspective of multi-sector aggregation, whereas CES functions are used from the macroeconomic perspective of growth and distribution.
[5] In contrast, Denison (1962) and Verspagen (1995), the latter on the basis of translog function estimates, favour increasing returns to scale.
[6] Antras (2004) tentatively attributes that result to capital price deflators capturing quality in the data of Krusell et al. (2000).
[7] We take both sides of the CES function to the power ρ, subtract the capital term, divide by $(1-\alpha)$, take both sides to the power $1/\rho$, and divide by $H^{\delta}L$.

Capital data from PWT9.1 are controversial because of the way of finding the initial value (Inklaar and Timmer 2013, Inklaar and Woltjer 2019). We make capital data ourselves using the perpetual inventory method $K(t) = K(t-1) + I(t) - \delta(t)K(t-1)$. The initial capital stock based on this formula is $K(0) = I(1)/(g_K+\delta(1))$ with $g_K \equiv (K(1)-K(0))/K(0)$. We approximate g_K from the Cobb-Douglas function as $g_K = [g_T - g_Y + (1-\alpha)(g_L+g_H)]/(-\alpha)$ for each period using growth rates of TFP, GDP, labour hours and human capital from PWT9.1. As per-period calculations for 1951 may start in booms or recessions we take the averages of the first six years for the growth rate of capital to construct the initial value. In the early 1950s, growth rates are high leading to low initial capital values. For post-communist periods of Eastern European countries, this method does not work because of highly negative growth rates from 1990-1994. Therefore, we try to find initial values of K/Y values linked to the above formula on a more intuitive case-by-case basis.

The calculation of LATC depends on the values of the distribution parameter α and the model choice $\delta = 1$ or zero. Piketty (2014) uses α = 0.21; Klump et al. (2007) estimate 0.22, which they round to 0.2; León-Ledesma et al. (2010) calculate 0.4; Ziesemer (2005) estimates CES function and marginal product of capital together for the USA and gets 0.38. We experiment with these values also going into the middle of this range setting $\alpha = 0.3$ and calculate levels and growth rates of A with $(\delta = 1)$ and without $(\delta = 0)$ human capital for alternative values of the CES parameter ρ corresponding to elasticities of substitution $\sigma = 1/(1-\rho)$ ranging from 0.1 to 0.99 and from 1.01 to 1.3 as $\rho=0$ cannot be used in (2). (2) can give negative results, a hyperbola with undefined regions, or imaginary numbers close to zero when K is very small relative to Y. We have to treat the imaginary numbers as non-available and we accept the negative results. The consequences will be visible in the regressions for low elasticities of substitution. Alternatives are enlarging K or dividing Y (equivalent to multiplying both distribution parameters α, 1-α) by some factor, which both seem inacceptable.

Results should also be plausible from the perspective of relative labour/capital-share ratios obtained as ratio of marginal products multiplied by the respective factors:

$$\frac{1-\alpha}{\alpha}\left(\frac{K}{AH^{\delta}L}\right)^{-\rho} \tag{3}$$

Tinbergen (1942) uses labour/capital shares of 0.75/025 = 3. Thereafter, traditional views used to be that this equals $0.7/0.3 = 2.33$. More recent discussions suggest $0.5/0.5 = 1$ (Inklaar and Timmer 2013). PWT9.1 have a range from 0.33 to 4.37 independent of a production function. This largest range would be associated with almost all elasticities of substitution. Calculating the values of (3) using the data for K, H and L, the labour/capital share ratio should be roughly between 1 and 3, if factor prices equal marginal products or deviate from it at the same percentage.[8] We will find the associated elasticities of substitution for each country.

Having calculated the data, we first run a regression for each of the growth rates of TFP, human capital, and the LATC variables on a constant and a trend with five autoregressive (ar) terms:

$$g_{it} = c_i + \beta t + u_{it},\ u_{it} = \sum_{j=1}^{5} \gamma_j u_{it-j} + \varepsilon_{it} \tag{4}$$

The coefficient of the trend will tell us whether growth slows down, within sample, but only for a constant panel average rate.

Second, we run fixed effects regressions of the LATC growth rates on their own lags, indexed j.

[8] An interesting, related theoretical case where marginal products are larger than factor prices is shown by Costrell (1986).

$$g_{i,t} = c + \sum_{j=1}^{6} \gamma_j g_{i,t-j} + c_i + c_t + u_{i,t} \tag{5}$$

In case of a positive constant and all slopes and their sum below unity this is a stable difference equation. If this difference equation is stable, we can find the long-run values, telling us how serious the LATC slowdown is for the two models and their alternative elasticities of substitution, according to the current trend.

Third, in the steady state of neoclassical models of exogenous and endogenous growth, the growth rate of the GDP equals the growth rate of LATC plus that of labour. In our terminology, this would be

D(logGDP) = d(logLATC) + d(loghc) + d(logempl) + d(logavh)

Here *hc* is human capital per worker; *avh* are average working hours of an employee; *empl* is the number of workers, in a certain year. We run a fixed effects regression for the GDP growth rate on the four variables on the right-hand side and a time trend with up to five autoregressive (ar) terms (p ≤ 5), assuming slope homogeneity:

$$d(logGDP)_{it} = \beta_1 d(logLATC)_{it} + \beta_2 \, d\big(log(hc)\big)_{it} + \beta_3 d(\log(empl))_{it} + \beta_4 d(\log(avh))_{it} + \beta_5 \, t + \beta_{0,i} + \beta_{0,t} + u_{it} \,, \quad u_{it} = \sum_{j=1}^{p} \gamma_j u_{it-j} + \varepsilon_{it}. \tag{6}$$

As we have data from 1950-2017, the Nickell bias is sufficiently small, and we do not need to resort to system GMM[9] analysis but rather use panel least squares with fixed effects for countries and periods ($\beta_{0,i}, \beta_{0,t}$) with cross-section weights for the estimation of standard errors. The results will tell us for which elasticity of substitution we are closest to the steady-state growth result.

Fourth, we use PWT9.1 data to calculate labour/capital-share ratios for alternative elasticities of substitution according to (3) and compare them to those in PWT9.1, which are obtained independently from a production function assumption. Those elasticities of substitution are most realistic, for which these ratios using a CES function are equal to those from PWT9.1, unless PWT9.1 data are not adequate or CES based marginal productivity ratios are higher than those measured by PWT9.1 in case of monopsonistic labour markets. This results in an elasticity of substitution, or intervals for it, for each country.

Fifth, we run a regression similar to equation (5) but now with full panel heterogeneity for human-capital corrected LATC growth rates for an elasticity of substitution of 0.8 in order to figure out which countries run into a productivity slowdown:

$$g_{i,t} = c_i + \sum_{j=1}^{3} \gamma_{ij} g_{i,t-j} + u_{i,t} \qquad \text{i = 1, ..., 69} \tag{7}$$

These are 69 equations, which we estimate simultaneously using the SUR (seemingly unrelated regression) method, which considers the contemporaneous correlation of the residuals. As this requires sufficiently high *T* compared to *N = 69*, we can use only three lags of which we have dropped the insignificant ones per country. A steady-state LATC growth rate can then be calculated as constant/(1- sum of coefficients of lagged variables). This can be compared to the mean of the dependent variables. Long-run rate minus mean rate is defined as slowdown, which is negative in case of having a slowdown and positive if we have none.

Sixth, we calculate the coefficient of variation of LATC growth rates for elasticities of substitution equal to 0.8 across countries for each year in order to see whether the dispersion of LATC growth is growing or shrinking. The coefficient of variation is a better measure of dispersion for growing

[9] General Method of Moments.

variables than the standard deviation, because in the formula for the latter all variables are growing over time and so does the standard deviation. Dividing by the average takes the average growth out.

Seventh, we estimate kernel density functions of LATC growth rates for 2017, 2007, and 1997 to see the whole distribution and its development over time. Whereas standard deviation and coefficient of variation are special indicators of the dispersion aspect of the distribution, we can also look at the whole distribution. Starting from the histogram with its arbitrary assumption on the width of the classes, which makes it sensitive to manipulation, the kernel density estimate is a smoothed version constructed from all possible histograms avoiding this manipulation. For any given number of columns (bins) of the histogram the width needed to cover all observations follows. A lower number of columns leads to a larger bias as density functions are nonlinear but also to a lower variance, which means higher efficiency. Silverman (1986) provides a statistical method to balance bias against inefficiency. As each number of bins and bandwidth is doing this with a certain probability the method smooths over all possible histograms and provides a unique solution for any given method to ensure that the integral under the density function is unity. We use the kernel named after its inventor Epanechnikov, because it is preferred by Silverman (1986).

3. Data

All data are taken from PWT9.1. In PWT terminology these are as follows. *rgdpna*, for output at constant 2011 national prices (in mil. 2011 US$); *HC* for human capital measured as years of schooling modified by rates of return (see Inklaar and Timmer 2013); *emp*(loyment) in million persons; yearly average hours (*avh*) for labour. Capital data are made as indicated above. We get fourteen LATC variables for fourteen elasticities of substitution stated in the pre-column of Table 1. For many countries there are no hours, labour or human capital data available. This limits the number of countries for which we can get LATC variables to 70. For St Lucia there are no human capital data and for others there is no TFP calculation or no labour shares in PWT9.1. We use the distribution parameter $\alpha = 0.4$ because for lower values we find equality of labour/capital share ratios only for elasticities of substitution much higher than unity.

4. Results

4.1 Some historical trends

We provide the LATC data for 70 countries, 1950-2017.[10] The US growth result for GDP per person 1950-2007 of 1.95% (Fernald and Jones 2014) compares to a labour-augmenting rate of technical progress of 1.98 or 1.93 for elasticities of substitution of 0.5 and 0.6, respectively, and 1.856 to 1.82% for the whole period. When including human capital ($\delta = 1$) the growth rate of LATC is between 1.37% and 1.32% for this period, and 1.3 and 1.27 for the whole period leaving 0.6 or 0.5 for human capital growth. For the sub-periods, we find that for periods of high GDP growth, LATC growth rates are a bit higher and for the low growth periods they are a bit lower than these values. This may be due to well-known issues of capacity utilisation, energy prices, as well as measurement of employment. LATC growth rates may be increasing or decreasing in the elasticity of substitution depending on the year. However, in the sub-periods shown in the appendix they are growing with the elasticity of substitution for. Using PWT9.1 capital data instead for $\alpha = 0.3$ (see appendix), US

[10] The data are available from https://www.merit.unu.edu/publications/wppdf/docs/wp2021-003-dataset.xlsx.
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growth rates for the whole period have a minimum at σ = 0.5, but not for the other sub-periods. However, for the UK, LATC growth rates averaged over the whole period are lower for higher elasticities of substitution. For Japan, for the whole period there is first a decrease, then an increase, and then a decrease again for α = 0.4. In short, the values of the elasticity of substitution and the distribution parameters are not monotonously related to the calculated LATC growth rates on the country level because of the non-linearities in (2). Below we show that this is different for time trends in the growth rates in panel average regressions based on data for α = 0.4.

Finally, (2) can give negative results, a hyperbola with a gap in the range of definition, or imaginary numbers when *K* is very small relative to *Y*. We find this for some early years for Bangladesh, Bulgaria, Myanmar, and Taiwan when CES is 0.1-0.7 (implying ρ in the interval (-9, -.43)) and *K/Y* is below 0.9. This leads to some missing observations in the regressions.

4.2 Productivity slowdown in trend regressions for LATC under panel homogeneity

We regress the growth rates of LATC on a constant and a trend with autoregressive residuals as formulated in equation (4); results are shown in Table 1. Regressions in Table 1 can be compared to those of TFP and human capital growth from PWT9.1 (both with ar(1-5) as in Table 1 and its notes):

$g_{TFP} = 0.0187 - 0.000308t$, 1960-2017, 64 countries, obs: 3266; mean dep. variable: 0.0062.

$g_{HC} = 0.011 - 5.059e\text{-}05t$, 1956-2017, 69 countries, obs: 3767; mean dep. variable: 0.0085.

Table 1: Growth trends of LATC 1950-2017 (a)

LATC with ↓		Without human capital (δ =0)				With human capital (δ=1)			
CES σ	P	Constant	trend (c)	obs(b)	Mean(d)	Const.	Trend (d)	obs(e)	Mean(d)
0.1	-9	0.0511	-0.000593	2872	0.02595	0.0406	-0.000536	2861	0.0178
0.2	-4	0.0506	-0.000586	2880	0.02578	0.0402	-0.000531	2896	0.0176
0.3	-2.33333	0.0507	-0.000573	2899	0.0261	0.0404	-0.00052	2887	0.0179
0.4	-1.5	0.0474	-0.000543	2929	0.0242	0.0396	-0.000486	2918	0.016
0.5	-1	0.0459	-0.000513	2936	0.024	0.0355	-0.000459	2925	0.0158
0.6	-0.66667	0.0437	-0.000474	2937	0.0235	0.0332	-0.000418	2926	0.0153
0.7	-0.42857	0.0412	-0.000431	2938	0.0228	0.0307	-0.000376	2927	0.0146
0.8	-0.25	0.0384	-0.000385	2942	0.0219	0.028	-0.000331	2931	0.0137
0.9	-0.11111	0.0357	-0.000338	2942	0.0212	0.0253	-0.000284	2931	0.013
0.99	-0.0101	0.0331	-0.000294	2942	0.0206	0.0227	-0.000241	2931	0.0124
1.01	0.009901	0.0325	-0.000284	2942	0.0204	0.022	-0.000231	2931	0.0122
1.1	0.090909	0.0299	-0.000239	2942	0.0197	0.0196	-0.000187	2931	0.0115
1.2	0.166667	0.027	-0.000189	2942	0.0189	0.0167	-0.000138	2931	0.0107
1.3	0.230769	0.024	-0.000139	2942	0.018	0.0137	-0.000088	2231	0.0099

(a) Dependent variable: LATC growth rates as in equation (4). Estimation method: Panel EGLS (country fixed effects; cross-section weights); iterated coefficients after one-step weighting matrix; cross-section weights (PCSE) standard errors & covariance (d.f. corrected); adj R-sq are between 0.1 and 0.32 falling from the first to the last line in the left-hand part of the table, and from 0.103 to 0.31 in the right-hand part; autoregressive coefficients not reported; ar(5) is significant, except when CES = 1.3 in the model with human capital (right-hand part of Table 1. (b) Sample (adjusted): 1956 - 2017; countries included: 70 and 69 (no human capital data for St. Lucia). (c) Always $p << 0.05$ for constant and trend. (d) mean dependent variable, unweighted.

All growth rates are positive but falling at small rates. For lower elasticities of substitution, we get higher initial growth rates, which are falling more strongly. Human capital per capita from PWT9.1

has the lowest initial growth rate (intercept) and the smallest fall according to the regressions above. TFP has a growth rate that is similar to those for elasticities of substitution around unity indicating that the translog functions in PWT9.1 are similar to Cobb-Douglas functions. Starting regressions in later periods does not change this. For LATC data based on capital data from PWT9.1, for which we also did the whole analysis, all coefficients and means in Table 1 are larger in absolute size, especially for the higher elasticities of substitution, suggesting a stronger slowdown than Table 1. Table 1, using data made for $\alpha = 0.4$, and the preceding regressions show the following trend results:

1. For all versions of LATC we find an LATC slowdown.[11]

Without human-capital correction,

1. LATC variants based on higher elasticities of substitution lead to lower slowdown and the panel average growth rate is slightly lower.
2. The slowdown of all LATC variants is weaker than that for TFP from PWT9.1 when elasticities of substitution are above unity.
3. Adjusted R-squared (not shown) go down when the CES value goes up. A constant trend explains less when CES values go from 0.1 to 1.3 and other reasons are needed, going beyond the scope of this paper.

With human-capital correction

1. LATC variants based on higher elasticities of substitution lead to lower slowdown, except for the interval 0.1-0.2 where it gets higher.
2. Human capital has a slower slowdown than TFP or any of the variants of LATC from the model with human capital growth.
3. Adjusted R-squared go down when the CES value goes up. A constant trend explains less when CES values go from 0.1 to 1.3 (not shown).

Overall, the slowdown does not vanish when using CES other than unity, but its speed is faster with lower CES while average LATC growth rates (mean dependent variables) are slightly higher.

Whereas Table 1 is an adequate within-sample consideration indicating the slowdown, out-of-sample, in the long run, growth rates would become highly negative, which is implausible. Moreover, trends may not be constant. Table 2 shows regressions results of the LATC rates on their own lags according to equation (5). With slopes and sum of slopes below unity, this is a stable difference equation that leads to constant long-run growth rates shown in the last column. With a positive constant, the long-run growth rates are all positive.

For the model without human capital, long-run growth rates for this panel of 70 countries go to a range of 1.81 – 2.67% with extremes found for the low and the highest elasticities of substitution in Table 2a. The slowdown in the end may be modest on average in this country panel, but it can be serious at the weaker end of the panel, and the trend may worsen in case of structural change in the drivers behind it. For the model with human capital, long-run growth rates for this panel of 69 countries go to a range of 1 – 1.81%. The range 1.5-1.75 suggested by Fernald (2018) is the upper part of our range. The slowdown in the end may be modest also for this version of the panel average. These numbers are higher than those of the recent description in the literature because period fixed effects absorb the crisis periods and emerging economies are included. Separating out the crises periods this way gives some support to an optimistic view only if crises can be avoided.

[11] This also holds when using in addition logs of the trend, squared, cubed, etc.

Table 2a	**Regressions of LATC growth rates on their own lags**			
Model without human capital				
Dependent variable	constant	lag 1	sum lag 2-6	long run
gt01	0.0186	0.1564	0.1464	0.0267
gt02	0.0178	0.1614	0.1128	0.0246
gt03	0.0186	0.3036	-0.0130	0.0263
gt04	0.0156	0.2506	0.1015	0.0241
gt05	0.0170	0.1961	0.0962	0.0241
gt06	0.0177	0.1824	0.1824	0.0279
gt07	0.0174	0.1810	0.0559	0.0229
gt08	0.0164	0.2025	0.0546	0.0220
gt09	0.0163	0.1940	0.0382	0.0213
gt099	0.0170	0.1627	0.0000	0.0203
gt101	0.0169	0.1617	0.0000	0.0202
gt11	0.0165	0.1582	0.0000	0.0196
gt12	0.0159	0.1557	0.0000	0.0189
gt13	0.0153	0.1538	0.0000	0.0181

Notes: gt0x means growth rate of technology for CES = 0.x. Method: Panel Least Squares with period and country fixed effects; Cross-section weights (PCSE) standard errors & covariance (d.f. corrected). Periods: 61-66. Countries: 70. Obs.: 2810 -3222 (depending on lag length). Adj. R-sq 0.16 – 0.265. DW 1.77-2.05 for all regressions. P-values mostly zero, and always below 0.12; coefficients of insignificant lags set to zero.

Table 2b	**Regressions of LATC growth rates on their own lags**			
Model with human capital				
Dependent variable	constant	lag 1	sum lag 2-6	long run
gth01	0.012	0.183	0.159	0.0175
gth02	0.012	0.191	0.116	0.0174
gth03	0.012	0.328	0.010	0.0181
gth04	0.010	0.271	0.097	0.0159
gth05	0.011	0.203	0.103	0.0159
gth06	0.011	0.205	0.070	0.0153
gth07	0.011	0.202	0.063	0.0147
gth08	0.010	0.220	0.061	0.0139
gth09	0.010	0.212	0.045	0.0131
gth099	0.009	0.204	0.036	0.0125
gth101	0.009	0.203	0.034	0.0123
gth11	0.010	0.166	0.000	0.0115
gth12	0.009	0.163	0.000	0.0107
gth13	0.008	0.159	0.000	0.0100

Notes: gth0x means growth rate of technology from model with human capital for CES = 0.x. Method: Panel EGLS (Cross-section weights); Cross-section weights (PCSE) standard errors & covariance (d.f. corrected). Periods: 61-66 . Countries: 69. Obs.: 2849 -3207. Adj. R-sq: 0.16-0.27. DW 1.76-2.03 for all regressions. All p-values mostly zero, and always below 0.11.

For the TFP data of PWT9.1, using the same method, 64 countries and 62 periods, together 3522 observations, we find

g_{TFP} = 0.00483 + 0.235799g_{TFP}(-1), R-sq = 0.17, p = 0.0000 for both coefficients. In the long run, we get g_{TFP} = 0.00483/(1-0.235799) = 0.00632, or 0.6 percent, which is much lower than LATC growth rates. For human capital per capita we find

g_{HC} = 0.00133 + 0.92g_{HC}(-1) - 0.3g_{HC}(-5) + 0.268g_{HC}(-6) - 0.17g_{HC}(-10) + 0.13g_{HC}(-11), leading to a long-run growth rate of 0.001596, or 0.16 percent.

Overall, according to PWT9.1 the slowdown goes much further than for our LATC rates, where the latter may be a maximum because crises are absorbed in the period fixed effects.

4.3 Steady-state or transitional growth?

Results from the estimation of growth equation (6) are shown in Table 3 and 4. Table 3, using the model without human capital, does not include human capital growth, whereas Table 4 does. For the human capital variable, the log difference used by Inklaar and Timmer (2013) performs better than the non-log difference used by Barro and Lee (2010). The autoregressive terms in (6) capture parts of transitional growth, business cycles, and substitute for serial correlation through misspecification for omitting the other 150 potential regressors (Durlauf et al. 2005). However, the adjusted R-squared suggests that many of these regressors like investment in capital would also work through the ones included in the regression, for which one could add equations to come to a dynamic simultaneous equation system, which is not the purpose of this paper though.

Table 3 Steady-state growth regressions for alternative elasticities of substitution (model without human capital)

CES	**Constant**	**g_{LATC} (CES)**	**g_{empl}**	**g_{avh}**	**trend**	**Adj. R^2**	**DW**	**ar terms**
0.1	4.33E-05	0.9997	0.99993	0.9998	-3.14E-7	0.999997	1.85	1,2,4,5
0.2	0.000587	0.9939	0.9966	0.9959	-6.39E-6	0.9999	1.955	1,2,4,5
0.3	0.0004134	0.93	0.9964	0.952	-5.6E-5	0.993	2.05	1, 5
0.4	0.009186	0.896	0.937	0.992	-9.52E-5	0.993	1.814	1, 5
0.5	0.011450	0.867	0.897	0.883	-0.000123	0.995	1.947	1,3
0.6	0.015127	0.823	0.853	0.84	-0.000163	0.995	1.93	1,3,4,5
0.7	0.019205	0.771	0.805	0.788	-0.000206	0.9945	1.91	1,3,4,5
0.8	0.023524	0.719	0.753	0.736	-0.00025	0.999	1.937	1,2,3
0.9	0.027431	0.6665	0.7	0.699	-.000289	0.995	1.98	1,2,5
0.99	0.031920	0.625	0.662	0.634	-.000341	0.989	1.95	1,2,3
1.01	0.03	0.615	0.655	0.624	-.000329	0.988	1.83	1
1.1	0.0356	0.57	0.612	0.576	-.000379	0.987	1.96	1,2,3
1.2	0.0387	0.52	0.57	0.525	-.00041	0.983	1.98	1,2,3,5
1.3	0.042	0.47	0.53	0.478	-.000449	0.976	1.95	1,3,5

Dependent variable d(log(GDP). Estimation method: Panel EGLS (Cross-section weights). Sample (adjusted): 1953(1956) -2017. Periods: 62 (+5-p, depending on autoregressive (ar(p)) terms; countries 70; obs: 2872 - 3082. Iterate coefficients after one-step weighting matrix. Cross-section weights (PCSE) standard errors & covariance (d.f. corrected). P values for other than ar(p) terms are 0.0000. Insignificant ar(p) terms eliminated when clearly above ten percent level. Period fixed effects not allowed with ar-terms.

Table 3 and 4 show that unit coefficients for LATC and all labour growth variables are obtained only for an elasticities of substitution below 0.3. These low elasticities are plausible when substitution actually takes place between goods at the household's utility level and is attributed less to production (Rowthorn 1999). For higher elasticities of substitution, we see lower coefficients except for intercept and trend. Adjusted R-squares are high but also falling when LATC data are based on higher elasticities of substitution. Conditional on the expectation that we should find unit coefficients for LATC and labour growth variables as in steady states of growth theory models, the results of Table 3 and 4 might seemingly favour low elasticities of substitution in production. However, more realistically, many countries are in transition and have falling interest rates. If elasticities of substitution are low, substitution in the transition does not affect capital-labour ratios, and results appear as if belonging to a steady state with no changes of interest rates. If elasticities of substitution are high instead, falling interest rates generate an additional non-steady-state effect leading to coefficients below unity.

Table 4 Steady-state growth regressions for alternative elasticities of substitution (model with human capital)

CES	**C**	g_{LATC} **(CES)**	g_{hc}	g_{empl}	g_{avh}	**trend**	**Adj. R^2**	**DW**	**ar terms**
0.1	4.35E-05	0.9997	0.9996	0.99993	0.9998	-3.17E-7	0.999997	1.83	1,2,4,5
0.2	0.000593	0.994	0.9917	0.9967	0.996	-6.42E-6	0.9999	1.95	1,2,4,5
0.3	0.003849	0.93	0.95	0.965	0.95	-5.46E-5	0.99994	2.046	1, 5
0.4	0.002466	0.968	0.963	0.974	0.973	-2.01E-5	0.993	1.81	1, 5
0.5	0.011415	0.87	0.845	0.899	0.886	-0.000121	0.996	1.965	1,3,4
0.6	0.015292	0.824	0.8	0.854	0.84	-0.000164	0.995	1.927	1,3,4,5
0.7	0.019385	0.77	0.75	0.8	0.788	-0.000207	0.995	1.91	1,3,4,5
0.8	0.023650	0.719	0.705	0.753	0.737	-.000252	0.994	1.976	1,2,3,5
0.9	0.027518	0.667	0.655	0.704	0.697	-.000290	0.993	1.94	1,2,3
0.99	0.030555	0.624	0.624	0.665	0.634	-.000324	0.988	1.83	1
1.01	0.031116	0.615	0.613	0.656	0.624	-.000329	0.988	1.83	1
1.1	0.035706	0.572	0.564	0.614	0.577	-.00038	0.987	1.96	1,2,3
1.2	0.038741	0.522	0.518	0.571	0.526	-.000411	0.983	1.98	1,2,3,5
1.3	0.042227	0.473	0.474	0.532	0.479	-.00045	0.976	1.95	1,2,5
rtfpna	0.028083	1.02	0.6	0.66	0.615	-.000255	0.977	1.956	1

Dependent variable d(log(GDP). Estimation method: Panel EGLS (Cross-section weights). Sample (adjusted): 1953(56) -2017. Periods: 62 (+5-p, depending on ar(p) terms); countries 69; obs: 2861 - 3207. Iterate coefficients after one-step weighting matrix. Cross-section weights (PCSE) standard errors & covariance (d.f. corrected). P values for slopes and intercepts are 0.0000. Insignificant ar(p) terms eliminated above ten percent level.

The last regression in Table 4 uses the TFP variable from PWT9.1. As, in Cobb-Douglas functions, TFP variables differ from LATC variables by an exponent 2/3, it is plausible that its coefficient is higher by a factor of about 3/2, compared to the coefficients of the LATC variables for unitary elasticities of substitution. This also raises the question how much using a translog function in PWT9.1 is different from using a Cobb-Douglas function, its special case.

Table 5 Correlation coefficients of TFP and LATC growth rates

GTH01	0.8455	GTH06	0.885	GTH101	0.88
GTH02	0.848	GTH07	0.891	GTH11	0.867
GTH03	0.855	GTH08	0.893	GTH12	0.844
GTH04	0.865	GTH09	0.89	GTH13	0.812
GTH05	0.876	GTH099	0.883	-	-

Note: GTH0x defines growth rate of LATC for elasticity of substitution 0.x from the model with human capital.

Table 5 shows that growth of TFP from the PWT9.1 is more strongly correlated with the growth of LATC from the human capital model when elasticities of substitution are around 0.8. Whereas one might expect that this should be around an elasticity of substitution of unity, we should keep in mind that we use different capital data than PWT9.1 when making technical change calculations. For regression analysis, it may matter which technical change series one uses as also seen in the other tables.

5. Results for panel heterogeneity

5.1 Linking elasticities to labour/capital-share ratios

So far, we have explored LATC results for all elasticities of substitution. Moreover, results for using distribution parameter values $\alpha = 0.3$ or $\alpha = 0.22$ instead of $\alpha = 0.4$ would change the above results only slightly numerically. The question then is how to find the more plausible values for the elasticities of substitution. For the labour/capital-share ratio from equation (3) the distribution parameter does matter a lot. The labour/capital-share ratio should probably be between the traditional value of 0.75/0.25 = 3 and the more recent one of 50/50 =1 (Inklaar and Timmer 2013) although PWT9.1 has a range from 0.33 to 4.37. The question then is, which value of the distribution parameter and elasticities of substitution in (3) bring about labour/capital-share ratios from (3) in this interval. For $\alpha = 0.4$ our data generate labour/capital-share ratios between 1 and 3 for values of σ mostly between 0.8 and 1.2 (not shown), but often outside this interval. Lower values of the distribution parameter require higher elasticities of substitution to be in this interval.

In order to come to a more specific result, we can compare the labour/capital-share ratios found for the alternative elasticities of substitution according to (3) to those from the labour share of PWT9.1, which have been derived without assumptions on production functions (Inklaar and Timmer 2013). Table 6 provides elasticities of substitution for which the theoretical labour/capital-share ratio is closest to that from PWT9.1. CES values of 0.5 and lower are mostly related to (former) developing countries. For India, Korea, the Netherlands, Poland, Portugal, Sweden there is a remarkable result that, over time, ever lower labour/capital share ratios according to PWT9.1 go together with ever higher elasticities of substitution. For Iceland, the CES is point 0.9 until 2007 and then increases to higher values during the crisis with, so far, no complete return. In Peru, the elasticity jumps from 0.4 beyond 1.3 in 1978. In Taiwan, the elasticity increases without a falling labour share from 1959 to 2000; then the labour share starts falling.

Overall, the elasticities of substitution obtained in this way are between 0.7 and 1.2, much higher than those from the literature reported in the beginning. More similar results would require that labour shares of PWT9.1 would be much higher, although they are corrected upward already. Then CES-based ratios could be much higher, which would be the case for lower elasticities of substitution.

Table 6 Countries' elasticity of substitution from equalising labour/capital-share ratios from CES and PWT (a)

Country	*CES*	*country*	*CES*	*country*	*CES*
Argentina	>1.3	Hungary	0.9-1	Poland	0.9-1.2
Australia	0.8 - 1	Iceland	0.9 (-1.1)	Portugal	0.5-1.2
Austria	0.9-1.1	Indonesia	1.3	Philippines	>1.3
Bangladesh	- (c)	India	0.6-1.3	Romania	1.1-1.3
Belgium	0.9 - 1	Ireland	1.1 - 1.3	Russian Fed.	1-1.1
Brazil	1 -1.3	Israel	1 -1.1	Singapore	1.2-1.3
Bulgaria	(0.5 -) 1.3	Italy	1 -1.2	Slovakia	1-1.2
Cambodia	- (c)	Jamaica	1 – 1.3	Slovenia	0.8-1
Canada	0.5-0.9	Japan	0.9-1.1	Spain	0.7 - 1
Chile	1.3	Korea Rep.	0.6-1.2	Sri Lanka	>1.3
China	1 – 1.2	Lithuania	1 - 1.3	St Lucia	(c)
China, HK	1.1 – 1.3	Luxemburg	1.2 - 1.3	South Africa	1.1-1.3
Colombia	1.3	Latvia	1 – 1.2	Sweden	0.9-1.1
Costa Rica	1.1	Malta	1.1-1.3	Switzerland	0.9
Croatia	0.9 – 1	Malaysia	>1.3	Taiwan	0.1-0.9
Cyprus	1 – 1.2	Mexico	>1.3	Thailand	>1.3
Czech Rep.	1.1 – 1.2	Myanmar	(c)	Trindd.&Tobg.	1.1-1.3
Denmark	0.8 – 1	Nigeria	0.4	Turkey	>1.3
Ecuador	0.9-1.3	Netherlands	0.7-1.1	Unit. King	1 – 1.1
Estonia	0.6-0.8	Norway	1 – 1.2	Uruguay	1.1-1.3
Finland	0.8-1.1	New Zealand	1 -1.1	USA	0.9-1
France	0.7 – 1	Pakistan	- (c)	Venezuela	(>)1.3
Germany	0.8 – 1	Peru (b)	0.2-0.4, >1.3	Vietnam	(c)
Greece	1.1 – 1.2				

(a) Numbers in parentheses are exceptions. (b) labour shares fall from 0.74 to 0.45. (c) missing labour share data in PWT9.1.

The literature for wage-productivity gaps finds that marginal products of labour (MPL) are higher than wages and other labour costs, and discuss the reasons, mostly monopsonistic labour markets reducing labour demand and decreasing wages.[12] We use their results under the assumption that interest rates equal the marginal product of capital.[13] Under this assumption, the labour/capital ratios from CES functions divided by that of PWT9.1 is equal to the marginal-productivity-to-wage ratio in this gap literature. The MPL-to-wage ratio is linked to the Pigovian exploitation rate $E = (f'-w)/w$ or $f'/w = 1+E$ (Persky and Tsang 1974). Conceptually, this assumes that all labour costs are well included in the calculations, in addition to wages; for example, training costs paid by firms emphasised by Altman and Fisher (1969) and/or fixed costs of hiring as in models of Pissarides (2000). Both need to be re-earned over time and therefore marginal productivity conditions do not hold at every point in time (Gottschalk 1978; Manning 2011).[14]

[12] Manning 2021 reviews the conceptual literature.

[13] In Liu et al. (2010) the profit rate is 1.34 the marginal revenue product of capital and in Thurow (1968) it is between 2.5 and 1.5, bringing the labour/capital-share ratios to even higher values. Gottschalk (1978) also finds that capitals get more than its marginal product, and labour gets less.

[14] If they are credit financed, labour costs are turned into per-period capital costs (Pissarides 2000; Manning 2011).

Table 7 Countries' elasticity of substitution from matching labour/capital-share ratios from CES and PWT for an MPL-to-wage ratio of 1.6 (a)

Country	*CES*	*country*	*CES*	*country*	*CES*
Argentina	0.9-1.3	Hungary	0.7-0.8	Poland	0.7-0.9
Australia	0.7-0.8	Iceland	0.7 -0.9	Portugal	0.3-0.9
Austria	0.7-0.9	Indonesia	1-1.3 (e)	Philippines	1.1-(>)1.3
Bangladesh	- (c)	India	0.5-1	Romania	0.9-1.1
Belgium	0.7 -0.8	Ireland	0.8 – (>)1.3	Russian Fed.	(0.8-) 0.9
Brazil	0.8-0.9 (0.99)	Israel	0.8-0.9	Singapore	1-1.1
Bulgaria	(0.1)0.8-1.1(1.3)	Italy	0.7-1	Slovakia	0.8-0.9
Cambodia	- (c)	Jamaica	0.8-1.1 (e)	Slovenia	0.7-0.8
Canada	0.4-0.8	Japan	0.5-0.9 (d)	Spain	(0.1) 0.3 – 0.9
Chile	(0.9) 1-1.1 (1.3)	Korea Rep.	0.3-1 (d)	Sri Lanka	>1.3
China	0.3-0.9 (d)	Lithuania	0.8-1	St Lucia	(c)
China, HK	0.9 – 1.3 (e)	Luxemburg	1 - 1.2	South Africa	0.8-0.9
Colombia	1-1.1	Latvia	0.8 – 1	Sweden	0.7-0.9
Costa Rica	0.7-0.8	Malta	0.9-1	Switzerland	0.7-0.8 (d)
Croatia	0.7 – 0.8	Malaysia	>1.3	Taiwan	0.4-0.7 (d)
Cyprus	0.8-1	Mexico	1.1-1.3	Thailand	0.8-1.3
Czech Rep.	0.9 – 1	Myanmar	(c)	Trindd.&Tobg.	1.1-1.3
Denmark	0.4 – 0.8	Nigeria	0.5-1 (d)	Turkey	1.1-(>)1.3
Ecuador	0.7-1.3 (e)	Netherlands	0.5-0.9 (d)	Unit. King	0.8-0.9
Estonia	0.8-0.9	Norway	0.9-1	Uruguay	0.9-1.1
Finland	0.8-1.1 (d)	New Zealand	0.8-0.9	USA	0.7-0.8
France	0.5 – 0.8	Pakistan	- (c)	Venezuela	1-1.2
Germany	0.6 – 0.8	Peru (b)	0.1-0.3, (d) 1.1-1.3	Vietnam	(c)
Greece	0.9 – 1				

(b) Middle of the range reported by Dobbelaere and Mairesse (2013). Numbers in parentheses are exceptions. (b) labour shares fall from 0.74 to 0.45. (c) missing labour share data in PWT9.1. (d) increasing over time. (e) decreasing over time.

Persky and Tsang report that Liu and Hildebrand (1965) found an MPL-to-wage ratio of 171% for the US stone and glass industry 1967, and of 0.87 for US transport equipment (non-exploitation). Thurow (1968) finds a rate of 1.77 for 1930 and 1.59 for 1957 for the US economy. Persky and Tsang (1974) extend Thurow's work and report an MPL-to-wage ratio of 1.59 for 1965. Liu et al. (2010) find an MPL-to-wage ratio of 1/0.92 = 1.08 for Taiwan. Brummund (2012) finds that current wages are 5.5/18.2 of competitive wages, implying an MPL-to-wage ratio of 3.31. Elgin and Kuzubas (2012) find a rate of 1.14 for Turkish manufacturing. Elgin and Kuzubas (2013) find a rate of 1.15 for 31 countries. Biewen and Weiser (2014) find only small deviations from marginal products for manufacturing plants in Chile 2001-2006 and conclude that larger firms have more monopsonistic power. Okudaira et al. (2019) find that workers get only 67% of the MPL in Japanese manufacturing as an average over plants, implying an average MPL-to-wage ratio of 1.49. Brooks et al. (2019) find an impact of monopsony power on labour share of 0.10 and 0.15 for manufacturing industries in China and India respectively, which corresponds to an MPL-to-wage ratio of 1.22 and 1.67. Tortarolo and Zarate (2020) find a ratio of 1.11 for manufacturing in Colombia. Mertens (2020) reports a range of 0.66-1.32 with an average standard deviation of 0.51 for Germany's industry at the two digit level. Dobbelaere et al. (2020) find an MPL-to wage ratio of 1/0.45 = 2.22 for the 49% of the German plants, which are under the monopsonistic regime.

Dobbelaere and Mairesse (2013) report a range of 1-5 for the wage elasticity of labour supply in the literature. This corresponds to a range of 0.2-1 for the Pigou measure of exploitation and a range of 1.2-2 for the MPL-to-wage ratio, which is slightly narrower than the range from our literature evaluation, 0.66 – 3.31.[15]

MPLs are estimated from Cobb-Douglas functions in most of these papers. Exceptions are Okudaira et al. (2019), Tortarolo and Zarate (2020), Dobbelaere et al. (2020) using a translog function, and Liu et al. using the quadratic terms of a translog function. Other things equal, the MPL from a CES function would be higher with a negative CES parameter belonging to an elasticity of substitution below unity.[16] This would imply even higher ratios of MPL-to-wage. Gottschalk (1978) adds an administration function to the production functions.

It may be interesting to modify the results of Table 6 by way of considering that the MPL-to-wage ratio is 1.6, the middle of the range reported by Dobbelaere and Mairesse (2013). Then, the labour/capital-share ratios from CES functions are by a factor 1.6 higher than those of the PWT9.1 data. Table 7 shows that then the elasticities of substitution are by and large lower by 0.2. If, in addition the marginal product of capital is smaller than interest and dividend rates as in Hildebrand and Liu (1965), Thurow (1968), Gottschalk (1978) and Liu et al. (2010), this would decrease the PWT based ratio relative to the CES based ratios leading to a factor larger than 1.6 and corresponding lower elasticities of substitution again. Finally, most studies are analysing industry or its manufacturing part, some include services but almost none includes the government sector which is most human capital intensive. As machines have a minor role there, elasticities of substitution may actually be smaller again when the government sector could be included. Users of the data can best select the series for the respective elasticity of substitution using background information regarding the country in question and the research question.

5.2 Productivity slowdown for individual countries

Next, we use LATC growth rates from the model with human capital and CES = 0.8, regressing them on a constant and three of its lags. The results are shown in Table 8.

Table 8 **Productivity slowdown or speed up for 69 countries**

Country	*Constant*	*Coeff. sum (a)*	g^*_{LATC} *(b)*	*mean (c)*	*slowdown (d)*	*p of const. (e)*
Argentina	0.0055	-0.1653	0.0048	0.0036	0.0012	0.4062
Australia	0.0228	-0.5146	0.0150	0.0149	0.0001	0.0000
Austria	0.0100	0.5664	0.0231	0.0187	0.0045	0.0009
Belgium	0.0096	0.5251	0.0203	0.0168	0.0035	0.0001

[15] Bosworth et al. (1994) and Zavodny (1999) show that the gap is increasing over time in the USA especially since 1983 even when both are deflated in the same way as emphasized by Feldstein (2008). According to Table 3 in Bosworth et al. (1994) this is also the case for the private sector of France, Italy, Germany, and Japan for all sub-periods, and in manufacturing this is also the case for the UK. In later years these trends are strong in Japan and the USA, absent in the UK and weak in the other countries mentioned (Škare and Škare 2017).

[16] Manning (2021) considers CES functions in a brief appendix. However, the assumed neutral technical change is known to have quite undesirable growth properties like increasing marginal products of capital.

Bangladesh	-0.0010	0.6730	-0.0032	-0.0121	0.0089	0.8373
Bulgaria	-0.2829	0.0000	-0.2829	-0.2888	0.0059	0.0372
Brazil	0.0054	0.3448	0.0082	0.0068	0.0014	0.3275
Canada	0.0073	0.2113	0.0093	0.0078	0.0014	0.0031
Switzerland	0.0137	-0.0936	0.0125	0.0111	0.0014	0.0000
Chile	0.0061	0.1481	0.0072	0.0079	-0.0007	0.3720
China	0.0177	0.2871	0.0248	0.0230	0.0018	0.0037
Colombia	0.0057	0.1795	0.0069	0.0048	0.0021	0.0659
Costa Rica	0.0100	0.3432	0.0152	0.0087	0.0065	0.0334
Cyprus	0.0033	0.3432	0.0051	0.0049	0.0001	0.3146
Czech Rep.	0.0130	0.3208	0.0191	0.0195	-0.0004	0.0151
Germany	0.0194	0.2459	0.0257	0.0237	0.0020	0.0000
Denmark	0.0146	0.0000	0.0146	0.0127	0.0019	0.0000
Ecuador	0.0024	0.0000	0.0024	0.0016	0.0009	0.7452
Spain	0.0131	0.2510	0.0176	0.0160	0.0016	0.0027
Estonia	0.0174	0.3920	0.0287	0.0278	0.0009	0.0464
Finland	0.0185	0.2150	0.0235	0.0202	0.0033	0.0000
France	0.0074	0.6823	0.0231	0.0194	0.0037	0.0040
Unit. King	0.0151	0.0000	0.0151	0.0136	0.0015	0.0000
Greece	0.0092	0.5949	0.0228	0.0143	0.0085	0.0930
China, HK	0.0253	-0.1425	0.0221	0.0197	0.0024	0.0000
Croatia	0.0108	0.3055	0.0156	0.0137	0.0019	0.0820
Hungary	0.0104	0.0000	0.0104	0.0110	-0.0006	0.0298
Indonesia	0.0081	0.2160	0.0104	0.0103	0.0001	0.2169
India	0.0197	0.0000	0.0197	0.0199	-0.0002	0.0002
Ireland	0.0397	-0.1371	0.0349	0.0341	0.0008	0.0000
Iceland	0.0144	0.0441	0.0150	0.0162	-0.0012	0.0030
Israel	0.0124	-0.2232	0.0101	0.0077	0.0025	0.0009
Italy	0.0083	0.5341	0.0179	0.0136	0.0043	0.0095
Jamaica	0.0017	0.0000	0.0017	-0.0011	0.0028	0.8523
Japan	0.0157	0.3990	0.0261	0.0230	0.0031	0.0000
Cambodia	0.0286	-0.0880	0.0263	0.0260	0.0003	0.0000
Korea Rep.	0.0202	0.2368	0.0264	0.0250	0.0014	0.0000
Sri Lanka	0.0175	0.1768	0.0213	0.0191	0.0022	0.0004
Lithuania	0.0384	0.0000	0.0384	0.0367	0.0017	0.0000
Luxemburg	0.0066	0.1778	0.0081	0.0048	0.0032	0.1811
Latvia	0.0295	0.3709	0.0469	0.0431	0.0038	0.0014
Mexico	-0.0006	0.1893	-0.0007	-0.0022	0.0015	0.9051
Malta	0.0236	0.0000	0.0236	0.0241	-0.0006	0.0000
Myanmar	0.0085	0.4773	0.0163	0.0188	-0.0025	0.2360
Malaysia	0.0098	0.1053	0.0110	0.0090	0.0020	0.0582
Nigeria	-0.0382	0.0000	-0.0382	-0.0319	-0.0063	0.1547
Netherlands	0.0112	0.3559	0.0173	0.0155	0.0018	0.0002
Norway	0.0166		0.0166	0.0169	-0.0003	0.0386
New Zealand	0.0071	0.1553	0.0084	0.0098	-0.0014	0.1038
Pakistan	0.0085	0.2797	0.0117	0.0094	0.0023	0.0666
Peru	-0.0035	0.4014	-0.0058	-0.0082	0.0024	0.6049
Philippines	0.0065	0.4945	0.0128	0.0037	0.0091	0.2919

Poland	0.0296	0.1318	0.0341	0.0335	0.0005	0.0000
Portugal	0.0090	0.2419	0.0119	0.0065	0.0054	0.0382
Romania	0.0411	0.1973	0.0512	0.0534	-0.0022	0.0006
Russian Fed.	0.0136	0.5656	0.0313	0.0193	0.0120	0.0661
Singapore	0.0156	0.3409	0.0236	0.0192	0.0045	0.0073
Slovakia	0.0324	0.0512	0.0341	0.0351	-0.0010	0.0000
Slovenia	0.0101	0.2605	0.0136	0.0126	0.0011	0.0872
Sweden	0.0118	0.4014	0.0197	0.0164	0.0033	0.0000
Thailand	0.0178	0.0000	0.0178	0.0157	0.0021	0.0074
Trindd.&Tobg.	0.0276	0.4712	0.0522	0.0307	0.0215	0.0001
Turkey	0.0188	-0.2541	0.0150	0.0132	0.0018	0.0096
Taiwan	0.0290	-0.0081	0.0288	0.0272	0.0015	0.0000
Uruguay	0.0243	-0.0995	0.0221	0.0203	0.0018	0.0014
USA	0.0138	-0.1660	0.0118	0.0114	0.0004	0.0000
Venezuela	0.0030	0.2875	0.0042	-0.0054	0.0096	0.6713
Vietnam	0.0216	0.0000	0.0216	0.0177	0.0039	0.0013
South Africa	-0.0132	0.4788	-0.0254	-0.0105	-0.0149	0.0163

(a) Sum of coefficients of slopes of estimated eq. (7). (b) long-run growth rate of LATC (constant/(1-(a)). (c) mean dependent variable of growth rate. (d) slowdown is (b)-(c). (e) constant, g*, and mean are not set to zero when insignificant.

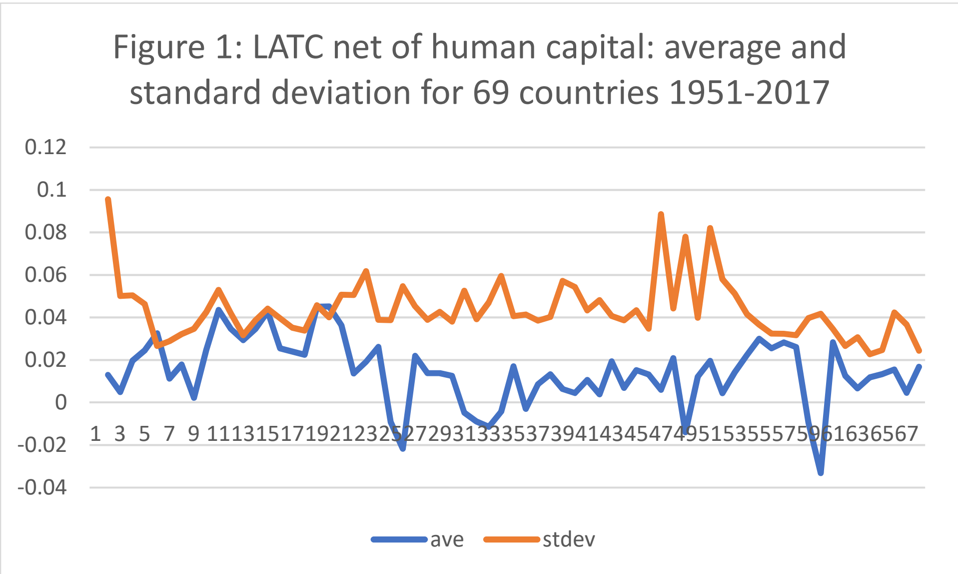
Countries have a slowdown defined as long-run growth rate minus mean dependent variable if the sign in column 'slowdown' is negative. This is the case for 13 of 69 countries. These 13 countries are dominating the panel regressions of the previous section, where we found a slowdown on average for the 69 countries. Moreover, comparing to the mean dependent variable gives less emphasis to the period with strong technical progress before 1973 (Fernald 2018; Chart 2). Some of the EU countries have a slowdown: Czech Rep, Hungary, Malta, Romania, Slovakia. Other rich countries with slowdown are Iceland, New Zealand, and Norway. Emerging economies with slowdown are Chile, India, and South Africa. Some of these countries had high growth rates which are hard to sustain. Among the poor countries for which we have data and find the slowdown are Myanmar and Nigeria, which are weak in turning natural resources into productivity. Countries that are going to speed-up at more than a half percentage point (long-run minus mean > 0.005) are Bangladesh, Bulgaria, Costa Rica, Greece, Portugal, Russian Fed., Trinidad&Tobago, and Venezuela.

More or less surprisingly, Australia, Canada and the USA are not among the countries with slowdown. Perhaps their often claimed slowdown is not in the LATC growth rate but rather in human capital where they are very advanced. Fox (2018) shows for Australia that technical progress keeps increasing, but efficiency is falling. Sharpe and Tsang (2018) look at TFP of Canadian industries but not the macroeconomy. Canada's productivity slump 2001-2009 is most likely temporary according to the analysis of Alexopoulos and Cohen (2018) and ours. Kohlscheen and Nakijima (2020) focus neither on technical change nor human capital but look at US GDP growth. Murray (2018) explains the productivity fall from the 1995-2004 to the 2004-2015 period for the US business sector. Antolin-Diaz et al. (2017) find a downward shift in the mean growth rate (a different definition of slowdown than ours) of the real US GDP at the beginning of the 2000s. Chart 2 of Fernald (2018) may also give the impression of a strong slowdown, but the period of high technical change before 1973 is now only the first third of the data, which is important when estimating a constant time trend but much less so in the estimates of the differential equations. However, Fernald (2018) interprets the period 1995-2004 as exceptional and the other periods after 1973 as normal. This would imply that a downward mean shift from the beginning 2000s may shift back upwards when more data are added as found by Fernald (2014). For the Bai-Perron test for the USA (not shown) we find two breaks for gth08 = c when testing for *L+1* versus *L* breaks (all lags are insignificant in the single equation tests). The corresponding regressions reveal that the reason is no LATC growth between 1973-1983. Before and after this period the growth rates are 1.33 and 1.47 respectively, which is too small to be seen as different from each other by many of the alternative tests. Only when we assume five breaks by assumption (the maximum number allowed by the Bai-Perron test for our data), 1995 is coming up as a breakpoint candidate and so are 2006 or 2008.

6. Distribution: Con- or divergence?

6.1 The cross-country coefficient of variation of LATC over time

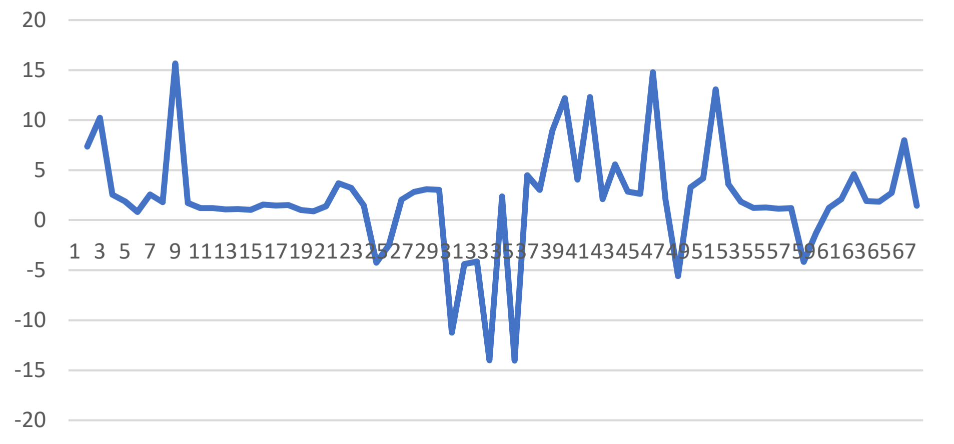
The next question is whether the distribution of technical change will be about constant or show convergence or divergence. Next, we calculate the average, the standard deviation and their ratio, the coefficient of variation, for the growth rates of LATC from the model with human capital.[17] Figure 1 shows the average and the standard deviation per year. Until 1973 rates of technical change are high. Then they fall below two percent. The deepest points are 1975, 1982, 1998, and 2009, which are associated with the pass-through of the high oil prices, the Latin American debt crisis, the Asian crisis, and the financial crisis. The late peaks are 2004, 2006, 2010, which are the end of the ICT bust and return to normal after 2009. The standard deviation is inversely symmetric to the average because it subtracts the average.



The coefficient of variation in Figure 2 deviates from the possible constancy mainly during the lost decade of the 1980s and the ICT bubble 1996-2001. After 2010, the coefficient of variation is slightly higher though and more volatile than it was in the 1960s and 1970s; this period is too short to see strong trends of convergence or divergence in it.

[17] We delete an outlier for Bulgaria 1999 of -3.58.

Figure 2: Coefficient of variation for 69 countries, 1951-2017



6.2 Kernel density distribution of LATC for 2017, 2007, 1997

We calculate the kernel density distribution for the human-capital corrected LATC growth rates derived for a constant elasticity of substitution of 0.8 for 1997, 2007 and 2017.

Figure 3a: Kernel density of LATC growth rates in 1997

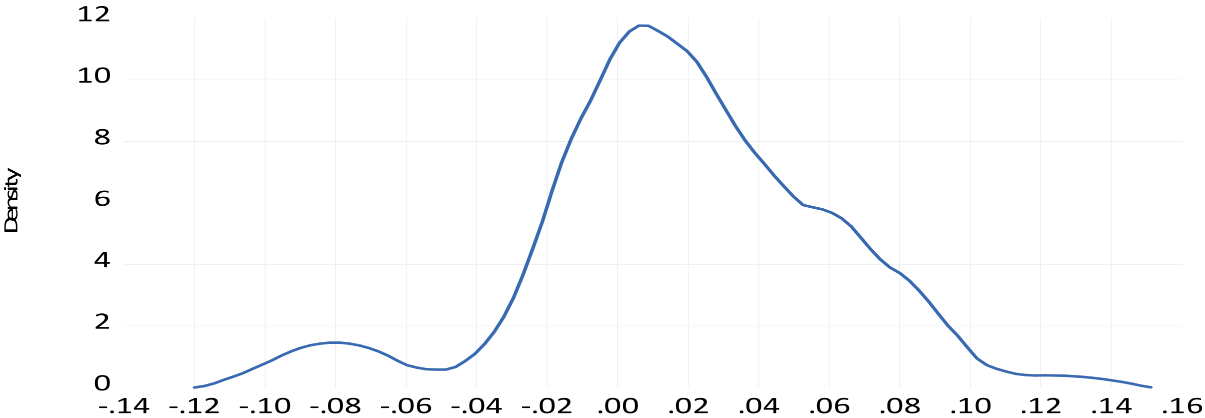


Figure 3b: Kernel density of LATC growth rates in 2007

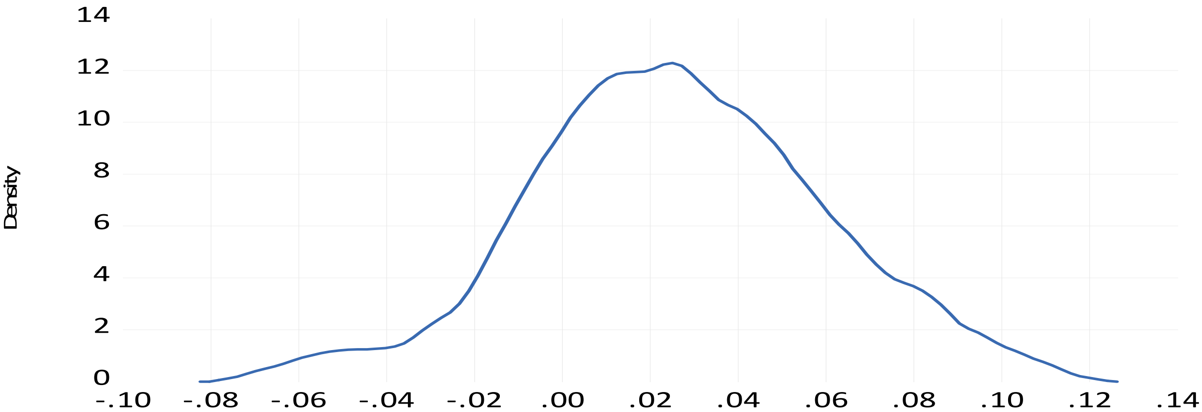
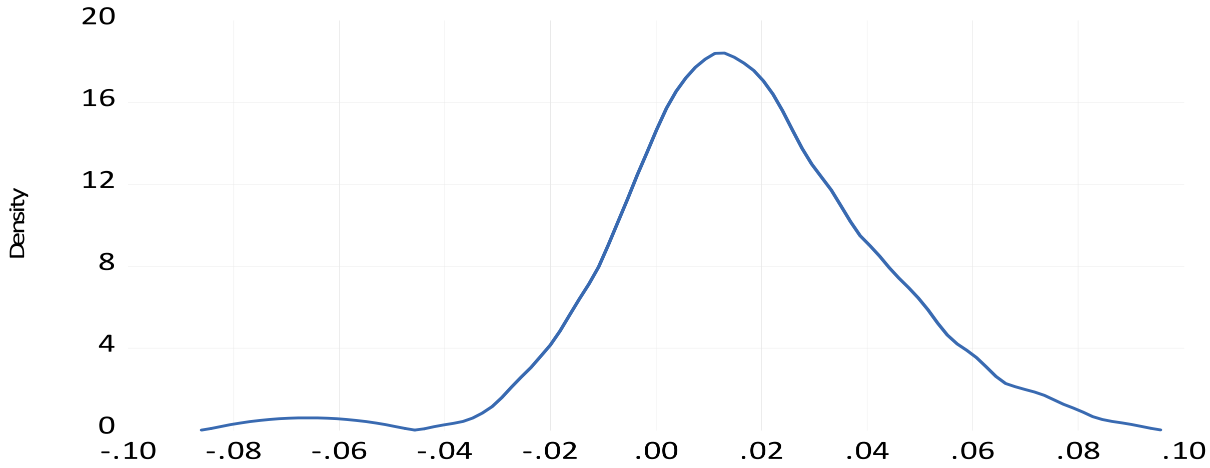


Figure 3c: Kernel density of LATC growth rates in 2017



For earlier years than 1997, the number of countries is much lower, making comparison difficult. The result is shown in Figure 3a-c. Over time, the range on the horizontal axis is getting less broad. The peak in the last figure is higher than the earlier ones. However, about half of all countries have a growth rate of more and the other half of less than the traditional OECD growth rate of two percent. This means that half of all countries are falling behind whereas the other half is catching up in that year. However, these countries need not be always the same ones over the period 1997-2017 and may reflect catching up or falling behind only temporarily. In the end, the lack of a trend in terms of the coefficient of variation and the limited changes in the distribution shows that there is neither convergence nor divergence in terms of LATC growth rates.

7. Summary, conclusion, policies, and remarks of caution

We have calculated and provided levels and growth rates of labour-augmenting technical change from a CES production function for 70 (69) countries from 1950 to 2017.

Regression of the growth rates on a constant trend for the whole period 1951-2017 support the productivity slowdown view for all values of elasticities of substitution through a dynamic panel data analysis with fixed effects assuming slope homogeneity. Autoregressive regressions for the LATC growth rates show that the slowdown is mild on average for our panel of countries because most of it occurs after 1973. Of course, individual countries may escape from the slowdown and others may have a more serious one. Our values for long-run growth rates of LATC are high because time fixed effects capture the crises periods in the panel analysis.

Policies dealing with crises preventively may be considered as promising. A new crisis which is not yet in our data is the COVID-19 crisis. We are all hoping for good effects of a vaccine, which would allow to return to a high productivity. The development of the vaccines has been supported through mission oriented R&D, which may have positive growth effects also when defined more broadly than just medical research (Ziesemer 2019a,b). Moreover, publicly financed R&D expenditures have fallen much (Archibugi and Filippetti 2018). Soete et al. (2020) and Ziesemer (2020) show that permanent shocks on publicly performed R&D have growth enhancing effects in many countries. R&D policies enhancing mission-oriented and public R&D may well be helpful against the productivity slowdown and almost certainly better than cutting publicly performed R&D.

Only for low elasticities of substitution can we confirm the steady-state growth result that output growth rates equal those of technical change and labour. However, our estimates suggest that there are non-steady state processes going on and the lowest elasticities of substitution are therefore not very plausible.

We find elasticities of substitution per country mostly around unity when matching the labour/capital-share ratio from marginal products of the CES function with labour/capital share ratios found by PWT9.1 independent of a production function assumption. However, when the deviation of marginal products of labour from wages is considered in line with the literature they go down to around 0.8. We present the results for the most plausible range of elasticities for 64 countries where all relevant data are available. If marginal products of capital are below interest and dividend rates our way of doing calculations might reveal even lower elasticities of substitution. If the estimation literature would take the government sector into account, even lower elasticities of substitution might be obtained.

Assuming an elasticity of substitution of 0.8 for all countries, we have selected the corresponding LATC growth rates and regressed them on their own three lags. We find that 13 of 69 countries have a productivity slowdown. Some are rich, some are poor, most are emerging economies. Australia, Canada, and the USA are not among them when we look out-of-sample. The literature looks within sample. Looking in detail at the underlying reason requires the space of another paper, but it is obvious that for these three countries the human capital index in PWT9.1 is falling since about 1980.

Analysis of coefficients of variation and kernel density distributions do not support ideas of convergence or divergence beyond short periods.

Our approach of making LATC data, the main intention of this paper, intentionally avoids special emphasis on explicit analyses of episodes of rising and falling oil prices, high, falling, and low interest rates, skill-biased technical change and wage inequality, ICT bust 2001-2004, as well as capital-augmenting ICT and robots,[18] or job and wage polarisation, or financial crisis 2007-2013; we have this in common with those who calculated TFP measures.[19] The effects of these periods are of course included in the capital and labour data used when making the LATC data. We hope though that the LATC data we deliver are as interesting and helpful as the available TFP data based on the special case of Cobb-Douglas functions or similar revenue functions. Users of the data should use country specific information on the elasticity of substitution to select the most adequate data series.

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[18] See Schubert and Neuhäusler (2018) and Klump et al. (2007). Schubert et al. (2020) survey many aspects at disaggregated levels.

[19] Bergeaud et al. (2017) show that some of these waves do not change the long-run pattern of TFP.

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Appendix LATC growth rate variation from elasticity of substitution and distribution parameter using PWT capital data.

	ces	*0.1*	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*0.99*	*1.01*	*1.1*	*1.2*	*1.3*
	parameter	*-9.000*	*-4.000*	*-2.333*	*-1.500*	*-1.000*	*-0.667*	*-0.429*	*-0.250*	*-0.111*	*-0.010*	*0.010*	*0.091*	*0.167*	*0.231*
USA	50-17	0.0192	0.0193	0.0193	0.0194	0.0184	0.0197	0.0199	0.0202	0.0204	0.0206	0.0207	0.0209	0.0212	0.0215
alpha 0.3	50-07	0.0207	0.0208	0.0208	0.0209	0.0211	0.0213	0.0215	0.0217	0.0220	0.0222	0.0223	0.0226	0.0228	0.0231
	50-73	0.0267	0.0267	0.0267	0.0269	0.0271	0.0273	0.0276	0.0279	0.0283	0.0286	0.0287	0.0290	0.0294	0.0298
	74-95	0.0138	0.0138	0.0138	0.0138	0.0139	0.0140	0.0141	0.0142	0.0143	0.0144	0.0145	0.0146	0.0147	0.0148
	'08-17	0.0107	0.0107	0.0107	0.0108	0.0109	0.0110	0.0111	0.0112	0.0113	0.0114	0.0115	0.0116	0.0117	0.0118
USA	50-17	0.0192	0.0193	0.0193	0.0195	0.0185	0.0199	0.0202	0.0206	0.0210	0.0214	0.0215	0.0219	0.0225	0.0230
alpha 0.4	50-07	0.0207	0.0208	0.0208	0.0210	0.0212	0.0215	0.0218	0.0222	0.0226	0.0231	0.0232	0.0236	0.0242	0.0249
	50-73	0.0267	0.0267	0.0268	0.0269	0.0272	0.0276	0.0280	0.0285	0.0291	0.0297	0.0298	0.0305	0.0312	0.0321
	74-95	0.0138	0.0138	0.0138	0.0139	0.0140	0.0141	0.0143	0.0144	0.0146	0.0148	0.0149	0.0151	0.0153	0.0156
	'08-17	0.0107	0.0107	0.0108	0.0108	0.0110	0.0111	0.0113	0.0115	0.0117	0.0119	0.0119	0.0121	0.0124	0.0126
USA	50-17	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003	0.0004	0.0006	0.0008	0.0008	0.0010	0.0013	0.0016
difference	50-07	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003	0.0005	0.0006	0.0008	0.0009	0.0011	0.0014	0.0017
of 0.4 - 0.3	50-73	0.0000	0.0000	0.0000	0.0001	0.0001	0.0003	0.0004	0.0006	0.0008	0.0011	0.0011	0.0014	0.0018	0.0023
	74-95	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0002	0.0003	0.0004	0.0004	0.0005	0.0006	0.0008
	'08-17	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0002	0.0003	0.0004	0.0004	0.0005	0.0007	0.0008
UK	50-17	0.0229	0.0228	0.0228	0.0226	0.0224	0.0220	0.0217	0.0213	0.0209	0.0205	0.0204	0.0201	0.0196	0.0192
α= 0.3	50-07	0.0265	0.0265	0.0264	0.0262	0.0259	0.0256	0.0252	0.0248	0.0244	0.0239	0.0239	0.0234	0.0230	0.0225
	50-73	0.0329	0.0329	0.0326	0.0320	0.0312	0.0301	0.0289	0.0277	0.0263	0.0250	0.0247	0.0234	0.0219	0.0203
	74-95	0.0227	0.0227	0.0226	0.0226	0.0225	0.0224	0.0222	0.0221	0.0219	0.0217	0.0217	0.0215	0.0213	0.0210
	08-17	0.0018	0.0018	0.0018	0.0017	0.0016	0.0015	0.0014	0.0013	0.0011	0.0010	0.0010	0.0008	0.0006	0.0004
UK	50-17	0.0229	0.0228	0.0227	0.0225	0.0223	0.0217	0.0211	0.0205	0.0199	0.0192	0.0191	0.0184	0.0175	0.0166
α= 0.4	50-07	0.0265	0.0265	0.0264	0.0261	0.0257	0.0252	0.0246	0.0240	0.0232	0.0225	0.0224	0.0216	0.0206	0.0196

	50-73	0.0329	0.0329	0.0325	0.0317	0.0305	0.0290	0.0272	0.0252	0.0229	0.0207	0.0202	0.0177	0.0146	0.0113
	74-95	0.0227	0.0227	0.0226	0.0226	0.0224	0.0223	0.0221	0.0218	0.0215	0.0212	0.0211	0.0208	0.0203	0.0198
	08-17	0.0018	0.0018	0.0018	0.0017	0.0016	0.0014	0.0013	0.0010	0.0008	0.0005	0.0005	0.0002	-0.0002	-0.0006
UK	50-17	0.0000	0.0000	0.0000	-0.0001	-0.0001	-0.0003	-0.0005	-0.0007	-0.0010	-0.0013	-0.0014	-0.0017	-0.0021	-0.0026
difference of 0.4, 0.3	50-07	0.0000	0.0000	0.0000	-0.0001	-0.0002	-0.0004	-0.0006	-0.0008	-0.0011	-0.0014	-0.0015	-0.0019	-0.0024	-0.0029
	50-73	0.0000	0.0000	-0.0001	-0.0003	-0.0007	-0.0011	-0.0017	-0.0025	-0.0034	-0.0043	-0.0046	-0.0057	-0.0073	-0.0091
	74-95	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0001	-0.0002	-0.0003	-0.0004	-0.0005	-0.0005	-0.0007	-0.0010	-0.0013
	08-17	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0001	-0.0002	-0.0002	-0.0003	-0.0004	-0.0005	-0.0006	-0.0008	-0.0010
Japan	50-17	0.0378	0.0378	0.0377	0.0375	0.0345	0.0368	0.0363	0.0358	0.0353	0.0348	0.0347	0.0342	0.0336	0.0330
α = 0.3	50-07	0.0431	0.0430	0.0429	0.0426	0.0423	0.0418	0.0412	0.0406	0.0400	0.0394	0.0393	0.0386	0.0379	0.0372
	50-73	0.0683	0.0683	0.0682	0.0681	0.0680	0.0678	0.0676	0.0675	0.0673	0.0671	0.0671	0.0669	0.0667	0.0666
	74-95	0.0310	0.0310	0.0307	0.0302	0.0295	0.0285	0.0275	0.0263	0.0251	0.0240	0.0237	0.0225	0.0211	0.0197
	08-17	0.0080	0.0080	0.0080	0.0080	0.0081	0.0082	0.0083	0.0084	0.0085	0.0087	0.0087	0.0088	0.0090	0.0092
Japan	50-17	0.0378	0.0378	0.0377	0.0374	0.0340	0.0363	0.0357	0.0349	0.0340	0.0332	0.0330	0.0320	0.0308	0.0295
α=0.4	50-07	0.0431	0.0430	0.0429	0.0425	0.0420	0.0413	0.0404	0.0395	0.0384	0.0374	0.0371	0.0360	0.0345	0.0329
	50-73	0.0683	0.0683	0.0682	0.0680	0.0678	0.0676	0.0673	0.0671	0.0668	0.0665	0.0664	0.0661	0.0657	0.0654
	74-95	0.0310	0.0309	0.0306	0.0299	0.0289	0.0275	0.0260	0.0242	0.0221	0.0201	0.0196	0.0174	0.0146	0.0115
	08-17	0.0080	0.0080	0.0080	0.0080	0.0081	0.0082	0.0084	0.0086	0.0088	0.0090	0.0091	0.0094	0.0097	0.0102
Japan	50-17	-0.00000001	-0.0000051	-0.00004	-0.0001	-0.0005	-0.0004	-0.0007	-0.0009	-0.0013	-0.0017	-0.0017	-0.0022	-0.0028	-0.0035
difference0.4, 0.3	50-07	-0.00000002	-0.0000061	-0.00005	-0.0001	-0.0003	-0.0005	-0.0008	-0.0011	-0.0016	-0.0020	-0.0021	-0.0027	-0.0034	-0.0043
	50-73	-0.00000002	-0.0000040	-0.00002	-0.0001	-0.0001	-0.0002	-0.0003	-0.0004	-0.0005	-0.0006	-0.0007	-0.0008	-0.0010	-0.0012
	74-95	-0.00000002	-0.0000108	-0.00009	-0.0003	-0.0006	-0.0010	-0.0015	-0.0022	-0.0030	-0.0039	-0.0041	-0.0051	-0.0065	-0.0082
	08-17	0.00000000	0.0000004	0.00000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003	0.0004	0.0004	0.0005	0.0007	0.0010

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