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Yvan Lengwiler

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Universität Basel
Peter Merian-Weg 6
4052 Basel, Switzerland
wwz.unibas.ch

Corresponding Author:
Prof. Dr. Yvan Lengwiler
Tel. +41 61 207 33 69
yvan.lengwiler@unibas.ch

Climate Protection versus Economic Convergence?

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Abstract

Global economic convergence and protection of the climate are both worthwhile goals. Yet, there is an inherent tension between them. Greenhouse gases are a waste product that is often emitted in the production process. Limiting such emissions therefore hampers the accumulation of income and capital. I expand Solow's growth model to accommodate green house gases, and use this to estimate the contribution of such emissions to economic development. The sobering insight is that we would not have witnessed any convergence in the last 45 years if poorer countries had not increased greenhouse gas emissions.

Keywords: climate change, convergence, growth theory, growth accounting, green house gases, GHG, carbon emissions, pollution, poverty, natural resources.

JEL classification: O44.

Correspondence: University of Basel, Dept of Business and Economics (WWZ), Peter Merian-Weg 6, P.O. Box, CH-4002 Basel, Switzerland. Email: yvan.lengwiler@unibas.ch.

1 Introduction

Income is quite unevenly distributed around the globe. The average Chilean had 38% of the income of the average US American citizen in 2018. The average Bangladeshi had only 7% of this value to live on. In 1975, the situation was more extreme. The people of Chile lived on 22% of the American, and the Bangladeshi on 4%. Convergence of incomes has been slow, but some notable progress has been achieved.

Over the same time, the emissions of greenhouse gases (GHG) have also increased, by 70% worldwide (Gütschow, Günther, Jeffery, and Gieseke, 2021). While it is true that rich countries emit on average more GHG per capita, almost all the increase of GHG emissions in the last 40 years originated in poorer countries. In fact, from 1975 to 2018, China's share of global GHG emissions alone increased from 6% to 24%, that of India from 2% to almost 6%, while that of the USA has decreased from 18% to 12%, and that of the five major Western European countries[1] has decreased from 10% to under 5% (see left panel of Figure 1).

But the pattern is not confined to these very large economies. It extends to smaller ones as well. In the last four decades, relatively poorer economies have increased their GHG emission quite aggressively, while the richer countries have kept emissions more or less constant, and many European countries have absolutely reduced them (right panel of Figure 1). The correlation between log income per capita in 1975 and the growth rate of GHG emissions from 1975 to 2018 is −0.65.

Figure 1 about here

This is also true with respect to GHG emissions *per capita*. Many of the very rich countries have decreased their GHG emissions per capita substantially (Sweden −59%, France

[1] Germany, UK, France, Italy, and Spain together are comparable in size to the USA.

−44%, Germany −35%), while the fastest growing emerging economies have increased their GHG emissions per capita quite dramatically (China +337%, Korea +310%, Malaysia +233%).

Of course, this cannot be too surprising. GHG emissions go hand in hand with production, and since we have observed faster growth of income per capita in formerly poorer countries, we should expect the share of GHG emissions from these countries to increase as well.

But this also implies that there is a tension between the goals of more convergence and reduction of GHG in the atmosphere. In this paper, I quantify the importance of GHG emissions for economic growth using an extended Solow growth model. The sources of the data for the empirical analysis is described in appendix A.

I find that all of the convergence of incomes we have witnessed over the past four decades would be absent if GHG emissions of emerging economies had not been allowed to increase. In other words, advancements of wealth in poorer countries will be difficult if GHG emissions are not allowed to increase there. Yet, given the size of these economies, it will not be possible to limit aggregate GHG emissions without emerging economies also contributing to this effort.

2 Some stylized facts

Man-made GHG emissions have increased a lot since the invention of the steam engine. This is to be expected, as the industrial revolution has allowed human production processes to use carbo-hydrate fuels in much greater quantities than before. As a result, GHGs are a natural waste product of many industrial production processes.

Simon Kuznets (1955) has documented that, as an economy takes off, income inequality first tends to rise, but then reduces again as the wealth gets more spread out with time. It has been hypothesized that the same is true for environmental measures: as the economy takes off, the environment first takes a beating, but then gradually improves again (Grossman and Krueger, 1991, Brock and Taylor, 2010). The evidence for the environmental Kuznets curve is still debated, including the evidence that it exists for green house gases (Moomaw and Unruh, 1997, Stern, 2004, Lipford and Yandle, 2010, Kacprzyk and Kuchta, 2020).

Figure 2 about here

Indeed, the cross sectional relationship between GHG emissions per capita and income per capita is roughly linear in 1975, see the red bullets in the left panel of Figure 2. No Kuznets relationship is visible at all. At the end of the sample (in 2018, blue bullets) the situation seems to have changed somewhat and a hump-shaped relationship at the highest income levels seems to form. This is, of course, not sufficient evidence to posit the existence of a Kuznets curve for GHG emissions.

It is true that (at least until recently) richer countries emit more GHG per capita than poorer countries do. The opposite is true with respect to GHG emissions per unit of real GDP (right panel of Figure 2). There can be different explanations for this. One story is that poorer countries have a different composition of industries, relying more on agriculture and heavy industry, which emits more GHG per value added. Another possible explanation is that reducing GHG is cheaper in richer countries for some reason. The empirical evidence presented later suggests that this might indeed be the case. In fact, the two explanations might be two faces of the same coin: reducing GHG emissions in an economy that relies on agriculture and heavy industry may be much more costly than doing so in an economy that relies on services and the production of intellectual property.

Both panels of Figure 2 also reveal a (slow) downward shift of GHG emissions between 1975 and 2018, for all income brackets. Globally, some GHG-saving technology seems to be adopted everywhere.

3 Expanded Solow model

Robert Solow's classic growth model (Solow, 1956) features two production factors: labor that grows exogenously, and capital that needs to be accumulated through financial investments. As is well known, this model fails empirically in an important way. It implies a much too high output-elasticity of capital. Adding human capital resolves this issue (e.g., Mankiw, Romer, and Weil, 1992). Human capital is another factor that must be accumulated, but this time not via financial investments but by education. I assume that the production function is of the Cobb-Douglas constant elasticity type,

$$Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta}, \tag{1}$$

where Y is output, K is physical capital, H is human capital, L is labor, and A is the level of labor-augmenting productivity, capturing progress in how the economy transforms inputs into outputs. All capital letter variables here are functions of time. Two of these factors grow exogenously with a given exponential rate, $L(t) = L(0)\exp(nt)$, $A(t) = A(0)\exp(gt)$. K and H are accumulated by investments and are depreciated by a constant rate δ,

$$\dot{K} = s_k Y - \delta K, \quad \dot{H} = s_h Y - \delta H. \tag{2}$$

s_k is the investment quota and s_h is a measure of investments into human capital (education, for instance). For simplicity, physical and human capital are assumed to depreciate at the same rate δ.

Notice how Solow's model (as well as the formulations of his predecessors Harrod (1939) and Domar (1946)) exclude land or nature from the production process. This is in contrast to the classicals, such as David Ricardo or Adam Smith. The classicals wrote in the pre-industrial time and land was an obvious production factor in an agrarian economy. Of course, land can (hardly) be enlarged, so this is a limiting factor. As a result, the factor that can be influenced by humans experience diminishing returns to scale, because land does not grow along. In an industrial economy dominated by machines and factories, agriculture lost its dominant role in the economy and the limitations of land became much less pronounced. In such a world, dropping the availability of land from the model (as the neo-classicals did) is appropriate.

With the heightened relevance of ecological concerns, it may be time to revisit the exclusion of nature from the production function. There are many ways to do this. Nordhaus (1992) has studied a simple but effective formulation that integrates various ecological aspects. In his formulation, effective output is measured as GDP minus the pollution that is generated by the production process. I will treat the pollution problem slightly differently here.

First of all, I propose to measure the contributions of nature to the production process only by accounting for the emission of GHG. Other aspects could easily be integrated, but I will focus on this pressing issue at this time. Unlike Nordhaus, I treat nature (or nature's absorption of GHG) as a *production factor*, which may be a bit unusual, since nature does not provide any input into the production process in the usual sense. But, by removing a "bad," the garbage man also contributes to GDP. In the same sense, nature contributes to GDP by conveniently disposing of GHG, which makes production of goods and services easier.

Empirically, GHG emissions have increased over time in several economies, at roughly constant growth rates, while in others they have remained almost constant or have somewhat decreased. I therefore model GHG emissions as an exogenous exponentially growing process,

$$C(t) = C(0)\exp(pt),$$

where p is the individual growth rate of pollution with GHG emissions by a country. The extended production function is

$$Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta-\gamma} C^{\gamma}. \tag{3}$$

4 Steady state growth path

In the steady state, Y and K and H will converge to a fixed relationship, i.e. K/Y, H/Y, K/H converge to constant values. It is not difficult to compute that $K^*/H^* = s_k/s_h$ in the steady state (stars denote steady state values).

The focus in this section is on income *per capita* (Y/L) in steady state. In Solow's model with no nature, Y/L grows at the rate of technical progress g in the steady state. In the model with nature, this relationship is modified,

$$\frac{d}{dt}\log\left(\frac{Y}{L}\right)^* = (1-\gamma\psi)g + \gamma\psi(p-n) =: \xi, \tag{4}$$

where $\quad \psi = (1-\alpha-\beta)^{-1}.$

Note that population growth that exceeds the growth of GHG disposal in nature decreases the steady state growth rate of income per capita ξ. Essentially, some of the technical progress g is used to substitute the contributions of nature to the production process. As a result, not all of the technical progress transforms into higher income. Because n and p are idiosyncratic for each country, each country also has a different trend growth rate of income per capita.

This fact can be leveraged empirically: if all countries in the sample are on their respective steady state growth paths, the discrete time version of (4),

$$\frac{1}{t}\left(\log\frac{Y_i(t)}{L_i(t)} - \log\frac{Y_i(0)}{L_i(0)}\right) = (1-\gamma\psi)g + \gamma\psi(p_i - n_i) = \xi_i, \tag{5}$$

can be estimated.

I assume that α, β, γ, and g are common across all countries. n_i and p_i as well as average income per capita growth (the left-hand variable), however, are country-specific. It is not possible to estimate all parameters of the model using just the steady state growth equation, but it is possible to estimate the growth rate of technical progress g as well as $\gamma\psi$.

Note that (5) is valid only along the country-specific steady state growth paths. It expresses the implication of the model that the trend growth rate of income per capita depends on the population and pollution growth rates of a particular country. In other words, this regression assumes that all countries are on their respective steady state growth paths from 1975 to 2018. If a country started off in 1975 far away from its steady state, the equation will not be accurate and the regression is then mis-specified.

Table 1 reports the results. The unconstrained OLS regression, in the upper half of the table, yields highly significant coefficients. The explanatory power is better for the poorer countries or the full data set than for the group of richer countries.

Table 1 about here

(5) implies that the coefficients for p_i and n_i should sum to zero. A test to this effect is, however, rejected. This could indicate that the model is not correct, or that the assumption that countries are close to their steady state paths is not warranted.

Imposing the (rejected) constraint nevertheless allows to extract g and $\gamma\psi$, see lower half of Table 1. For the full sample, g is estimated to be 4.7% per year. For the richer countries, g is considerably smaller ($g = 1.9\%$), for poorer countries it is larger (11.8%). $\gamma\psi$ is also an important statistic. As discussed above, if labor and GHG emissions grow proportionally to each other ($p = n$), then the trend growth rate of income per capita is $\xi = (1-\gamma\psi)g$, so $\gamma\psi$ is the share of technical progress that does not contribute to increases of income per capita, but is used to compensate for the declining contribution of nature. According to the regression, $\gamma\psi$ is 66% for the full sample. This is much smaller (22%) for the richer countries, but is much larger (88%) for the poorer selection of countries. Therefore, the far higher estimate of technical progress in the poorer countries does not translate into faster long term growth. In fact, all three country samples predict a trend growth rate (conditional on $p = n$) of about 1.5% per year.

5 Conditional convergence

The assumption that all countries in our sample are close to their respective steady state paths from 1975 onwards is more palatable for some countries than for others. This assumption is reasonable for the most advanced economies (USA, Canada, Australia, New Zealand, and the rich Western European economies), but several "emerging market" economies have experienced a remarkable catching up in the past four decades. It stands to reason that these countries started out below their steady state paths in 1975. As a result, the growth rate of output that we measure for those countries should exceed their steady state values, putting the regression reported in Table 1 into jeopardy.

We can do better. The model can be solved for initial conditions off the steady state path by formulating an "intensive form." Define the new the variable,

$$X(t) := (A(t)L(t))^{1-\gamma\psi} C(t)^{\gamma\psi}. \tag{6}$$

Note that $X(t) = X(0)\exp((\xi + n)t)$ and grows at the constant rate $\xi + n$. Lower case variables denote the intensive forms, i.e. levels divided by $X(t)$, so $y(t) := Y(t)/X(t)$, $k(t) := K(t)/X(t)$, $h(t) := H(t)/X(t)$. The model in intensive form is

$$y(t) = k(t)^{\alpha} h(t)^{\beta},$$

$$\dot{k}(t) = s_k y(t) - (\xi + n + \delta)k(t),$$

$$\dot{h}(t) = s_h y(t) - (\xi + n + \delta)h(t).$$

In steady state, the intensive forms are constant,

$$y^* = \left(\frac{s_k^{\alpha} s_h^{\beta}}{(\xi + n + \delta)^{\alpha+\beta}} \right)^{\psi},$$

with similar expressions for k^* and h^*. When the economy starts off steady state, it converges uniformly ($y(t) \to y^*$), and the speed of convergence is, to a first order approximation, given by

$$\log(y(t)) - \log(y(0)) \approx (1 - \exp(-\lambda t))\,(\log y^* - \log y(0)),$$

$$\text{with} \qquad \lambda := (1 - \alpha - \beta)(\xi + n + \delta).$$

Note that the steady state intensive value y^* is a function of country-specific parameters, namely the two investment quotas s_k and s_h and the growth rate of GHG pollution p and labor n. Likewise, the speed of convergence λ is also a function of p and n. The steady state solution of the model predicts a connection between the (long term) growth rate and country-specific parameters, as captured by (4) and estimated in Table 1. But the general solution that also captures country-specific convergence speeds and thus produces a much more intricate relationship. This opens up the possibility of a richer and more precise estimation.

One small issue needs to be addressed: s_h, the share of output invested into human capital, is not observed. We have a proxy for this, namely the Cohen-Soto-Leker education data. This metric (denoted with edu) is not measured as share of output, however. I assume that the share of output invested into human capital is proportional to the education measure,

$$s_h := \sigma \,\text{edu}. \tag{7}$$

The common proportionality factor σ is, of course, not observable.

From this it is possible to derive an equation that is suitable for estimation,

$$\left.\begin{aligned}
&\frac{1}{t}\left(\log\frac{Y_i(t)}{L_i(t)}-\log\frac{Y_i(0)}{L_i(0)}\right)\approx\xi_i-\frac{1-\exp(-\lambda_i t)}{t}\log(\mathrm{gap}_i)+\epsilon_i,\\
&\quad\xi_i=(1-\gamma\psi)g+\gamma\psi(p_i-n_i),\\
&\quad\psi=(1-\alpha-\beta)^{-1},\\
&\quad\lambda_i=(1-\alpha-\beta)(\xi_i+n_i+\delta),\\
&\quad\log(\mathrm{gap}_i):=\log Y_i(0)-\Big((1-\psi\gamma)\log L_i(0)+\psi\gamma\log C_i(0)+\mathrm{const}\Big)\\
&\qquad\qquad\qquad-\psi\Big(\alpha\log(s_k)_i+\beta\log(\mathrm{edu}_i)-(\alpha+\beta)\log(\xi_i+n_i+\delta)\Big),\\
&\quad\mathrm{const}:=\psi\beta\log\sigma+(1-\psi\gamma)\log A(0).
\end{aligned}\right\}\tag{8}$$

ϵ_i is the country-specific residual, measuring average growth rates of output per capita not explained by the model.

One can immediately see that (8) is an extension of (5). The latter contains just ξ_i on the right-hand side. The second component of (8) involving gap_i captures the adjustment dynamics off steady state.

Table 2 about here

Table 2 reports the results of confronting this equation with the data. The upper part of the table reports the fit of a linear version of (8), meaning that the functional form of (8) is ignored; the country-specific variables (p_i, n_i, $(s_k)_i$, edu_i, $\log Y_i(0)$, $\log L_i(0)$, $\log C_i(0)$) are simply used as explanatory variables in a linear regression. This is just for comparison with the unconstrained regression in the lower part of Table 1, to see whether the functional form of (8) improves the quality of the estimation. Comparing the two specifications reveals that neither is consistently superior.

Three main findings emerge: First, for the full sample, all elasticities are statistically significant. The elasticity of human capital is reasonable ($\beta = 0.2$) and does not vary much with income classes. The elasticity of labor is surprisingly small ($1-\alpha-\beta-\gamma = 0.14$), and is also not dramatically different between both income groups.

Second, the elasticity of physical capital is as expected for the full sample ($\alpha = 0.25$), but significantly larger for richer countries ($\alpha = 0.43$) than for the poorer group ($\alpha = 0.19$). For all three country samples, g and δ are not estimated with great precision; they are not significantly different from zero. But the point estimates especially of the depreciation rates are still interesting. The richer countries experience higher depreciation rates (5%) than the poorer countries (0%).

This is broadly compatible with the literature on the declining labor share. With a constant returns to scale technology and competition, the income shares of the factors should be equal to their respective elasticities, and it has been a long established stylized fact that the income share of labor is roughly 2/3. However, in the past years, this share seems to decline, and much research has been produced to explain this observation (for a useful summary of this literature, see Grossman and Oberfield, 2021). Some of these explanation are stories that argue that the elasticity of capital has increased, for instance, because intellectual property has gained importance, and the depreciation rate has increased as product cycles shorten. The increased share of capital implies, in turn, a smaller income share of labor. Table 2 is broadly compatible with this literature in the sense that richer countries seem to experience a higher depreciation rate (δ) and a higher elasticity of capital (α).

However, the equalization of elasticities with income shares does not fully work in this model, because nature is an “income-less factor.” Nature does contribute to output but is not financially compensated for it because it is a public good. Thus, the income share that would belong to nature is appropriated by the privately owned factors (labor, human capital, and physical capital).

Third, the elasticity of GHG emissions is surprisingly large with ($\gamma = 0.39$). Moreover, the output-effect of GHG is much greater in poorer economies ($\gamma = 0.51$) than in the richer group ($\gamma = 0.14$). This implies that reducing GHG emissions is *relatively cheaper in richer countries*. Essentially, drastically reducing GHG emissions in richer countries while simultaneously increasing them in poorer countries would make economic sense. This is not a new conclusion and is in line with the Summers-Pritchett memo that caused much uproar in the 1990s.[2] This finding is also compatible with early econometric research that pointed to a concave relationship between economic development and CO_2 emissions (Holtz-Eakin and Selden, 1995).

6 Convergence without GHG?

Fitting the extended growth model to the data reveals that the output-elasticity of GHG emissions is about 0.4 and thus is economically extremely important. The choice of a country to emit more or less GHG has therefore great consequences for the income per capita that its population can enjoy.

The extended Solow growth model presented here also implies a worrying negative connection between population growth and speed of development. Empirically, poorer countries experience faster growing populations. Keeping GHG emissions fixed, every percent higher trend population growth implies that the per capita income grows by 0.7% less long term. This implies long term divergence.

However, the impoverishing effect of population growth can be counteracted by

[2] https://en.wikipedia.org/wiki/Summers_memo

increasing GHG emissions. In fact, according to (4), only the difference between the growth rate of GHG emissions p and population growth n affects the growth of affluence along the steady state path.

It is therefore maybe not surprising that in the last four decades poorer countries have increased their GHG emissions much more than richer countries have. As will be demonstrated now, this is the reason why we have witnessed some convergence of incomes at all.

Figure 3 about here

The left panel of Figure 3 depicts the (log) income per capita in 1975 on the horizontal axis versus that value in 2018 on the vertical axis, for the 82 countries in the sample. Most countries have made progress. The initially poorer countries, however, have traveled upwards faster on average than the already richer countries. Just by visual inspection, the slope of a line trough this scatter plot is less than unity, implying some amount of convergence. This is also verified by observing the development of the Gini coefficient: in 1975, it was 0.60 among this group of countries; by 2018, the Gini has fallen to 0.46.

Consider now a counterfactual development. Suppose GHG emissions were fixed from 1975 onward for each individual country. In other words, we set $p_i = 0$ for each i. Equation (8) can be used to compute the development of income per capita in this hypothetical scenario, given the estimated parameters and the residuals ϵ_i from the regression reported in Table 2 (full sample). The right panel of Figure 3 shows the result: All of the convergence is gone. In fact, we even see some divergence, as the European group of countries and the USA (and Myanmar) are the only ones, broadly speaking, who are still able to significantly increase their well-being. All other countries remain more or less stuck at their initial levels.

This is again verified by the Gini, which now increases from 0.60 initially to 0.66 in 2018.

The sobering insight here is that all of the convergence (and even more than that) that we have seen in the last four decades is due to the increase of GHG emissions of poorer countries, and, to some extent, the decrease of such emissions by richer countries. It appears, therefore, that the goal of halting or even reversing the expansion of GHG emissions and the goal of fighting global poverty and divergence are at odds with each other, at least if the burden of GHG emission reductions are shared by all countries to the same extent.

7 A predicament

Poorer countries have increased their GHG emissions significantly, while richer countries have increased them much less or even absolutely reduced them. As a result, the share of emissions that emanates from poorer or emerging countries has increased a lot. I find that this change of relative GHG emissions is the *only reason* why any convergence of income has been achieved. Had poorer countries not increased their GHG emissions relative to rich countries, no economic convergence would have materialized in the last 40 years.

This observation reveals a deep tension between the goals of fighting climate change and achieving global economic convergence. Faster convergence requires that poorer countries increase their GHG emissions *per capita* ($p_i > n_i$), while richer countries do the opposite ($p_i < n_i$). This also makes sense economically: the estimation indicates that reducing GHG emissions in rich countries has a smaller effect on output than doing so in poorer countries. Thus, overall welfare is increased by cutting back GHG emissions in richer countries more.

The left panel of Figure 4 shows that this is exactly what has happened in four very large economies. India and China have increased their emissions *per capita*, while the USA and Western Europe have decreased them in the last two decades.

Figure 4 about here

The right panel of Figure 4 shows that the GHG-intensity of these four large economies is quite heterogeneous. In fact, India and the USA are very comparable in terms of how much GHG they emit per unit of GDP. Western Europe emits today only half as much GHG per GDP as the USA or India. China, however, emits much more. This may be due to the significant industrial production that takes place in China, but can also be due to weaker environmental standards.

Of the four very large economies depicted in Figure 4, the USA and China stand out because they have relatively large GHG emissions for their respective income brackets (see Figure 2). The USA clearly still has potential to reduce its GHG footprint. It emits 13% of worldwide GHG and its emissions per capita and per GDP are high compared to other advanced economies. China, however, is even more relevant. It emits about a quarter of all GHG. Per capita, it emits 45% more than the global average, yet its income per capita is average at best.

Global income convergence in the last few decades would not have happened if the emerging economies had not significantly increased their GHG emissions. But given the size of the emerging or of the still poor economies today, it will not be possible to reduce aggregate GHG in the atmosphere sufficiently if only the rich countries contribute to this effort. Less wealthy economies will have to cut back as well. How to do this while still advancing global economic convergence is quite a predicament.

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A Data

The empirical analysis is cross sectional and requires data on real output, labor input, investments into physical and human capital, and GHG emissions. For real income (Y) and labor (L) I use the Penn World Tables, Version 10.0 (Feenstra and Timmer, 2015). Output is measured by national accounts data available in PWT (`rgdpna`). For labor (L), the population (`rgdpna`) is most widely available, so I use this. n denotes the average annual growth rate of L. The GHG emissions (C) are taken from ClimateWatch.[3] p denotes the average annual growth rate of C. To capture the convergence of steady state growth paths, observations at two points in time are required. I use 1975 and 2018 providing a span of more than 40 years.

Note that population is not the most accurate representation of labor input. It ignores the age distribution, the labor market participation, and the hours typically worked per week (which can vary widely through time and between economies). So, a better measure is to multiply the number of employed people (`emp`) with average hours worked (`avh`). Unfortunately, these data are available in PWT only for relatively few countries, with a bias in favor of richer countries. The main analysis will therefore be based on the simple population measure. Appendix B reports a robustness check using the more precise labor measurement on a restricted selection of countries.

Measures of investments into physical and human capital are required as well. Investment into physical capital (s_k) is also taken from PWT and is simply measured as the share of GDP going into investments (`csh_i`). I use averages from 1975 to 2018. As a proxy for investments into human capital, I follow the literature (the classic contributions are

[3] `https://www.climatewatchdata.org/`, all sectors, Kyoto GHG, PIK database. PIK is the Potsdam Institute for Climate Impact Research, see Gütschow et al. (2021).

Barro, 1991, Mankiw et al., 1992) and use educational attainment. Specifically, I use the CSL data (Cohen and Soto, 2007, Cohen and Leker, 2014). These data are available in ten year intervals. I use the average educational attainment of 25 to 64 year olds of the cohorts from 1970 to 2010.

Very small countries (less than 2 million inhabitants) are excluded. With these restrictions, complete data are available for the following 82 countries: Switzerland, Norway, United States, Netherlands, Canada, Sweden, Denmark, Australia, Austria, Germany, France, Italy, New Zealand, Belgium, United Kingdom, Finland, Spain, Greece, Ireland, Japan, Argentina, Iran, Singapore, Portugal, Hungary, Mexico, South Africa, Brazil, Turkey, Angola, Uruguay, Jamaica, Costa Rica, Iraq, Syria, Ecuador, Peru, Algeria, Nicaragua, Bulgaria, Jordan, Colombia, Chile, Bolivia, El Salvador, Malaysia, Paraguay, Dominican Republic, Tunisia, Côte d'Ivoire, Philippines, Nigeria, Republic of Korea, Honduras, Zambia, Thailand, Egypt, Cameroon, Ghana, Morocco, Kenya, Madagascar, Senegal, Haiti, Sudan, Indonesia, Zimbabwe, Sierra Leone, China, Niger, India, Benin, Bangladesh, Tanzania, Nepal, Uganda, Malawi, Burundi, Burkina Faso, Ethiopia, Myanmar, Mali. The countries are ordered here according to their income per capita in 1975.

In order to check whether the model behaves the same depending on the affluence of a country, I divide this set into two groups. The countries from Switzerland to Colombia have a higher income per capita than the average of all 82 countries. These 42 countries comprise the "richer countries" sample. The remaining 40 countries, from Chile to Mali, constitute the "poorer countries" sample.[4]

[4]Code that downloads all required data and reproduces the main regressions is available at `https://github.com/ylengwiler/ClimateVersusConvergence/`

B Robustness checks

As discussed in the text, population is not the best measure of labor input. It ignores labor market participation and age distribution, as well as the average length of the workday, which varies significantly, from 2447 hours per year in Brazil to 1382 hours per year in Germany, for each employed person (values for the year 2018).

Unfortunately, this more precise measurement is available only for 38 countries. But we can check the importance of the labor measure by and estimating (5) and (8) with hours worked vs. population as the measure of labor input using only the 38 countries for which both labor measures are available.

Table 3 reports these results. Comparing the two, we can conclude that the labor measure does not have a substantial effect on the estimated parameters. Therefore, using population as a proxy for labor input instead of the more precise hours does not seem to cause massive damage to the quality of the estimate.

Table 3 about here

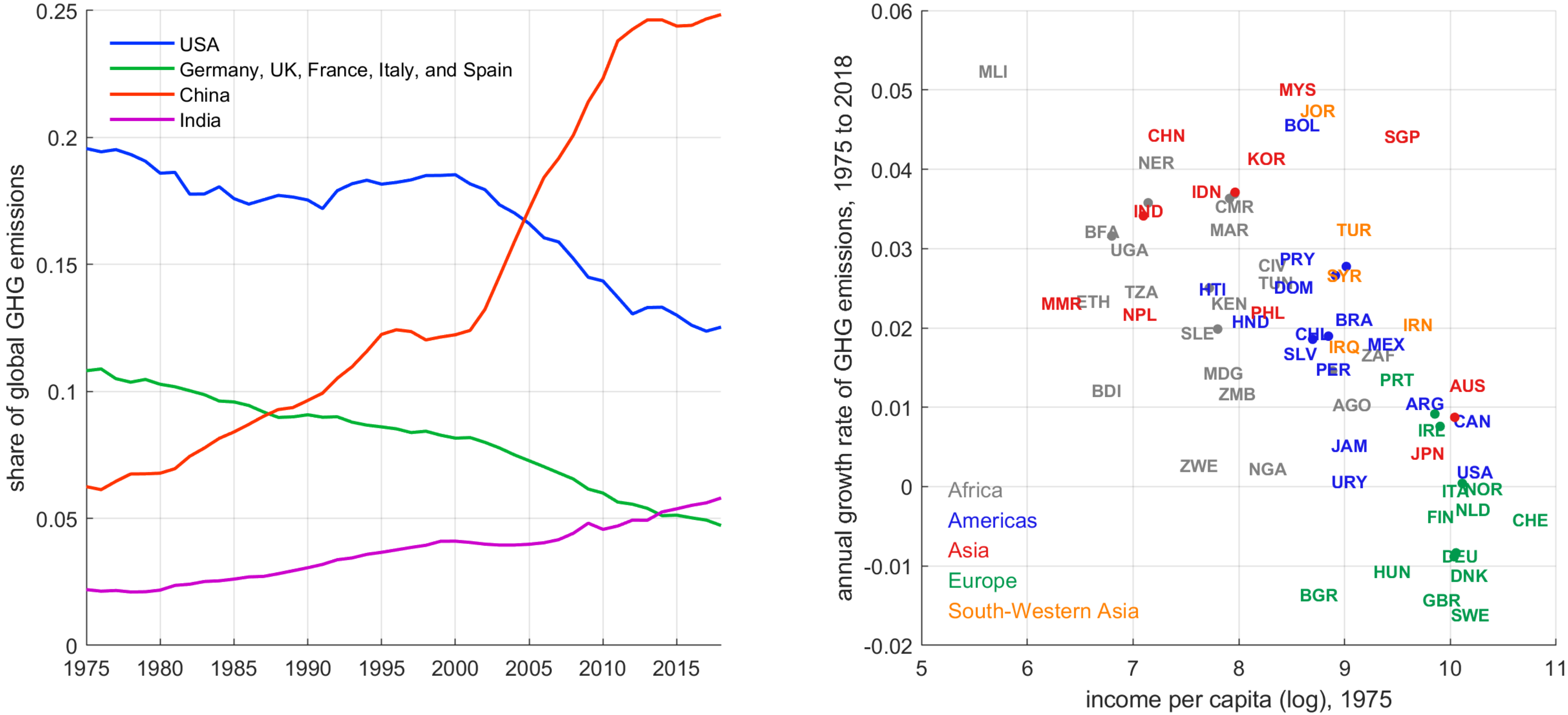

Figure 1: GHG emissions: growth rate (left panel) and share of global emissions for four major economies (right panel). Some iso-codes are replaced with bullets to improve legibility.

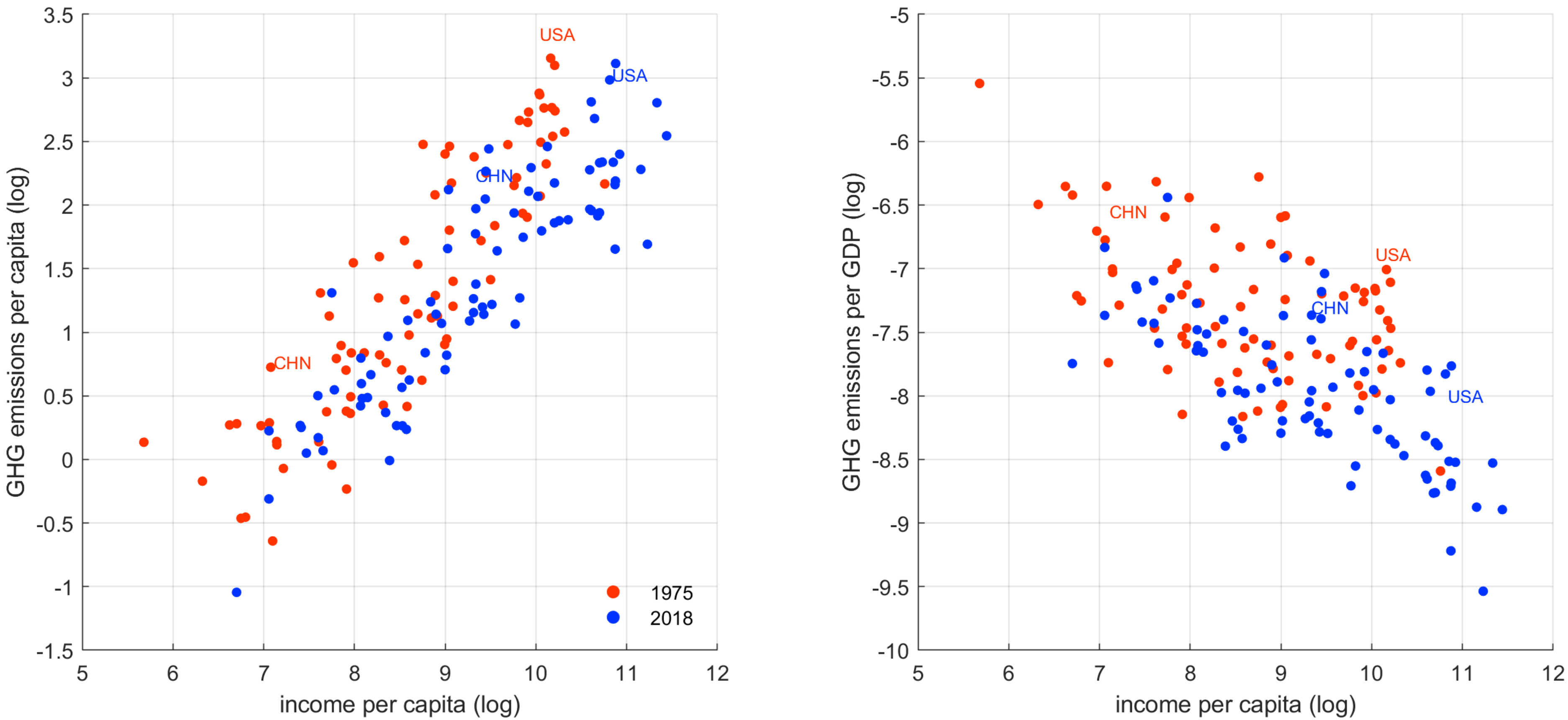

Figure 2: GHG emissions per capita (left) and per unit of GDP (right). The USA and China are singled out in these charts because these are two very large economies that emit, for their respective income brackets, comparably large amounts of GHG.

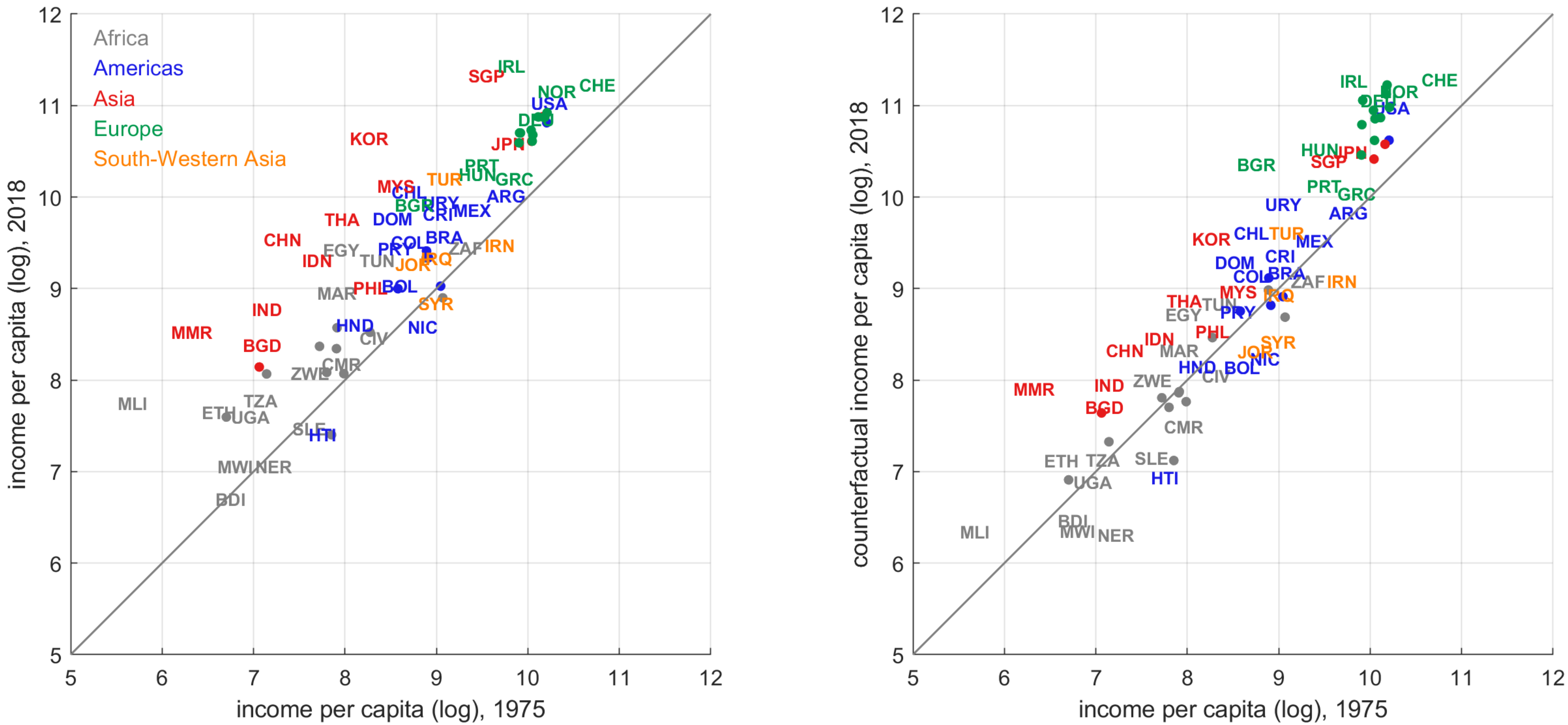

Figure 3: Income per capita (log), 1975 vs 2018: effective (left) and counterfactual (right).

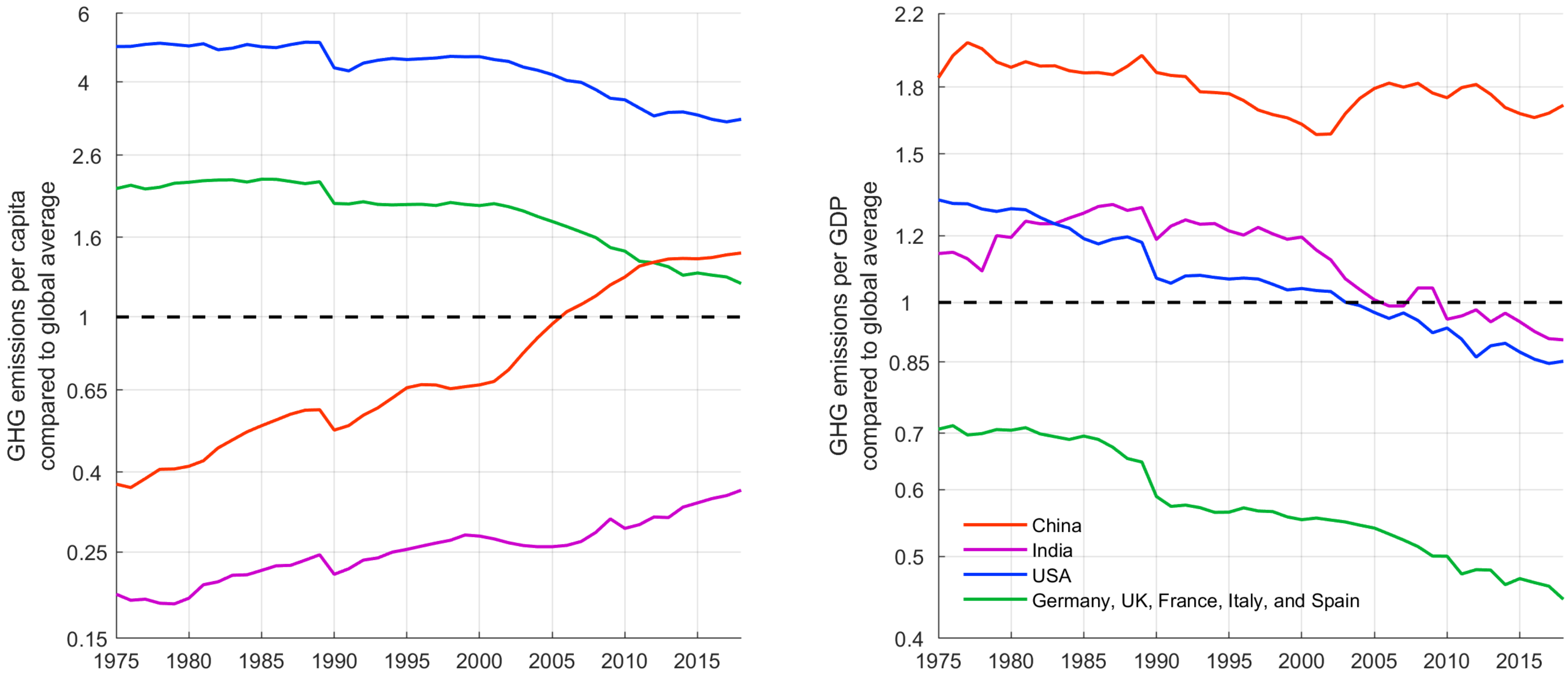

Figure 4: GHG emissions per capita (left) and per GDP (right), four major economies. (There is a structural break in 1990 because population and GDP data become available in this year for 23 additional countries of the former Soviet Union and Yugoslavia, which shifts the global averages.)

Table 1: Regression results equation (5).

	all countries			richer countries			poorer countries		
unconstrained	coef	sign.	std err	coef	sign.	std err	coef	sign.	std err
const	0.0233	***	0.0019	0.0209	***	0.0018	0.0310	***	0.0096
p	0.6906	***	0.0945	0.3660		0.1908	0.6809	***	0.1685
n	−1.138	***	0.1410	−0.8576	***	0.2060	−1.3718	***	0.2781
coef restriction	0.00	***		0.00	***		0.00	***	
std err residual	0.0103			0.0086			0.0112		
R^2 adj	0.448			0.214			0.562		
log likelihood	260.23			141.59			124.46		
AIC	−6.274			−6.600			−6.073		
constrained	coef	sign.	std err	coef	sign.	std err	coef	sign.	std err
const	0.0158	***	0.0012	0.0148	***	0.0018	0.0144	***	0.0018
$p-n$	0.6641	***	0.1052	0.2196		0.2073	0.8779	***	0.1248
g	0.0472	***	0.0157	0.0190	***	0.0066	0.1178		0.1190
$\gamma\psi$	0.6641	***	0.1052	0.2196		0.2073	0.8779	***	0.1248
$(1-\gamma\psi)\,g$	0.0158	***	0.0012	0.0148	***	0.0018	0.0144	***	0.0018
std err residual	0.0112			0.0096			0.0117		
R^2 adj	0.354			0.020			0.522		
log likelihood	253.21			136.44			122.15		
AIC	−6.127			−6.402			−6.007		
std dev dependent	0.0139			0.0097			0.0169		
# obs	82			42			40		

Note: Huber-White standard errors. Significance: 5%*, 2%**, 1%***. Test for coefficient restriction: H_0: coef p + coef n = 0; p-value is reported in table.

Table 2: Regression results equation (8).

	all countries			richer countries			poorer countries		
linear	coefficient	sign.	std err	coefficient	sign.	std err	coefficient	sign.	std err
const	0.1072	***	0.0127	0.0872	***	0.0243	0.1061	***	0.0219
p	0.5898	***	0.0910	0.4916	***	0.1456	0.6100	***	0.1384
n	−0.9911	***	0.1204	−0.8709	***	0.1958	−1.1770	***	0.2286
s_k	0.0436	**	0.0177	0.0662	***	0.0222	−0.0027		0.0296
edu	0.0017	***	0.0005	0.0017	***	0.0006	0.0012		0.0007
$\log Y(0)$	−0.0134	***	0.0017	−0.0114	***	0.0032	−0.0123	***	0.0027
$\log L(0)$	0.0075	***	0.0022	0.0059		0.0045	0.0053		0.0031
$\log C(0)$	0.0069	***	0.0020	0.0053		0.0027	0.0099	***	0.0029
std err residual	0.0079			0.0073			0.0082		
R^2 adj	0.679			0.443			0.765		
log likelihood	285.14			151.70			139.78		
AIC	−6.759			−6.843			−6.589		
non-linear	parameter	sign.	std err	parameter	sign.	std err	parameter	sign.	std err
α	0.2477	*	0.1134	0.4301	***	0.0667	0.1850		0.2201
β	0.2169	***	0.0612	0.2686	***	0.0495	0.2265		0.1231
γ	0.3913	***	0.0915	0.1363	**	0.0553	0.5110	***	0.1484
δ	0.0080		0.0112	0.0505		0.0288	−0.0021		0.0181
g	0.0730		0.0382	0.0000		0.0268	0.1063		0.1864
const	4.826	***	0.2795	3.600	***	1.1895	5.113	***	0.7609
$1-\alpha-\beta-\gamma$	0.1441	***	0.0474	0.1650	***	0.0553	0.0774		0.0751
$\gamma\psi$	0.7309	***	0.1019	0.4525	**	0.1685	0.8684	***	0.1343
$(1-\gamma\psi)\,g$	0.0196	***	0.0054	0.0000		0.0147	0.0140		0.0118
std err residual	0.0084			0.0073			0.0090		
R^2 adj	0.632			0.439			0.721		
log likelihood	278.45			150.37			135.13		
AIC	−6.645			−6.875			−6.457		
std dev dependent	0.0139			0.0097			0.0169		
# obs	82			42			40		

Note: Huber-White standard errors. Significance: 5%*, 2%**, 1%***.

Table 3: Robustness check: Using hours worked instead of population.

	equation (5)							equation (8)					
	L = hours worked			L = population				L = hours worked			L = population		
unconstrained	coef	sign.	std err	coef	sign.	std err	*linear*	coef	sign.	std err	coef	sign.	std err
const	0.0232	***	0.0022	0.0231	***	0.0028	const	0.1083	***	0.0304	0.1602	***	0.0220
p	0.7646	***	0.1081	0.7646	***	0.1085	p	0.2061		0.1236	0.1744		0.1175
n	−0.9872	***	0.1917	−0.9801	***	0.3238	n	−0.6234	***	0.1581	−0.4123		0.2205
							s_k	0.0774	***	0.0171	0.0921	***	0.0184
							edu	0.0001		0.0007	0.0005		0.0007
							$\log Y(0)$	−0.0176	***	0.0027	−0.0187	***	0.0026
							$\log L(0)$	0.0072	***	0.0022	0.0089	***	0.0022
							$\log C(0)$	0.0090	***	0.0032	0.0084	**	0.0032
coef restriction	0.06			0.37									
std err residual	0.0085			0.0085			std err residual	0.0052			0.0049		
R^2 adj	0.515			0.569			R^2 adj	0.821			0.860		
log likelihood	128.74			128.74			log likelihood	150.65			153.00		
AIC	−6.618			−6.618			AIC	−7.508			−7.632		
constrained	coef	sign.	std err	coef	sign.	std err	*non-linear*	param.	sign.	std err	param.	sign.	std err
const	0.0204	***	0.0014	0.0211	***	0.0014	α	0.4737	***	0.1144	0.4693	***	0.0946
$p-n$	0.7087	***	0.1107	0.7117	***	0.0857	β	0.1050		0.1249	0.1564		0.0938
							γ	0.1768		0.0870	0.1323		0.0686
							δ	0.0197		0.0188	0.0520		0.0342
							g	0.0368		0.0290	0.0110		0.0451
							const	1.596		1.5238	6.016	***	0.9766
g	0.0699	**	0.0270	0.0730	***	0.0219	$1-\alpha-\beta-\gamma$	0.2445	***	0.2445	0.2419	***	0.0358
$\gamma\psi$	0.7087	***	0.1107	0.7117	***	0.0857	$\gamma\psi$	0.4197	***	0.4197	0.3536	***	0.0095
$(1-\gamma\psi)\,g$	0.0204	***	0.0014	0.0211	***	0.0014	$(1-\gamma\psi)\,g$	0.0214		0.0134	0.0071		0.0281
std err residual	0.0087			0.0085			std err residual	0.0056			0.0055		
R^2 adj	0.497			0.572			R^2 adj	0.793			0.821		
log likelihood	127.52			128.38			log likelihood	146.63			147.19		
AIC	−6.606			−6.651			AIC	−7.401			−7.431		
std dev dependent	0.0122			0.0130			std dev dependent	0.0122			0.0130		
# obs	38			38			# obs	38			38		

Note: Huber-White standard errors. Significance: 5%*, 2%**, 1%***. Test for coefficient restriction (equation (5)): H_0: coef p + coef $n = 0$; p-value is reported in table.

The following material is

not for publication.

C Derivations

C.1 K/Y and H/Y converge to constants

The laws of motion of K and H (2) imply that K/Y and H/Y converge to some constants. This implies that Y, K, and H all grow at the same rate in the long run. Since $\dot{K}/K = \dot{H}/H$ in the steady state, by (2), we have $s_k \frac{Y}{K} - \delta = s_h \frac{Y}{H} - \delta$, and thus

$$H^* = \frac{s_h}{s_k} K^*. \tag{9}$$

This also allows to simplify the production function in steady state from two to just one endogenous variable,

$$Y^* = (K^*)^{\alpha+\beta} \left(\frac{s_h}{s_k} \right)^{\beta} (AL)^{1-\alpha-\beta-\gamma} \, C^{\gamma}. \tag{10}$$

C.2 Steady state growth rate

From (3),

$$\frac{\dot{Y}}{Y} = \alpha \frac{\dot{K}}{K} + \beta \frac{\dot{H}}{H} + (1-\alpha-\beta-\gamma)(g+n) + \gamma p. \tag{11}$$

Because in steady state Y and K and H grow at the same rate, this simplifies to

$$\left(\frac{\dot{Y}}{Y} \right)^* = \xi + n, \tag{12}$$

$$\text{where} \quad \xi = (1-\gamma\psi)g + \gamma\psi(p-n)$$

$$\text{and} \quad \psi = (1-\alpha-\beta)^{-1}.$$

(4) follows immediately.

Because ξ depends on p and n, which are both observable variables, and the growth rate of output is also observable, this equation lends itself to an empirical investigation if we assume that all countries are on their steady state growth paths. This regression is reported in Table 1.

C.3 Steady state output and intensive form

Taking the log differential of (10) allows to express the steady state growth rate in a different fashion,

$$\begin{aligned}\left(\frac{\dot{Y}}{Y}\right)^{*} &= (\alpha+\beta)\left(\frac{\dot{K}}{K}\right)^{*} + (1-\alpha-\beta-\gamma)(g+n)+\gamma g \\ &= s_k(\alpha+\beta)\left(\frac{Y}{K}\right)^{*} - (\alpha+\beta)\delta + (1-\alpha-\beta-\gamma)(g+n)+\gamma g. \end{aligned} \tag{13}$$

(2) was used to get to the second line. (11) and (13) must be equal. We use this to solve for $(Y/K)^*$,

$$\left(\frac{Y}{K}\right)^{*} = \frac{\xi+n+\delta}{s_k}. \tag{14}$$

Plugging this back into the production function (10) yields the steady state values for capital, human capital, and output, i.e. $K^*(t) = [(\xi+n+\delta)^{-1} s_h^{\beta} s_k^{1-\beta} (A(t)L(t))^{1-\alpha-\beta-\gamma} C^{\gamma}]^{\psi}$ etc. Note, however, that these three variables all grow at the common rate $\xi+n$. We therefore normalize the system by dividing by the auxiliary variable

$$X(t) = (A(t)L(t))^{1-\gamma\psi} C(t)^{\gamma\psi} = X(0)\exp((\xi+n)t), \tag{15}$$

and denote the normalized variables with lower case names, so $y(t) := Y(t)/X(t)$, $k(t) = K(t)/X(t)$, etc, as well as $y^* = Y(t)^*/X(t)$, etc. Note that y^*, k^*, h^* are not functions of time. We call this the *intensive form*. The model in intensive form is as follows,

$$\left.\begin{aligned}
&y(t) = k(t)^{\alpha} h(t)^{\beta}, \\
&\dot{k}(t) = s_k y - (\xi + n + \delta)k(t), \\
&\dot{h}(t) = s_h y - (\xi + n + \delta)h(t),
\end{aligned}\right\} \tag{16}$$

$k(t) \to k^*$, $h(t) \to h^*$, $y(t) \to y^*$ as $t \to \infty$, and

$$\left.\begin{aligned}
y^* &= \left(\frac{s_k^{\alpha} s_h^{\beta}}{(\xi + n + \delta)^{\alpha+\beta}} \right)^{\psi}, \\
k^* &= \left(\frac{s_k^{1-\beta} s_h^{\beta}}{\xi + n + \delta} \right)^{\psi}, \\
h^* &= \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{\xi + n + \delta} \right)^{\psi}.
\end{aligned}\right\} \tag{17}$$

C.4 Speed of convergence

If there was only one variable, *k or h*, (16) would be a Bernoulli differential equation and easily solved explicitly. Unfortunately, this is a system of Bernoulli differential equations and no explicit solution is known.

We can still estimate the speed of convergence in a neighborhood of the steady state by taking the first order Taylor approximation of a logarithmic version (i.e. log-linearalizing the system).

In general, let z be some variable we wish to log-linearlize around z^*, and let ρ be some scalar. Then

$$z^\rho \approx (z^*)^\rho\,(1-\rho(\log z^* - \log z)).$$

Using this on (16) yields

$$\begin{aligned}
\frac{\dot k}{k} &\approx s_k(k^*)^{\alpha-1}(1-(\alpha-1)(\log k^* - \log k))\,(h^*)^\beta(1-\beta(\log h^* - \log h)) - (\xi+n+\delta),\\
\frac{\dot h}{h} &\approx s_h(k^*)^{\alpha}(1-\alpha(\log k^* - \log k))\,(h^*)^{\beta-1}(1-(\beta-1)(\log h^* - \log h)) - (\xi+n+\delta),\\
\frac{\dot y}{y} &= \alpha\frac{\dot k}{k} + \beta\frac{\dot h}{h}.
\end{aligned}$$

By definition of the steady state, (16) and (17), we have $s_k(y^*/k^*) = s_h(y^*/h^*) = \xi + n + \delta$. Using this, we find[5]

$$\begin{aligned}
\frac{\dot k}{k} &\approx (\xi+n+\delta)\,[(1-\alpha)(\log k^* - \log k) - \beta(\log h^* - \log h)],\\
\frac{\dot h}{h} &\approx (\xi+n+\delta)\,[-\alpha(\log k^* - \log k) + (1-\beta)(\log h^* - \log h)],\\
\frac{\dot y}{y} &\approx (\xi+n+\delta)\,(1-\alpha-\beta)\,[\alpha(\log k^* - \log k) + \beta(\log h^* - \log h)].
\end{aligned}$$

Furthermore, $\log y^* - \log y = \alpha(\log k^* - \log k) + \beta(\log h^* - \log h)$, and therefore

$$\frac{\dot y}{y} \approx \lambda\,(\log y^* - \log y), \qquad \text{where} \quad \lambda := (1-\alpha-\beta)\,(\xi+n+\delta). \tag{18}$$

λ is the approximate speed of convergence of y,

$$\log(y(t)) - \log(y(0)) \approx (1-\exp(-\lambda t))\,(\log y^* - \log y(0)). \tag{19}$$

[5]Terms involving $(\log k^* - \log k)\,(\log h^* - \log h)$ are dropped because they are of second order size.

In this model, the steady state level (y^*) is specific for each country, because it depends on investment rates and population and pollution growth rates, (17). The speeds of convergence (λ) are also idiosyncratic for each country, as they depend on country-specific population and pollution growth rates as well according to (18).

C.5 Deriving an estimation equation

We use the prediction of the speed of the convergence to the conditional steady states to estimate the common parameters of the model that hold for all countries. Ideally, we would like to estimate α, β, γ, g, and δ, and also $A(0)$, the average technological level across all countries. However, we will see that this is not quite possible.

The intensive form $y(t)$ cannot be observed directly, since the normalizing factor $X(t)$ is a function of estimated parameters. So we have to first translate (19) into a form that uses only observable quantities.

First, use (7) to relate the CSL education proxy edu to the human capital investment quote s_h. Furthermore, by definition,

$$\log y(0) = \log Y(0) - \log X(0),$$

$$\log y(t) = \log Y(t) - \log X(t) = \log Y(t) - \log X(0) - (\xi + n)t,$$

$$\log X(0) = (1 - \psi\gamma)(\log A(0) + \log L(0)) + \psi\gamma \log C(0),$$

$$\log y^* = \psi\alpha \log s_k + \psi\beta \log s_h - \psi(\alpha + \beta)\log(\xi + \delta + n).$$

Country-specific observables are $Y_i(0)$, $Y_i(t)$, $L_i(0)$, $C_i(0)$, n_i, p_i, $(s_k)_i$, and edu_i. We will attempt to estimate α, β, γ, δ and g. To that avail, we collect all terms that do not involve country-specific observables into a constant,

$$\left.\begin{aligned}
&\log Y_i(t) - \log Y_i(0) \approx (\xi_i + n_i)t + (1 - \exp(-\lambda_i t)) \times \\
&\qquad\qquad \Big(\psi\alpha \log(s_k)_i + \psi\beta \log(\mathrm{edu}_i) - \psi(\alpha+\beta)\log(\xi_i + n_i + \delta) \\
&\qquad\qquad\quad - \log Y_i(0) + (1 - \psi\gamma)\log L_i(0) + \psi\gamma \log C_i(0) + \mathrm{const}\Big), \\
&\text{with} \quad \mathrm{const} := \psi\beta \log\sigma + (1-\psi\gamma)\log A(0).
\end{aligned}\right\} \tag{20}$$

Formulating this relationship in terms of the average growth rate of income per capita yields (8) in the main text, which is the second estimation equation. This form reveals that this is an extension of the first estimation equation (5).

D Results for individual countries

Table 4: Main data and results for individual countries. ξ, ϵ, and t_{half} are computed using the regression of (8), Table 2, non-linear specification, full sample.

iso	$\Delta \log Y/t$	p	n	ξ	ϵ	$t_{\text{half}}{}^{\dagger}$
CHE	1.784%	−0.413%	0.690%	1.158%	0.651%	48.87
NOR	2.620%	−0.018%	0.666%	1.464%	0.653%	44.16
USA	2.784%	0.190%	0.932%	1.422%	−0.071%	41.04
NLD	2.171%	−0.279%	0.513%	1.385%	0.219%	47.97
CAN	2.515%	0.839%	1.104%	1.770%	−0.526%	35.22
SWE	2.054%	−1.608%	0.456%	0.456%	0.823%	75.58
DNK	1.915%	−1.112%	0.297%	0.934%	0.320%	63.71
AUS	3.042%	1.280%	1.377%	1.893%	−0.462%	31.80
AUT	2.127%	0.041%	0.353%	1.736%	0.182%	44.79
DEU	1.898%	−0.870%	0.123%	1.239%	0.097%	59.87
FRA	1.969%	−0.835%	0.511%	0.980%	0.325%	56.47
ITA	1.527%	−0.048%	0.215%	1.771%	−0.079%	46.44
NZL	2.322%	0.873%	1.002%	1.870%	−0.608%	35.25
BEL	1.991%	−0.884%	0.375%	1.044%	0.053%	58.31
GBR	2.235%	−1.425%	0.416%	0.619%	0.640%	70.54
FIN	2.208%	−0.373%	0.366%	1.424%	−0.032%	49.97
ESP	2.216%	0.759%	0.613%	2.071%	0.204%	37.15
GRC	1.176%	0.915%	0.360%	2.370%	−0.985%	36.66
IRL	4.769%	0.718%	0.998%	1.759%	1.802%	36.38
JPN	2.161%	0.432%	0.287%	2.069%	−0.330%	41.00
ARG	1.863%	1.055%	1.255%	1.818%	−0.408%	33.42
IRN	1.641%	2.052%	2.130%	1.907%	−1.534%	26.76
SGP	6.331%	4.423%	2.175%	3.607%	1.600%	19.67
PRT	2.248%	1.355%	0.260%	2.764%	0.182%	33.84
HUN	1.687%	−1.060%	−0.188%	1.327%	−0.020%	66.74
MEX	2.825%	1.806%	1.744%	2.009%	0.010%	28.42
ZAF	2.228%	1.667%	1.931%	1.771%	−1.295%	28.75
BRA	2.687%	2.115%	1.558%	2.371%	−0.256%	27.37
TUR	4.321%	3.246%	1.721%	3.078%	1.019%	23.11
AGO	3.041%	1.040%	3.438%	0.211%	−0.106%	29.09
URY	2.551%	0.069%	0.460%	1.678%	−0.410%	44.04
JAM	0.816%	0.523%	0.860%	1.718%	−1.827%	38.32
CRI	3.897%	2.774%	2.024%	2.512%	1.188%	24.26
IRQ	3.558%	1.769%	2.769%	1.233%	−0.396%	26.95
SYR	1.525%	2.665%	1.884%	2.534%	−0.922%	24.80
ECU	3.064%	2.660%	2.077%	2.390%	−0.411%	24.57

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Table 4 — continued from previous page

iso	$\Delta \log Y/t$	p	n	ξ	ϵ	t_{half} †
PER	2.905%	1.484%	1.696%	1.809%	−0.043%	30.06
DZA	3.210%	1.458%	2.170%	1.444%	−0.708%	29.32
NIC	1.336%	1.896%	1.941%	1.932%	−1.515%	27.70
BGR	2.209%	−1.354%	−0.499%	1.339%	0.318%	78.88
JOR	4.881%	4.743%	3.659%	2.756%	0.142%	17.94
COL	3.584%	1.857%	1.685%	2.090%	0.399%	28.29
CHL	4.499%	1.938%	1.325%	2.412%	0.661%	28.52
BOL	2.918%	4.565%	1.906%	3.907%	−1.305%	19.57
SLV	1.989%	1.685%	1.012%	2.455%	0.131%	30.33
MYS	5.868%	5.015%	2.215%	4.011%	0.195%	18.42
PRY	4.195%	2.883%	2.124%	2.519%	−0.604%	23.78
DOM	4.598%	2.525%	1.687%	2.576%	1.387%	25.56
TUN	3.904%	2.580%	1.663%	2.635%	0.804%	25.39
CIV	3.510%	2.798%	3.171%	1.691%	1.244%	22.86
PHL	3.926%	2.202%	2.207%	1.960%	0.117%	26.06
NGA	3.202%	0.234%	2.624%	0.217%	−0.234%	35.54
KOR	6.393%	4.139%	0.858%	4.362%	0.501%	21.50
HND	3.741%	2.089%	2.586%	1.601%	−0.098%	25.95
ZMB	3.113%	1.178%	2.920%	0.691%	−1.260%	29.34
THA	5.322%	3.709%	1.151%	3.834%	0.333%	22.37
EGY	5.590%	3.687%	2.180%	3.066%	1.832%	21.41
CMR	3.359%	3.543%	2.835%	2.482%	−0.554%	21.16
GHA	4.073%	3.631%	2.540%	2.762%	0.230%	21.21
MAR	4.080%	3.246%	1.640%	3.138%	0.446%	23.20
KEN	4.112%	2.320%	3.096%	1.397%	0.295%	24.45
MDG	1.850%	1.436%	2.897%	0.896%	−1.226%	28.18
SEN	3.377%	1.986%	2.717%	1.430%	0.170%	26.17
HTI	1.030%	2.500%	1.816%	2.464%	−2.201%	25.48
SDN	4.380%	2.503%	2.875%	1.692%	0.068%	24.12
IDN	5.421%	3.723%	1.656%	3.475%	0.602%	21.82
ZWE	2.980%	0.273%	1.931%	0.752%	−0.922%	37.16
SLE	1.832%	1.941%	2.148%	1.812%	−0.613%	27.19
CHN	6.180%	4.435%	1.006%	4.470%	−0.217%	20.62
NER	3.039%	4.095%	3.407%	2.467%	−0.724%	19.39
IND	5.604%	3.486%	1.803%	3.195%	0.644%	22.33
BEN	5.074%	3.576%	2.925%	2.440%	0.730%	20.99
BGD	4.938%	3.412%	1.940%	3.039%	1.047%	22.39
TZA	4.507%	2.463%	2.877%	1.662%	−0.844%	24.24
NPL	4.232%	2.180%	1.718%	2.301%	0.217%	26.85
UGA	4.679%	2.993%	3.212%	1.804%	−0.377%	22.26
MWI	3.424%	3.158%	2.825%	2.208%	−1.147%	22.19

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Table 4 — continued from previous page

iso	$\Delta \log Y/t$	p	n	ξ	ϵ	t_{half} †
BDI	2.458%	1.216%	2.570%	0.974%	−0.332%	29.79
BFA	4.791%	3.224%	2.712%	2.338%	0.472%	22.12
ETH	5.209%	2.344%	2.814%	1.621%	0.939%	24.73
MMR	6.432%	2.321%	1.307%	2.705%	1.627%	26.89
MLI	7.327%	5.242%	2.510%	3.961%	0.081%	17.80

† t_{thalf} is the time needed (in years) to bridge half of the gap to the steady state path, computed as $\log(2)/\lambda$.