Convergence and Divergence in Growth Regressions

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Introduction: Why?

- An important empirical questions in economic growth is whether countries tend to converge or to diverge?

- This questions is approached in many ways. Growth regressions find β-convergence, namely convergence conditional on some explanatory variables. But what does it actually mean? And how are these variables chosen? Others look in various ways at distributional dynamics, and usually find divergence. DJT (2005), Barro (2012), Jones (2015).

- This paper offers an extended growth regression model that allows both for convergence and for divergence and enables us to estimate its separate dynamic parameters. It also reconcile the above conflicting findings.

Introduction: What?

- We show that the conditional convergence, namely β-convergence, which is found in growth regressions, should be interpreted as convergence of output per worker to the path of labor augmented TFP.

- But these paths of TFP can either follow the global frontier fully or only partially. The latter countries actually diverge from the global frontier.

- Hence, we find that despite the evidence of β-convergence, which we reaffirm, there is significant divergence between countries that follow the frontier fully, and countries that follow it partially, and between the latter countries as well.

Introduction: How?

- First, we use data not only on output, but also on labor augmented TFP, which is calculated in a similar way to TFP. Such data are now available from PWT 8.0.

- Second, we use a variable that represents the global frontier. Thus, we can estimate by how much the labor-augmented TFP of each country follows the global frontier, in the long-run and in the short-run as well.

- Third, using these two dynamic variables, TFP and the global frontier, enables us to estimate the dynamic parameters without control variables, which are so controversial.

The Growth Regression Model

- To present our contribution we embed it within the canonical Growth Regression Model, as presented in DJT.

- Output is described by: $Y(j,t) = F\left[K(j,t), A(j,t)L(j,t)\right]$

- The labor force grows at a rate $n(j)$ and productivity grows at a rate $g(j)$:

$$L(j,t) = L(j,0)\exp(n(j)t) \qquad A(j,t) = A(j,0)\exp(g(j)t)$$

- Most studies assume that g is common to all countries.

The Long-Run Equilibrium

- Output per worker: $$y(j,t) = \frac{Y(j,t)}{L(j,t)}$$
- Efficiency Output per worker:

$$y^{E}(j,t) = \frac{Y(j,t)}{L(j,t)A(j,t)} = F\left[\frac{K(j,t)}{L(j,t)A(j,t)},1\right]$$

- The marginal productivity of capital is:

$$MPK(j,t) = F_{K}\left[K(j,t), A(j,t)L(j,t)\right] = F_{K}\left[\frac{K(j,t)}{L(j,t)A(j,t)},1\right]$$

- In the long-run marginal productivity of capital is constant, equal to $r + \delta$. Hence so is capital relative to efficiency labor.

The Convergence Assumption

- So in the long-run $K(j,t)/[L(j,t)A(j,t)]$ is constant.

- Hence, efficiency output per worker is also constant in the LR:

$$y^E(j,t) = F\left[\frac{K(j,t)}{L(j,t)A(j,t)},1\right] \xrightarrow[t\to\infty]{} y^E(j,\infty)$$

- The main assumption of growth regressions is that this convergence is gradual:

$$\ln y^E(j,t) = b(j)\ln y^E(j,\infty) + [1-b(j)]\ln y^E(j,t-1)$$

- Gradual adjustment is due either to a closed economy, or to adjustment costs of capital, which applies also for open economies. The $b(j)$ is the famous rate of convergence.

Cross-Country Growth Regressions

- From the convergence equation we can derive the common form of growth regressions: a cross-section regression, where the rate of growth is averaged over a long period:

$$\frac{\ln y(j,T) - \ln y(j,0)}{T} = g(j) + \frac{1-[1-b(j)]^T}{T} \ln A(j,0) +$$
$$+ \frac{1-[1-b(j)]^T}{T} \ln y^E(j,\infty) - \frac{1-[1-b(j)]^T}{T} \ln y(j,0)$$

- Initial TFP and its rate of growth are not observed. They are controlled for by various explanatory variables. As a result this estimation cannot differentiate between a level effect and a rate of growth effect of an explanatory variable.

The Extension of the Model I

- We extend the growth regression model by assuming that instead of growing at a fixed rate $g(j)$, the country's labor-augmented TFP follows the global frontier. The long-run path of TFP is described by:

$$\ln LRA(j,t) = a(j) + d(j)\ln F(t)$$

- *LRA* follows the global frontier. If *d* is equal to 1, it follows the frontier fully, if it is lower than 1, it follows it partially.

- The assumption that *d* can be less than 1, is justified mainly empirically. Theoretically it should be related to the literature on partial adoption of technologies.

The Extension of the Model II

- The global frontier itself is growing steadily over time, at an average rate *g*:

$$\ln F(t) = \ln F(t-1) + g + v(t)$$

- The long-run TFP is not reached immediately, but gradually. Assume that *A* is converging to *LRA* at a rate *c*(*j*), which is country specific.

$$\ln A(j,t) - \mathrm{E}_{t\text{-}1} \ln LRA(j,t) = [1 - c(j)][\ln A(j,t-1) - \ln LRA(j,t-1)]$$

- Hence, each country has three parameters that need to be estimated: *b*(*j*), *c*(*j*), and *d*(*j*). We see below that *b* and *c* are quite similar across countries, but *d* is not.

Estimation of Output Convergence to TFP: Panel Cointegration

- The basic growth regression model implies:

$$\ln y(j,t) - \ln A(j,t) - \ln y^{E}(j,\infty) =$$
$$= [1 - b(j)]\left[\ln y(j,t-1) - \ln A(j,t-1) - \ln y^{E}(j,\infty)\right]$$

- Hence, output should be cointegrated with labor-augmented TFP plus a constant, with coefficient of cointegration equals 1.

- The error correction coefficient should be $b(j)$. According to an open economy adjustment cost theoretical model this coefficient should be around 2 percent.

Estimation of Output Convergence to TFP: A Growth Regression

- We can also write the convergence of efficiency output per worker directly and get:

$$\ln y^E(j,t) - \ln y^E(j,t-1) =$$
$$= b(j)\ln y^E(j,\infty) - b(j)\ln y^E(j,t-1)$$

- This equation implies that we can also examine this convergence through the usual tools of growth regressions, but with respect to y^E instead of y.

- This enables us an estimation of the rate of convergence b in an alternative method.

Estimating TFP Convergence and Divergence: Panel Cointegration

- The extension of the growth regression model implies:

$$\ln A(j,t) - d(j)\ln F(t) - a(j) =$$
$$= [1 - c(j)]\left[\ln A(j,t-1) - d(j)\ln F(t-1) - a(j)\right] - d(j)v(t)$$

- Hence, productivity should be cointegrated with the global frontier, where the coefficient of cointegration is $d(j)$.

- The error correction coefficient should be $c(j)$.

- Note that productivity might converge to its long-run path, but at the same time diverge from the frontier, if $d(j) < 1$.

Estimating TFP Convergence and Divergence: Differences

- We can also write the dynamic equation of productivity that follows the global frontiers in differences over T periods and get:

$$\ln A(t+T) - \ln A(t) = [1 - c(j)][\ln A(t+T-1) - \ln A(t-1)] +$$
$$+ c(j)d(j)[\ln F(t+T-1) - \ln F(t-1)]$$

- This equation means that the rate of productivity growth depends on the lagged rate of productivity growth and on the lagged rate of growth of the global frontier.

- Hence, estimating this equation enables us to calculate the coefficients c and d.

Estimating TFP Divergence through Output Divergence

$$\ln y(j,t) - d(j)\ln F(t) =$$
$$= \left\{1-[1-b(j)]^t\right\}\ln y^E(j,\infty) + \left\{1-[1-c(j)]^t\right\}a(j) +$$
$$+ [1-b(j)]^t\left[\ln y(j,0) - \ln A(j,0)\right] +$$
$$+ [1-c(j)]^t\left[\ln A(j,0) - d(j)\ln F(0)\right]$$

- Output is cointegrated with the global frontier at a coefficient $d(j)$. The error correction is a combination of b and c.

- Hence, output converges to a long-run path, which can diverge from the global frontier and from the countries at the frontier. This reconciles the findings of growth regressions and of divergence of the distribution of output across countries.

Data I

- We use the new PWT 8.0, which includes data on output, labor, capital and the labor share in income.

- We do not use the data on productivity in PWT 8.0, as it treats productivity as multiplicative, while we assume, following DJT and many others, that productivity is labor augmenting.

- In that case productivity is calculated in the following way:

$$\frac{\Delta A}{A} = \frac{1}{s_L}\left[\frac{\Delta Y}{Y} - \frac{\Delta K}{K}\right] + \frac{\Delta K}{K} - \frac{\Delta L}{L}$$

- This is similar to Solow, but divided by s_L.

Data II

- A balanced panel of output per worker and productivity restricts us to 81 countries over 1970-2008. We do not include the years of the current crisis.

- We also examine a smaller sample of 29 countries with data since 1950, mostly developed countries.

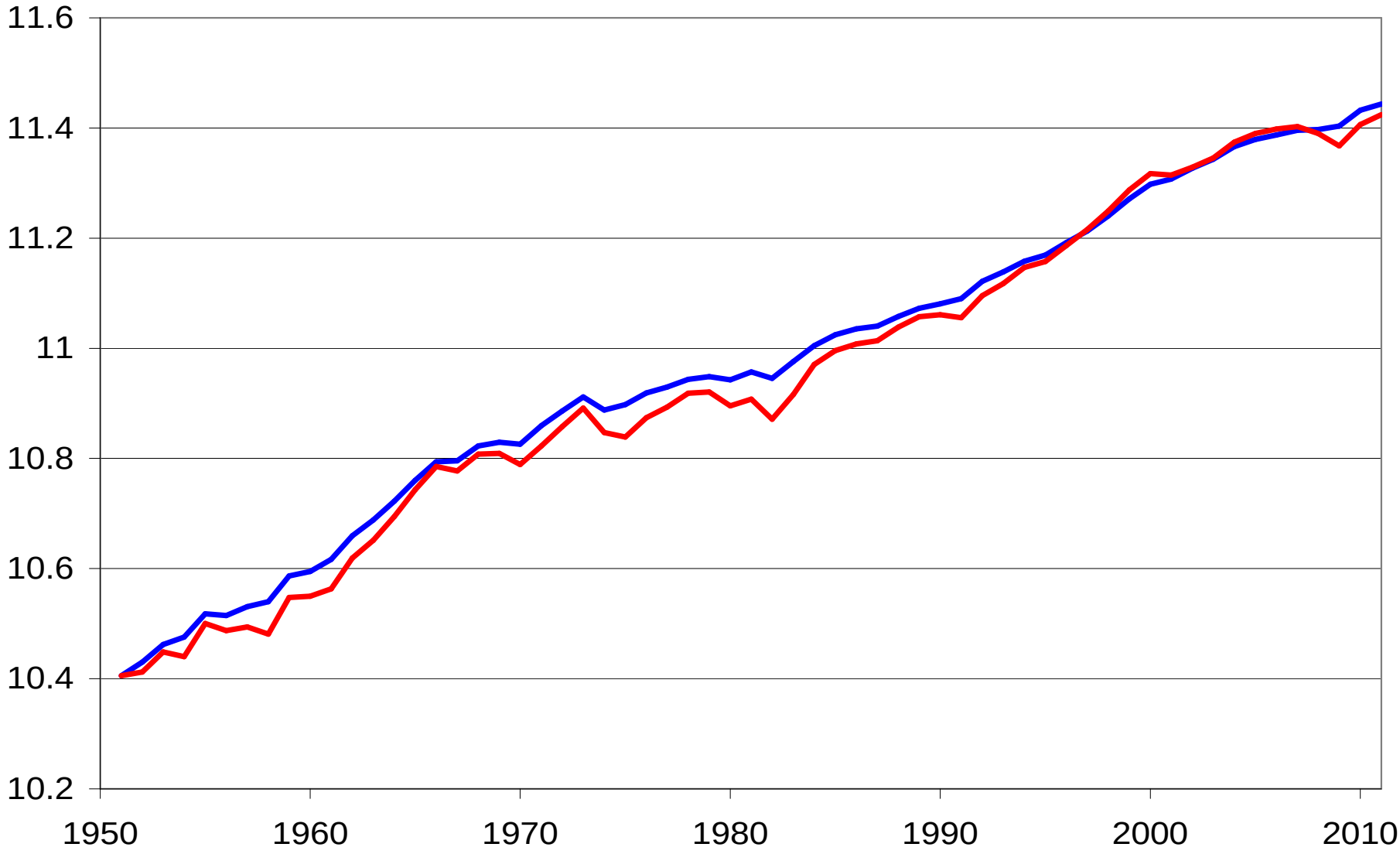
- We also use data on output per capita, but without productivity, from Maddison, which allows us to study 139 countries, over longer time, 1950-2008. Without some outliers (like oil producing countries) we have 124 countries.

- Most estimations use smoothed data over 5 years averages.

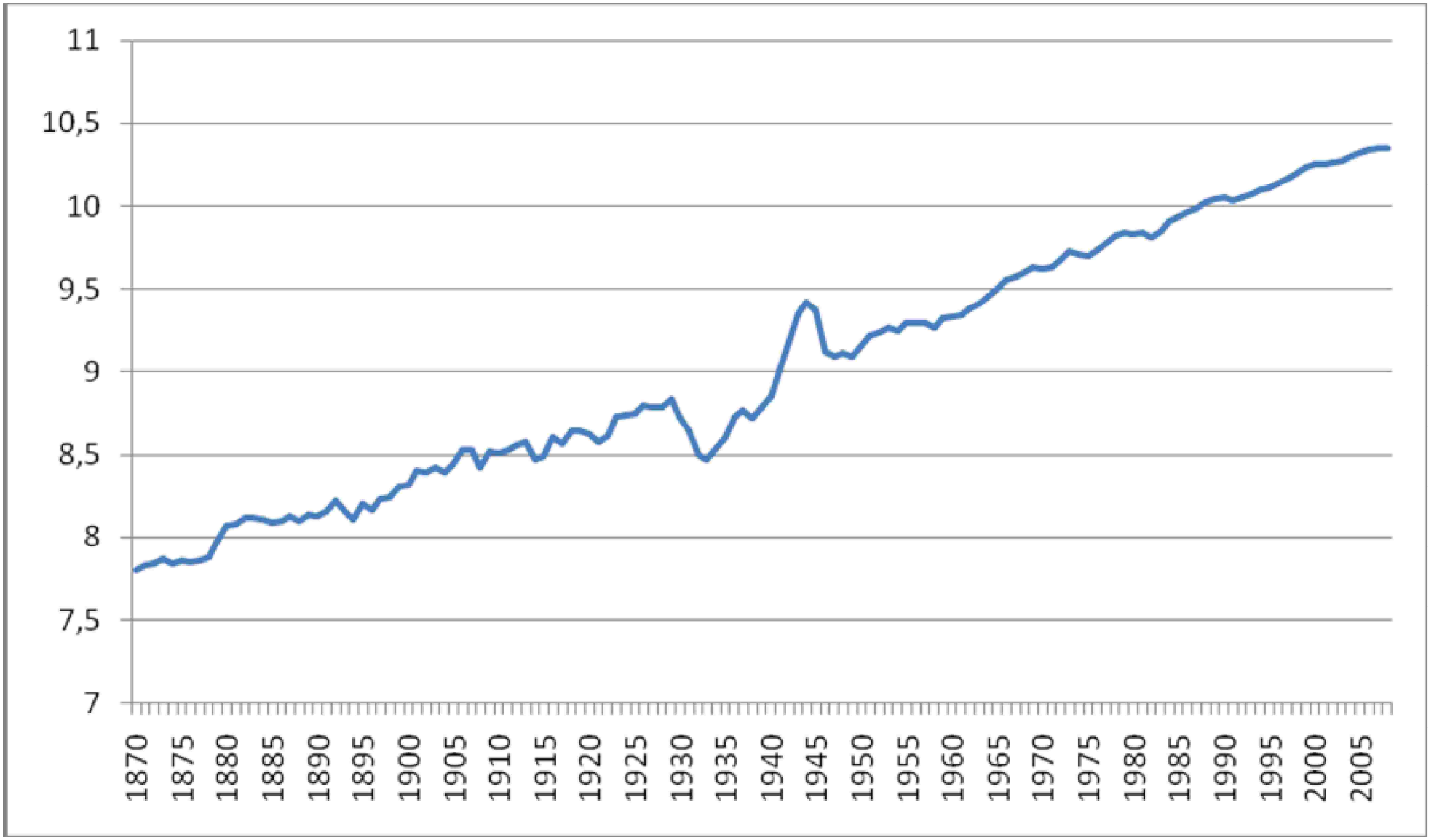
The Global Frontier

- For the global frontier we use as a proxy the US, which has a stable growth rate over the period and is the growth leader among the large developed countries.
- For estimations using PWT 8.0 data we use TFP of US.
- For estimations using Maddison data we use US output per capita.
- We test the time series of US TFP and of US output per capita and find that they indeed satisfy the dynamic assumption on the frontier F above.

US GDP per Worker and TFP: 1950-2010



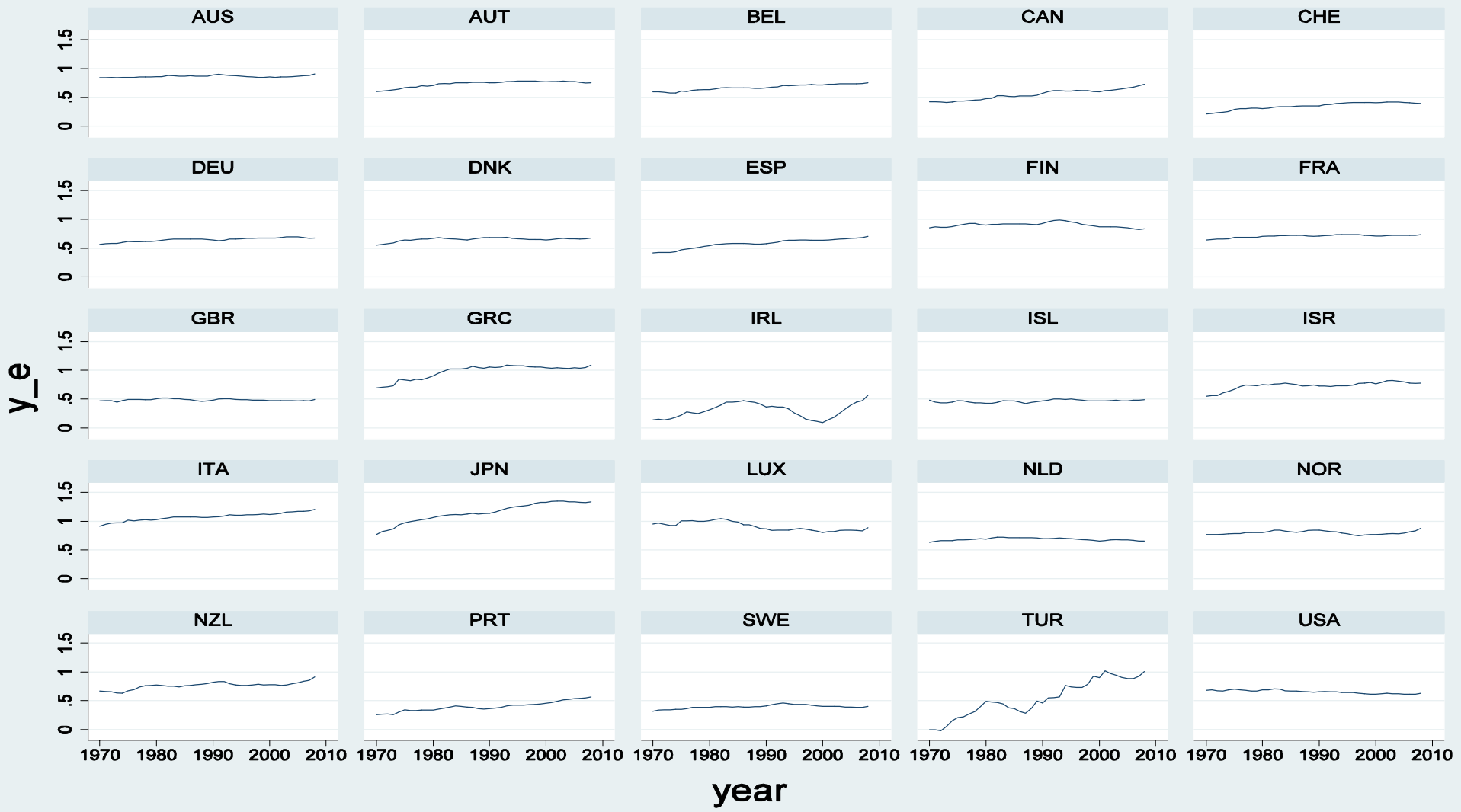
US GDP per Capita 1870-2010



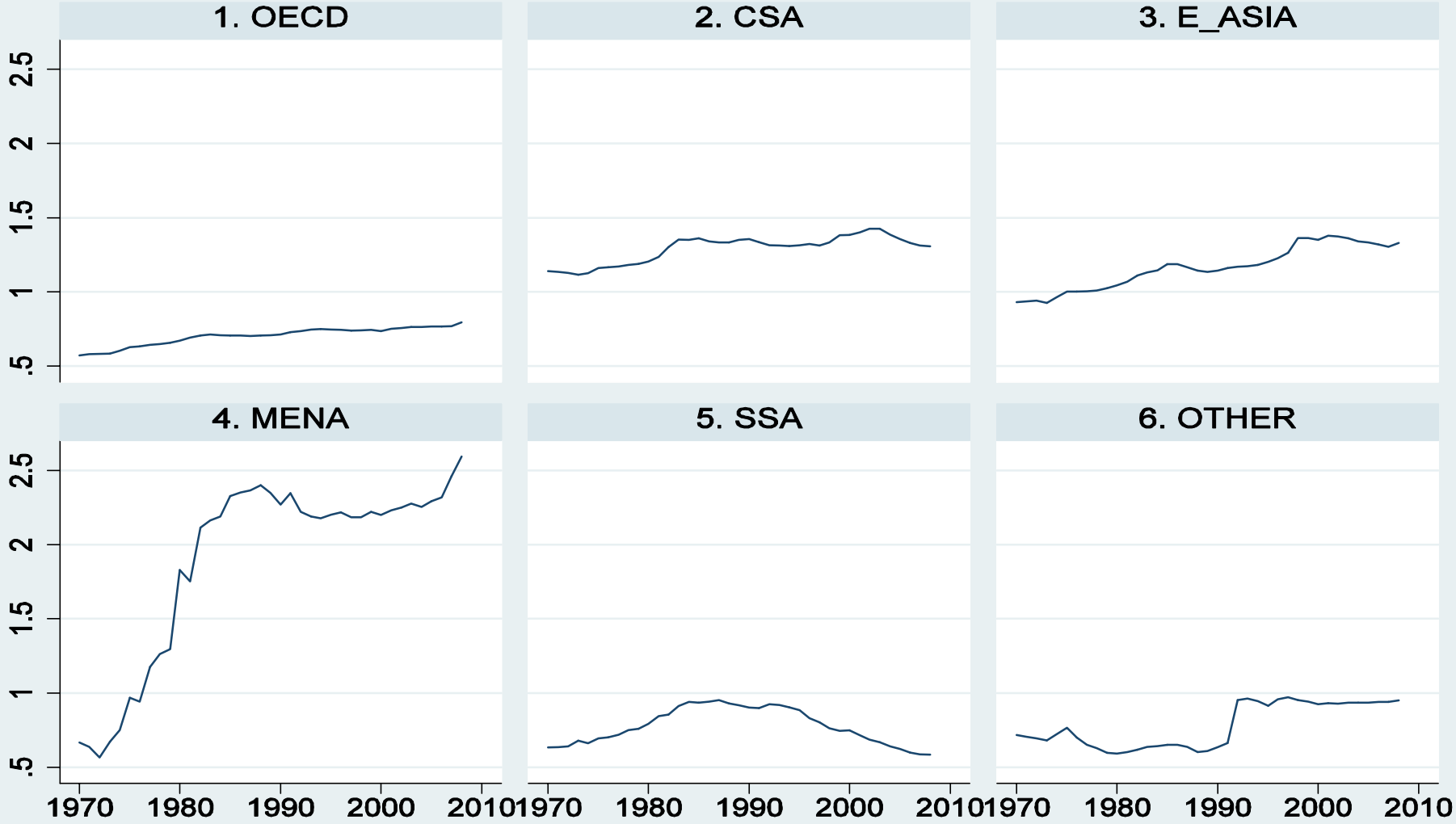
Panel Cointegration of Output per Worker over TFP

Coeff.	**1970-2008 (1)**	**OECD (2)**	**EA (3)**	**CSA (4)**	**SSA (5)**	**MENA & Others (6)**	**1950-2008 (7)**
Co-integration	0.943*** (0.18)	0.927*** (0.22)	1.987*** (0.92)	0.611** (0.33)	0.477*** (0.14)	1.018* (0.584)	1.171*** (0.29)
b	0.031*** (0.005)	0.023*** (0.005)	0.0094 (0.014)	0.031*** (0.006)	0.016*** (0.016)	0.079*** (0.02)	0.016*** (0.005)
No. of Countries	80	29	10	16	12	13	28

Efficiency Output per Worker across OECD Countries



Efficiency Output per Worker across Global Regions



Growth Regression of Efficiency Output per Worker

Coefficient	**(1) Pooled Smoothed**	**(2) Pooled Smoothed**	**(3) FE Smoothed**	**(4) PS Smoothed**	**(5) Pooled Raw**	**(6) FE Raw**
of Initial y^E	0.016*** (0.003)	0.0167* (0.009)	0.061*** (0.001)	0.062*** (0.005)	0.017*** (0.003)	0.072*** (0.001)
Calculated *b*	0.017	0.017	0.070	0.072	0.017	0.085
Constant	0.025*** (0.004)	0.030*** (0.01)	0.070*** (0.001)	0.060*** (0.006)	0.030** (0.012)	0.083*** (0.002)
gA		-0.702*** (0.15)			-0.728*** (0.17)	
R^2	0.11	0.31	within 0.48		0.25	within 0.47

Panel Cointegration of TFP on the Global Frontier

Coeff.	**1970-2008 (1)**	**OECD (2)**	**EA (3)**	**CSA (4)**	**SSA (5)**	**MENA & Others (6)**	**1950-2008 (7)**
d	0.495*** (0.13)	0.670*** (0.13)	1.392*** (0.48)	-0.009 (0.16)	-0.022 (0.43)	0.405 (0.55)	0.770*** (0.10)
c	0.089*** (0.006)	0.095*** (0.01)	0.093*** (0.02)	0.102*** (0.01)	0.050*** (0.02)	0.094*** (0.02)	0.036*** (0.006)
Test $d = 1$	χ^2=14.7 P=0.0001	χ^2=6.9 P=0.008	χ^2=0.68 P=0.41	χ^2=42.0 P=0.0000	χ^2=5.61 P=0.02	χ^2=1.17 P=0.28	χ^2=4.94 P=0.02
No. of Countries	71	28	10	15	11	7	27

Difference Estimation of TFP on the Global Frontier

Coefficient	**1970-2008 Differences (1)**	**1970-2008 Cointegration (2)**	**1950-2008 Differences (3)**	**1950-2008 Cointegration (4)**
Lagged gA	0.833*** (0.01)		0.849*** 0.01	
Lagged gF	0.136*** (0.02)		0.157*** (0.01)	
Calculated *d*	0.803	0.495	1.163	0.770
Calculated *c*	0.167	0.089	0.151	0.036
No. of Countries	70	71	28	27

Panel Cointegration of Output per Worker on the Global Frontier

Coeff.	**1970-2008 (1)**	**OECD (2)**	**EA (3)**	**CSA (4)**	**SSA (5)**	**MENA & Others (6)**	**1950-2008 (7)**
d	0.603*** (0.23)	0.955*** (0.20)	1.914*** (0.31)	0.239*** (0.09)	-0.026 (0.21)	-0.909 (2.03)	1.015*** (0.13)
EC	0.067*** (0.006)	0.068*** (0.05)	0.046*** (0.01)	0.086*** (0.01)	0.064*** (0.01)	0.059*** (0.02)	0.029*** (0.005)
Test of $d = 1$	χ^2=2.99 P=0.084	χ^2=0.05 P=0.823	χ^2=8.81 P=0.003	χ^2=64.9 P=0	χ^2=22.9 P=0	χ^2=9.53 P=0.002	χ^2=0.01 P=0.91
No. of Countries	71	28	10	15	11	7	28

Panel Cointegration of *y* on *F*: Maddison Data, 1950-2008

Coefficient	**Whole Sample**	**Without Oil & Outliers**
d	0.688*** (0.093)	0.708** (0.072)
Error Correction	0.0389*** (0.002)	0.0405*** (0.002)
Test for *d* = 1	χ^2=11.28 P=0.00	χ^2=16.63 P=0.00
Hausman Test for Heterogeneity	χ^2=2.80 P=0.094	χ^2=9.23 P=0.002
Countries	139	124

Divergence by Regions

Coefficient	**OECD**	**EA**	**CSA**	**SSA**	**MENA**	**EER**
d	1.096*** (0.09)	1.33*** (0.049)	0.600*** (0.104)	0.242** (0.11)	0.526*** (0.22)	0.98*** (0.15)
Error Correction	0.034*** (0.005)	0.025*** (0.006)	0.049*** (0.004)	0.042*** (0.004)	0.047*** (0.006)	0.027*** (0.005)
Test for *d* = 1	χ^2=1.26 P=0.263	χ^2=0.46 P=0.498	χ^2=14.9 P=0.000	χ^2=47.1 P=0.000	χ^2=4.51 P=0.034	χ^2=0.02 P=0.89
Countries	28	20	21	47	18	5

Effect of Explanatory Variables on *d*

- Next we estimate the effect of various explanatory variables on the estimated *d*.
- Previous growth regressions could estimate whether an explanatory variable affects output.
- The effects of these same explanatory variables on *d* can identify and isolate their long-run effect.
- We compare this estimation with a standard growth regression to check whether these long-run effect actually differ from the overall effect.

The Explanatory Variables I

- TROPIC is the share of land in a country that is tropical.
- COAST is the share of land in a country that is within 100 km from a coast or from a navigable river.
- ETHNIC is the measure of ethnic fractionalization in a country.
- Y_50 is the natural logarithm of the GDP per capita at 1950.
- EDU is the average years of schooling of people above age 15 during the time of the panel.

The Explanatory Variables II

- OPEN measures openness by trade policy over the years 1965-1990. A country is closed (i) if average tariff rate exceeded 40%; (ii) if non-tariff barriers covered more than 40% of imports; (iii) if it had a socialist economic system; (iv) if it had a state monopoly of major exports; or (v) if black-market premium exceeded 20% during the 1970s or the 1980s. This variable therefore measures both policy and institutions.

- G/Y is the share of public expenditures in GDP, averaged over the years 1950-1960.

- We also tried to add a variable that represents quality of institutions, but it was correlated with other variables and came out insignificant.

Excluding SEA and OECD

- In the following regressions we estimate the effects of these explanatory variables (except for ICRG, for insignificance) for all countries and then without South East Asia and even without the OECD countries.

- Some of the South East Asian countries are in the midst of a period of catching up with the frontier so their rate of growth is high and they appear to have *d* that is much higher than 1. We presume that this is not a long-run equilibrium.

- The OECD countries have $d = 1$, which is the maximum *d*. Hence they are at a corner solution, so that *d* is less sensitive to the various explanatory variables.

A Standard Growth Regression

Dependent Variable: Growth over 1950-2008			
Explanatory Variable	Full sample	W/O SEA	W/O SEA OECD
TROPIC	-0.704*** (0.235)	-0.938*** (0.242)	-0.906*** (0.281)
COAST	0.008*** (0.003)	0.007*** (0.003)	0.007** (0.004)
Y_50	-0.857*** (0.178)	-0.648*** (0.194)	-0.529*** (0.222)
ETHNIC	-0.766* (0.452)	-0.569 (0.422)	-0.530 (0.574)
EDU	0.149*** (0.059)	0.123** (0.060)	0.156** (0.076)
OPEN	1.109*** (0.231)	0.754*** (0.234)	1.190*** (0.471)
G/Y	-2.558*** (0.898)	-1.707** (0.859)	-1.883** (0.986)
CONST.	8.012*** (1.267)	6.527*** (1.343)	5.509*** (1.566)
R^2	0.61	0.60	0.52
Countries	90	77	57

Effect on *d*

Dependent Variable: *d*			
Explanatory Variable	**Full Sample**	**W/O SEA**	**W/O SEA OECD**
TROPIC	-0.287** (0.152)	-0.389*** (0.133)	-0.459*** (0.144)
COAST	0.004** (0.002)	0.002 (0.002)	0.003 (0.002)
Y_50	-0.468*** (0.127)	-0.240** (0.122)	-0.225* (0.137)
ETHNIC	-0.432* (0.282)	-0.417** (0.218)	-0.574** (0.304)
EDU	0.088** (0.039)	0.053 (0.038)	0.048 (0.043)
OPEN	0.591*** (.150)	0.319** (0.150)	0.875*** (0.291)
G/Y	-1.290** (0.578)	-0.483 (0.513)	-0.927 (.680)
CONST.	4.051*** (0.946)	2.517*** (0.835)	2.580*** (0.966)
R^2	0.45	0.44	0.48
Countries	90	77	57

Conclusions

- Including the global frontier and productivity in growth regressions can enrich the estimation of convergence and divergence of countries.
- We reconcile the results of growth regressions with alternative measures of convergence and divergence.
- We also estimate convergence without control variables.
- This approach also enables us to better evaluate various explanations to growth, by isolating the long-run effect.