Journal of International Business and Economy (2019) 20(1): 1-31 (31 pages)

JIBE
Journal of International Business and Economy

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INTERNATIONAL INCOME CONVERGENCE TO A COMMON TREND AND LONG RUN GROWTH ESTIMATION USING ECONOMIC INSTITUTIONS OF OECD ECONOMIES

ABSTRACT

In traditional studies of regional income convergence, the economies are assumed to follow a common long-run trend determined by common technology. For the group of OECD economies, this is a defensible assumption. In this paper, we estimate this long run component by recovering estimates of steady-state levels of output from the standard β convergence estimates in a panel data set. We use institutional indicators to help estimate production technology. Results indicate that many OECD economies were above their steady states last decade, explaining the subsequent slower pace of long-run growth.

Key Words: Cross-country output convergence, Development policy, Macroeconomic analyses of economic development, Institutions and growth, OECD, Panel data

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INTRODUCTION

A fundamental question in macroeconomic growth theory is whether or not one should assume that economic productivity exhibits diminishing returns to capital. In past decades, the same question over diminishing returns was also essential to the study of economic development: if the returns to capital diminish at higher levels of industrialization, then the returns to investment should be lower in developed economies and higher in the developing economies, causing those economies to grow faster and "converge" to the income levels of the most developed economies. Economic growth models using this assumption also treated technological progress as purely random and exogenous, a somewhat unsatisfying feature, one which was called into question by Romer (1986) and the burgeoning field of "endogenous growth theory." In this case, when production has constant or even increasing returns to capital investment, then there should be no such expectation of convergence in global incomes.

The subsequent period of research activity involved the search for statistical evidence in favor of one or another of these growth models. One well-known paper by Mankiw, Romer, and Weil (1992) used cross-country regressions to find evidence of diminishing returns to capital. In what became known as "conditional convergence," the researcher often finds convergence in incomes once you hold constant the differences in technology or human capital, for example. The result of conditional convergence has been known since then to be very robust, with South Korea being a primary example of an economy which grew faster over the long term, accumulating capital, attracting investment and catching up to higher income economies.

Macroeconomic growth theory was left in a state of flux for a brief period: the models which were most satisfying (endogenous growth theory) where not what was being borne out in the empirical results (convergence of incomes and diminishing returns to capital). Eventually, endogenous models become more sophisticated and now can incorporate diminishing returns to capital or can otherwise be made consistent with the observation that countries converge in incomes after controlling for structural differences (Barro and Sala-i-Martin, 2004). Many of these models incorporate the diffusion of technology (refer to Barro and Sala-i-Martin, 1997).

This current research attempts to use a version of the classic growth model with diminishing returns to capital, but which also incorporates an "endogenous" influence, particularly when the statistical model is derived from the theoretical model. While not "endogenous" in the sense that we explain the evolution of technology, we do add information about economic institutions which can influence the rate at which technology is created and diffused. As in Acemoglu, Johnson, and Robinson (2005), institutions are seen as a fundamental cause of long-run growth. As such, we create a model which appends an extra shift parameter to the neoclassical growth model.

Once the empirical analysis is undertaken, and we obtain statistical results, especially with respect to convergence, we develop a method to recover the theoretical model's parameters from the results of the dynamic panel data estimates. We can then explore, in a qualitative manner, the distributional properties of the economies over time. Specifically, we can estimate the level of average income that anyone economy would be predicted to have at any point in time in our sample. Our novel contribution here is not the qualitative method itself but combining the use of a dynamic panel as was first done in Islam (1995) with the qualitative computations in Cho and Graham (1996). It's argued that the use of panel data is the most sensible context to recover the parameters of the theoretical model. This is because the inclusion of observations from different time periods will permit the estimation of country-specific effects, something never accomplished in the older analyses of growth convergence.

The empirical results in this paper show that when applied to the OECD economies, the method of computing and comparing steady states can be used to illustrate the evolution of the countries' output gaps. We find that, outside of the periods of recovery from recessions, the trend is for OECD economies to begin the period below their steady states, move toward their steady states, and then in 2005, proceed to go above them and continue to move further above in 2010. The changes appear to be indicative of subsequent periods and indicate that, outside of any unexpected shock, the present period should be one of slow growth.

This paper proceeds as follows: a review the literature is the next section, but with an emphasis on the role of the marginal product of capital and how that is specified in a production function. It's important to illustrate the link between the theory and the statistical analysis because the qualitative illustration it leads up to is dependent upon this linkage. The qualitative statistical analysis is of the same nature as in Quah (1997) but is more theory-driven and is an outcome of the use of institutions in the model specification. The third section briefly lays out the testable hypotheses. The fourth section then illustrates the derivation of the empirical model. The neoclassical growth model is continuous and needs to be put into a discrete form in order for it to be estimable. This section describes the methods and assumptions needed to do this. The fifth section describes the data and estimation methods. The sixth section describes the results of the estimation. Two sets of regression results are presented - one without the measures of economic institutions and another set of estimations with the measures. This section also includes a graphical illustration of the economies' output gaps and how they evolve over time, leading up toward the present era. The final section concludes and offers directions for further research.

LITERATURE REVIEW AND REVIEW OF THE THEORY

As noted in the introduction, a diminishing marginal product of capital leads to the prediction of a negative relationship between the level of national income per worker and the subsequent growth rate of incomes (Solow, 1956; Mankiw et al., 1992; Howitt, 2000). With these diminishing returns, lower growth rates of income are expected at higher levels of national income regardless of whether the resulting growth rate is positive or negative. A higher level of average income will result in a lower (possibly negative) growth rate due to the higher level of capital needed to sustain this high level of income (Okada, 2006). When this single-economy model is imputed onto individual economies across the globe and technology is understood to be a perfectly transferable public good, the implication is that lower-income economies should grow faster. More precisely, if the economies could flawlessly share technologies and also have similar rates of capital depreciation and labor force growth, then they'd be expected to all be heading to the same fixed point: a similar long-run steady-state level of income growth. The now-classic statistical test of this is to try to find, across a panel of economies, a negative correlation between the level of income and an economy's growth rate. Ever since Mankiw, Romer, and Weil (1992), we have seen this conditional convergence result time and time again, but as long as we mostly control for the levels of technology, labor force growth rates, saving rates, depreciation rates, and growth rates of technology (Barro and Sala-i-Martin, 1992; Islam, 1995). However, it's not likely this set of assumptions is reasonable for a dataset containing a broad set of economies in various stages of technological development. To address this issue, estimates of these growth parameters can be included as controls. Another approach would be to treat a group of similar economies as a growth club and test to see if convergence is occurring within the group (Durlauf and Johnson, 1995; Quah, 1997; Phillips and Sul, 2007).

However, even after focusing the tests upon a sample of similar economies, and after including for a set of control variables, such as labor force growth rates, saving rates, depreciation rates, and growth rates of technology, the result of finding global income convergence is still somewhat unsatisfying. This sense is mainly due to the fact that productivity differences among the economies do exist, even if we're controlling for them, and moreover, they establish whether an economy is either increasing its capital stock or disinvesting in its capital stock on its way to a steady-state level of growth. Converging to a steady state by investing or disinvesting are very different circumstances which the β convergence result itself cannot distinguish. To illustrate this result, take the simplified dynamic regression equation (which ignores any control variables or error term) where y_t is the current growth rate in incomes and y_{t-1} is the previous period's level of income.

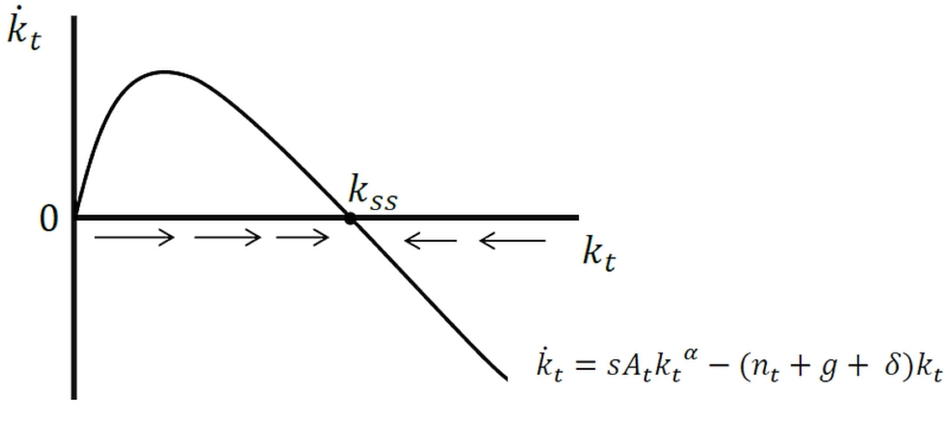
$$\dot{y}_t = b_0 + b_1 y_{t-1} \tag{1}$$

In this equation, if $b_1$is estimated to be negative and significant, then we've found evidence of β convergence because higher levels of income will experience slower growth rates. However, if this result only holds after we've controlled for the factors that make economies unique, such as latent factors representing technological development, then the conclusion that global incomes are converging toward equality (in reality) would be a misnomer (Barro and Sala-i-Martin, 1992). This conditional convergence result only indicates that the economies are exhibiting diminishing marginal product of capital and converging to their own unique steady-state levels of income, not an actual, observable common level of income. In getting to their individual steady-state levels of income, they may be experiencing positive or negative rates of growth (at least with respect to capital) as they converge to their steady-states.

To explain how this is in line with growth models containing a diminishing marginal product of capital, consider Figure 1 on the next page, a graph of the capital "transition equation" of a single economy in our model. This equation describes the rate of growth of capital, $\dot{k}_t$, as a function of k_t, the level of the capital stock. Note that the downward slope of the equation over most of the domain is due to diminishing returns to capital. This growth rate is determined by the difference between the inflows of investment and the portion of the existing capital which is used up in the production process.

The inflows of investment are determined by the fraction of output which is saved. These inflows are given by $sA_tk_t^{\alpha}$ where s is the saving rate, $y = sA_tk_t^{\alpha}$ is the production function, with A_t being total factor productivity (TFP) - a measure of technology. The term $(n_t + g + \delta)k_t$ gives the amount of capital which is used up and needs to be replaced, in which δ is the rate of depreciation, n_t is the growth rate of employment, and g is the growth rate of A_t. In Figure 1 we can also see that at lower levels of capital, the growth rate of capital per worker, $\dot{k}_t$, is positive. Within this single economy, there is convergence from below and toward the steady-state level of capital, k_{SS}. At higher levels of k_t, the growth rate falls below zero because of $sA_tk_t^{\alpha} < (n_t + g + \delta)k_t$, that is, investment is too low relative to the amount of capital which needs to be replaced. This is all because we model under the assumption that $\alpha < 0$ which implies that there are diminishing returns to capital and at higher levels of capital the marginal product of capital, as determined by $sA_tk_t^{\alpha}$, is falling. In finding evidence of this relationship, we pool all these economies into one regression to determine if this relationship exists on average (Quah, 1997). The point here is that no matter which side we are referring to, there will be a negative correlation between $\dot{k}_t$ and k_t therefore, a negative correlation between the growth rate in output, $\dot{y}_t$, and the level of output, y_t.

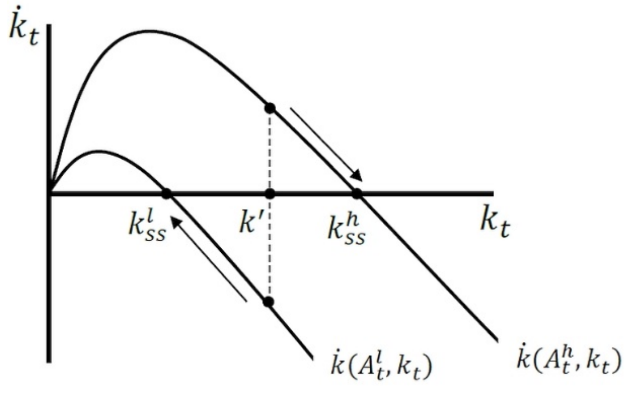
Figure 1: The Solow transition equation – Capital accumulation and disinvestment



If convergence from above the steady state results in a negative coefficient in Equation (1), then it's also possible that the countries are becoming less equal in their national incomes on the way to their own unique steady states, not necessarily more equal. Without acknowledging the possibility of convergence of an economy's income from above its own steady state, one might conclude that all economies are growing from below and approaching their unique steady states from the same direction (i.e. getting more equal). But allowing for differing growth parameters (s, A_t, n_t, δ, and g) and acknowledging convergence from above the steady state will lead to the prediction of possible divergence in incomes, not necessarily convergence, even if only partial.

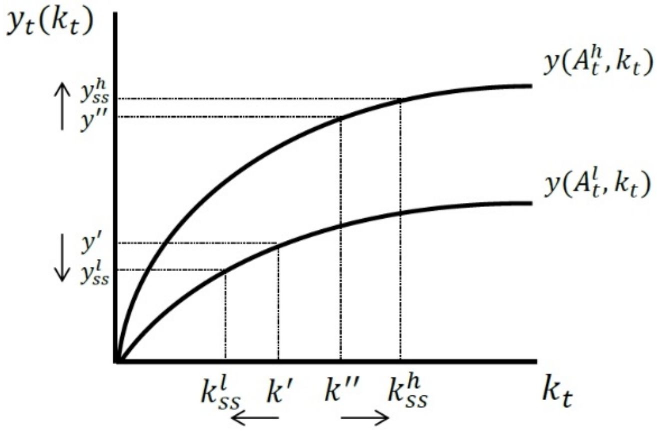
For instance, as in Figure 2, we can consider the same capital transition equation in the case that one economy is developed and has a high level of total factor productivity, given by A_t^h, and the other economy is still developing and a low level of total factor productivity, A_t^l. The latter case could also be an example of an economy which had just encountered a negative productivity shock, such as sudden political or financial instability. At the same level of capital equidistant from the two steady-state levels, k', a low-productivity economy will be experiencing rising but negative rates of growth while the developed economy will be experiencing positive but falling rates of growth. The rate of divergence would slow as they approach their respective steady states, but it would be divergence nonetheless. The methods developed in this paper allow for an explicit determination of whether an economy is converging from above or below its steady state. After finding the β convergence result, we can then calculate the steady states, as in Cho and Graham (1996) and Lee (2014). In the panel setting of conditional convergence, the steady-state level of output is determined by the unique population growth, education, and TFP estimates.

Figure 2: Economies with high and low productivities



In Figure 3, the levels of capital that are given in Figure 2 are used to show the resulting steady-state levels of income and the output gap. For the economy with high levels of productivity, the output gap $(y^h - y'')$ is positive and the economy would be predicted to grow from y'' to y^h. The amount by which the high-productivity economy will grow is smaller than the amount of per-worker income that the low-productivity economy will lose.

Figure 3: A developed and developing economy



Despite the relationship between a country's location relative to their steady state and the implication for subsequent growth as described above, very few theorists have chosen to write on this specific phenomenon. Within the results of standard empirical convergence estimates, it is straightforward to estimate the steady states. Cho and Graham (1996) are the first to do so and interpret the results as done in this paper. They correctly note that,

> With this result, one may find hardly any grounds for policies such as the World Bank's investment in these poorer countries with *the intent of pushing them towards their steady states*. (*Emphasis added*)

But the authors' purely cross-sectional methods do not permit the other side of the story: investment may be ineffective when above the steady state because TFP is too low to sustain it. Authors of the original cross-sectional studies (Mankiw et al., 1992; Cho and Graham, 1996) assumed that TFP was constant across economies. However, the panel data used herein permits a very different interpretation of the results. The conclusion is that development policies should first address inequalities in the factors that determine TFP (e.g. political stability, good economic institutions, technology transfers) and then we can focus on investment in capital goods. That is, stable institutions are themselves an investment with high returns (Ab, Muthiah, and Irfan, 2013).

TESTABLE HYPOTHESES

The final conclusions of this paper are somewhat qualitative in that the theory and empirical analyses allow us to illustrate how individual economies are distributed relative to their long-run, steady-state levels of income. We also observe how this distribution changes over time. There are, however, some standard empirical hypotheses that are tested along the way, and there are expectations about the qualitative analyses which can be confirmed by the results.

The first expected and hypothesized relationship is that between economic institutions and economic growth. The Economic Freedom index is discussed later in greater detail, but it should be noted for now that the components of the index are all weighted positively such that we expect a positive and significant relationship between this measure of the quality of economic institutions and the level of real per capita GDP.

We also would expect that after the measure of institutions is included in the models, we will still be able to detect conditional convergence in incomes. The statistical model is set up such that we would expect a coefficient on the lagged value of real GDP per capita which is greater than zero but less than one. This implies a positive correlation between the previous year's level of real GDP per capita and the current year's level, but the closer the coefficient is to one, then the smaller the gap between years (and the slower the growth rate). So, a positive coefficient of 0.5 implies that factors such as investment and TFP will cause enough annual growth to lead to an increase of half of the previous year's real GDP per capita. A coefficient of 0.9 would indicate only 10% is being made up. A coefficient greater than one indicates a divergence in incomes.

We also expect that in the end, the observable patterns in the evolution of the output gap in our economies will be consistent or offer insights into the current growth patterns. That is, we expect and hypothesize that our economies will evolve over time in some discernible pattern. We do not predict that the economies will move randomly above and below their steady state incomes from period to period, but rather that any movement will be slow and permit the observation of a descriptive long-run trend.

FROM A THEORETICAL MODEL TO AN EMPIRICAL ONE

As described above, in the convergence literature there is very little work which studies how the result of convergence from both below and above is underlying the theory and empirical results. To illustrate this link between theory and empirics, we review the derivation of the empirical model in light of convergence from both sides of the steady state. In doing so, it should also be shown how comparing countries with different production functions should proceed. To clarify, note that Equation (1) can be written in discrete form by specifying the change in output by $\dot{y}_t = y_t - y_{t-1}$. Then, the two forms of (unconditional) convergence are:

$$\dot{y}_t = b_0 - b_1' y_{t-1} \text{ and } y_t = b_0 + b_1 y_{t-1} \tag{2}$$

The two are algebraically and empirically equivalent convergence equations where the first form comes from subtracting y_{t-1} from both sides of the second, so that $b_1' = -1(1 - b_1)y_{t-1}$. You could run a regression in one form and then parameters and standard errors can be recovered algebraically to present the results in the other form. Both are forms of a partial adjustment model. If $b_1$were greater than 1 (i.e. $b_1' < 0$), then this would imply that incomes diverge: a higher initial level of output would result in even higher levels of output in the future. However, given the diminishing returns to capital in the Solow model, one would expect b_1 to be positive but less than 1. While the above model omits the additional control variables for presentation, we develop one which is inclusive of controls which can explain the differences in TFP. After Mankiw et al. (1992), the next development was to use panel data instead of cross-sectional data in estimating convergence.

One difference between calculating steady states in a panel data set and doing so in a cross-sectional setting as in Cho and Graham (1996) is that panel data contains multiple time periods so that we must manually define an initial time period in the data as the period in which $t = 0$. From there, the method simply recovers the parameter estimates and allows t to grow in a linear fashion from $t = 0$. The resulting derivation of the empirical model is similar to Islam (1995), except for a slight change in allowing for a linear growth rate in the analytical model, whereas in Islam (1995), the time trend is nonlinear in the analytical model despite becoming linear in the empirical model. Here this is accomplished by putting the (upcoming) final two equations into a discrete form before the last substitution of Equation (6) into Equation (5). The minor difference helps maintain continuity between the continuous analytical specification and the switch to the discrete empirical form. Islam's method and the one herein is based on Mankiw et al. (1992). Much of it is familiar, but the following discussion also describes how institutions are incorporated into this present work.

Incorporating institutions in the following manner is a novel contribution, unique to this paper. Conceptually and empirically, many of these types of institutional parameters can be entered as long as they are assumed to be independent of time. In what follows, the potential z are institutional factors such as regulation of property rights, ease of market entry, or other laws which ensure equal and efficient access to a country's economic institutions. These institutions are excludable because they can only affect the productivity of the country in which they are enforced and are thus distinct from time-dependent forms of non-rival and non-excludable technology. The other traditional non-excludable forms of technology are innovated or adopted at a rate which takes the familiar gt form where g is the growth rate of these forms of technology. In what follows, ρ represents the percent change in total factor productivity in response to a change in z, whichever measure of institutions z may be. Note that ρz can be a dot product of vectors such that $\rho z = \rho_1 z_1 + \rho_2 z_2 + \cdots + \rho_n z_n$, allowing for a multitude of such measures. The ρ can be estimated empirically, and they determine the relative impact of each productivity shock. Then total factor productivity can be given by:

$$A_t = \bar{A} e^{(gt + \rho z)} \quad (3)$$

In this paper, g is estimated as the regression coefficient on a time trend. Time t is a variable indicating how many periods have passed since an initial period. $\bar{A}$ is the time-invariant initial level of TFP which is estimated with the resulting country-specific effect. The growth rate of A_t is given by $\dot{A}_t / A_t = g$, since ρz does not depend on time. The following derivation is similar to Mankiw et al. (1992) with details found in Barro and Sala-i-Martin (2004). Aside from the per-worker solution methods found in Bernanke and Gürkaynak (2002) and the addition of a parameter, ρz which represents institutions, the model is standard. The production function can be expanded to $\ln y_t = \ln \bar{A} + gt + \rho z +$

$\alpha\hat{k}_t + \beta \ln \hat{h}_t$where y_t is per worker output. Capital stock per effective worker is given by $\hat{k}_t$ while the level of human capital per effective worker is noted as $\hat{h}_t$. Given that z is independent of time, the derivative of $\ln y_t$ w.r.t. time is then,

$$\frac{\dot{y}_t}{y_t} = g + \alpha\frac{\dot{\hat{k}}_t}{\hat{k}_t} + \beta\frac{\dot{\hat{h}}_t}{\hat{h}_t} \tag{4}$$

It should be noted that the left-hand of the equation is in per worker terms while the right-hand is ineffective worker terms. This allows $\dot{\hat{k}}_t/\hat{k}_t$ and $\dot{\hat{h}}_t/\hat{h}_t$ to be approximated with a first-order multivariate Taylor expansion around a constant, the steady state. After log-linearized expansions of the standard "equations of motion" for capital and human capital, and the substitution of these results into Equation (4), the solution eventually becomes:

$$\ln y_t = gt + e^{-\lambda t}\ln y_0 + \left(1 - e^{-\lambda t}\right)\ln y_0^* \tag{5}$$

where y_0 is an initial level of output per worker and y_0^* is an initial steady-state level of output per worker. When the steady state level of per worker output is evaluated at an initial period where $t = 0$, the term A_t is simplified and we have: $y_0^* = \bar{A}e^{\rho z}\left[\frac{s_k^{\alpha}s_h^{1-\alpha}}{(n+g+\delta)}\right]^{\frac{1}{(1-\alpha-\beta)}}$. We can then find the log of y_0^* to get,

$$\ln y_0^* = \ln \bar{A} + \rho z + \frac{\alpha}{(1-\alpha-\beta)}\ln s_k + \frac{\beta}{(1-\alpha-\beta)}\ln s_h - \frac{\alpha+\beta}{(1-\alpha-\beta)}\ln(n+g+\delta) \tag{6}$$

Equation (6) can now be substituted into Equation (5) to obtain:

$$\begin{aligned} \ln y_t = gt + e^{-\lambda t} \ln y_0 + \left(1 - e^{-\lambda t}\right) \ln \bar{A} + \left(1 - e^{-\lambda t}\right) \rho z \\ + \left(1 - e^{-\lambda t}\right) \frac{\alpha}{(1 - \alpha - \beta)} \ln s_k \\ + \left(1 - e^{-\lambda t}\right) \frac{\beta}{(1 - \alpha - \beta)} \ln s_h \\ - \left(1 - e^{-\lambda t}\right) \frac{\alpha + \beta}{(1 - \alpha - \beta)} \ln(n + g + \delta) \end{aligned} \tag{7}$$

Equation (7) is still in continuous form but is in a shape which shows the specification of parameters which can be estimated in a regression.

Discrete form and dynamic panel specification

The next steps are to 1) specify the empirical model by using Equation (7), and 2) to show how such an empirical model can be used to calculate per worker steady-state levels of income. What follows is similar to Islam (1995), however, in Islam's derivation, the change in notation from continuous to a discrete form comes before the final substitution of Equation (6) (i.e. steady state income as an initial value), into Equation (5) the solution to the dynamic equation. This leads to a nonlinear coefficient on g and would lead to a similar coefficient on z, the institutional parameters. Using $time = 0$ in the steady state equation before the substitution permits a simpler form. It also follows naturally from the solution of the differential equation which required an initial value at $time = 0$. Changing notation after substitution also gives a linear time trend ideal for the regression setting. This conforms nicely with theory as gt is increasing in constant scale over time and represents the deterministic increase in TFP above the initial $\bar{A}$ due to improvements in the level of technology.

To put things into a discrete estimable form, two changes to the notation in Equation 7 are made. We can define time period t and a lag time period $t - k$, with $t - k$ as an indicator for the lagged value. The length k refers to the lag period of time over which averages of the control variables are taken and over which the long run growth occurs. Following Islam and others, $k = 5$. In Equation (7), k is also the length of the time which has passed since period $t - k$.

The other change in notation is to use a time indicator of $\tau = 0, 1, 2, 3, 4, \dots$ where each of these intervals refers to a $k - year$ period. This is because, with panel data, each cross section will contain an average of several periods of time. To relate the time intervals within each cross-section, we use τ so that $g\tau$ grows linearly from period-to-period with each time period. Also, to fix a period in which all TFP is captured in $\bar{A}$ there is $\tau = 0$, which gives $g\tau = 0$. An additional lagged observation of output is then needed for period $\tau = -1$ for each cross-section of data. From there, the per worker steady state will have a common deterministic component of growth equal to the rate g. Making these substitutions in notation gives,

$$\begin{aligned} \ln y_t = g\tau + e^{-\lambda t} \ln y_{t-k} + \left(1 - e^{-\lambda t}\right) \ln \bar{A} + \left(1 - e^{-\lambda t}\right)\rho z \\ + \left(1 - e^{-\lambda t}\right) \frac{\alpha}{(1 - \alpha - \beta)} \ln s_{k_t} \\ + \left(1 - e^{-\lambda t}\right) \frac{\beta}{(1 - \alpha - \beta)} \ln s_{h_t} \\ - \left(1 - e^{-\lambda t}\right) \frac{\alpha + \beta}{(1 - \alpha - \beta)} \ln(n_t + g + \delta) \end{aligned} \tag{8}$$

Conceptually, on the right-hand side, we have distributed $\left(1 - e^{-\lambda t}\right)$ through the steady state equation and then substituted that into the discrete version of the solution to a dynamic equation. This result is a discrete form of Equation (7).

In order to make the final change to a dynamic panel model, we can specify the country-specific effect, the time trend and append a purely stochastic error term. This gives the following familiar empirical model:

$$y_{it} = \gamma y_{i,t-k} + \sum_{j=1}^{4} \beta_j x_{it}^j + \eta\tau + \mu_i + \nu_{it} \tag{9}$$

where we have:

$$y_{it} = \ln y_t, \qquad y_{i,t-k} = \ln y_{t-n}, \qquad \gamma = e^{-\lambda t},$$

$$\beta_1 = \left(1 - e^{-\lambda t}\right) \frac{\alpha}{(1-\alpha-\beta)}, \qquad \beta_2 = \left(1 - e^{-\lambda t}\right) \frac{\beta}{(1-\alpha-\beta)},$$

$$\beta_3 = \left(1 - e^{-\lambda t}\right) \frac{\alpha+\beta}{(1-\alpha-\beta)}, \qquad \beta_4 = \left(1 - e^{-\lambda t}\right)\rho,$$

$$x_{it}^1 = s_{k_t}, \qquad x_{it}^2 = s_{h_t}, \qquad x_{it}^3 = (n_t + g + \delta), \qquad x_{it}^4 = z_t,$$

$$\eta = g, \qquad \mu_i = \left(1 - e^{-\lambda t}\right) \ln \bar{A}$$

The parameters to be estimated are γ, β_1, β_2, β_3, η, and μ_i, the country fixed the effect. These can be estimated with any number of methods, but the preferred estimator is the "system GMM" described later. As was implied in the previous section, the initial steady-state level of per worker output can be recovered by setting $\eta\tau = 0$, on the righthand side of Equation (9) and then dividing each relevant parameter by $(1-\gamma)$. The standard error of the steady state can then be recovered with the "delta method" by using the standard errors of each relevant parameter and the standard error of $(1-\gamma)$. Recovering the steady state in this way is equivalent to defining the steady state as a point where $y_{i,t} = y_{i,t-k} = y_t^*$, then solving for y_t^* and setting $\eta\tau = 0$and $\nu_{it} = 0$. Calculating steady states in this manner is similar to how long-run values are calculated in any partial adjustment model.

DATA AND ESTIMATION METHODS

Before presenting the results, this section gives a brief overview of the data and then discusses several estimation issues which arise in this present context. Data come from a variety of standard sources.

Data

The Penn World Tables versions 7.1 and 8.0 from Heston, Summers, and Aten (2012) and Feenstra, Inklaar & Timmer. (2013), respectively, are the primary source of data. These sources provide measures of real GDP, population, and investment as a share of GDP, all in real terms and adjusted for purchasing power. Given the challenge of estimating a labor force and to remain consistent with Mankiw et al. (1992) and Islam (1995), per capita GDP is used instead of per worker GDP. "Output-side" real GDP at current PPPs (in mil. 2005US$) is used for the measure of output. Investment in physical capital is given by the "share of gross capital formation at current PPPs" in the Penn Tables 8.0. Data on education come from the Barro-Lee data set (Barro and Lee, 2012), with the preferred measure being the percent of adults over 25 who have completed secondary school. Other research uses enrolment figures, but completion rates give a better measure of the effectiveness of education. As a measure of institutions, we use the Economic Freedom Index constructed by the Fraser Institute and provided by Gwartney and Lawson (2012). The Economic Freedom Index is a comprehensive measure of various factors which measure the business climate of a country. In brief, the index measures the size of government, legal systems, property rights, monetary policy restraint, freedom to trade internationally, and regulation.

Estimation

It's assumed that by averaging over several years one can control for business cycle shocks. Neither Islam (1995) nor Caselli, Esquivel, and Lefort (1996) uses a time trend despite the fact that one is specified in the model. Instead, the authors use time dummies to control for the time-specific effects. Excluding a time trend means that more trend-variation will be caught by the error term which could, in turn, affect the estimation of the coefficient and variance on $(n_t + g + \delta)$ as worldwide population growth rates have been on a steady and continuous decline since the 1960s. On the other hand, including a time trend appears to make it less likely to find a significant relationship between $(n_t + g + \delta)$ and y_t. Ideally, the model should include both a time trend as a matter of theory and time dummies as an empirical method to control for time-specific heterogeneity coming from international macroeconomic shocks. The value of the time dummy must be added back into the intercept to compute TFP.

If several dummies must be dropped due to high collinearity, then a specification might only include a time trend, which is done here with some solace given that the data is averaged over five years as a way to address random time shocks. The augmented Solow model can also be estimated in an unrestricted or restricted form. One hypothesis of the Solow model is that in the long-run, the coefficients on investment, sy_t, and $(n_t + g + \delta)$ should be equal but with opposite sign. The two results bear little distinction in the final calculation of the initial steady states. A dynamic panel specification introduces several well-known empirical issues into the estimation. The estimation methods we use are pooled OLS, fixed effects (within estimator), and the preferred "system" GMM estimator. There are country-specific effects present and using the pooled OLS estimator will omit such a variable which will then end up in the error term. This in itself won't lead to bias, but the fact that there is a lagged dependent variable which also contains the specific effect makes for biased estimation in the case of OLS. With fixed effects, "within estimation" can be used but differencing using a time-averaged variable serves to introduce a time-averaged error term which will again be correlated with the lagged dependent variable (Nickell, 1981).

To avoid biased estimation then, the system GMM estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998) uses lagged, differenced, and lagged differenced values of the righthand variables as instruments. Such an estimator has been shown to be consistent and unbiased for a dynamic panel with more cross sections than time observations. The challenge in using such an estimator is that all combinations of lags can be used as instruments so there tends to be a proliferation of instruments and over-fitting if the estimator is used without caution (Roodman, 2009). But the Hansen J test statistic should help identify a model in which the instruments are valid. However, while the test is robust to heteroscedasticity, it is weakened by too many instruments. As recommended then, fewer instruments than cross-sections are used, with 54 instruments for 85 cross-sections.

As in Eicher and Schreiber (2010), the lags of the institutional instruments are also used as traditional exogenous IVs for identification purposes. The Arellano-Bond test for AR (1) and AR (2) are also used to test for unit roots. It's expected that the first-differenced instruments will have a unit root in AR (1) but not after, so valid estimation requires that the null hypothesis of no autocorrelation is rejected in AR (1) but is not rejected in AR (2). The null hypothesis of valid instruments is not rejected in the Hansen J tests. In order to add back out the country-specific effects and compute the unique steady states, we need to get estimates of the fixed effects which were differenced out during the system GMM estimation. In order to do so, we follow the procedure outlined by Caselli et al. (1996) and take time-averages of the error terms as follows. Equation (9) can be rewritten as:

$$\hat{\mu}_i + \hat{v}_{it} = y_{it} - \hat{\gamma} y_{i,t-k} - \sum_{j=1}^{4} \hat{\beta}_j x_{it}^j - \hat{\eta}\tau \tag{10}$$

and then we can compute

$$\bar{\hat{\mu}}_i = \frac{1}{k} \sum (\hat{\mu}_i + \hat{v}_{it}) \tag{11}$$

In practice, one can include a constant in the estimation. Its value represents the average country-specific effect. If so, the $\bar{\hat{\mu}}_i$ can be added to the constant in order to finally obtain an estimate of the term $(1 - e^{-\lambda t}) \ln \bar{A}$ which is found in Equation (8).

The OECD panel: 1980 – 2010

The group of countries representing the OECD can be found in the empirical analyses of Islam (1995), Lee, Pesaran and Smith (1997) and Bond, Leblebicioglu and Schiantarelli (2010) Arnold, Bassanini, and Scarpetta (2011) cite the technical reasons for using the sample. We'll discuss these reasons in the following sections while noting here that the similarities between the technology employed by the group of countries help address several theoretical and empirical issues. Barro and Sala-i-Martin (1992) used a similar strategy in focusing on the states of the United States to obtain cross sections with similar technologies.

Presently, 1980 is chosen as an initial period which allows for the inclusion of two additional countries to what was in Mankiw et al. (1992), for a total of 24 cross sections in the panel. Economies that entered the OECD prior to 1973 are used to avoid selection bias when measuring convergence. The main reason for starting in 1980 is due to data availability of the relevant institutional variables, however, this is conveniently the beginning stages of what became known as "the great moderation," a period of stability and steady growth. Box 1 lists the countries found in the sample. The panel is balanced, and each cross-section contains seven 5-year periods so that there are seven observations for each of the 24 cross sections.

Box 1: OECD Members in the sample (24 economies)

Australia	Denmark	Greece	Japan	Norway	Switzerland
Austria	Finland	Iceland	Luxembourg	Portugal	Turkey
Belgium	France	Ireland	Netherlands	Spain	United Kingdom
Canada	Germany	Italy	New Zealand	Sweden	United States

Estimation issues

There are a host of concerns associated with cross-country growth regressions. Many of these can be addressed by choosing a panel of countries which are similar enough to make the assumptions of common production technologies and common TFP growth more reasonable. This is the motivation behind finding "growth clubs" as in Durlauf and Johnson (1995), Canova (2004), and Phillips and Sul (2007) among others. Having homogenous production technology makes the critical assumption of the system-GMM estimator less questionable (Pesaran and Smith, 1995). As discussed in Eberhardt and Teal (2011), there are econometrically sophisticated ways to deal with some of the concerns over variations in

TFP. Presently, there are dynamic factor methods which allow for, not only country-specific levels of TFP but country-specific growth rates in TFP and shares of physical and human capital (Pesaran, 2006; Bai, 2009; Teal and Eberhardt, 2009). Here, we don't allow quite as much flexibility in the estimator but adopt the strategy of using a sample in which so much flexibility isn't as important as in one which mixed in developing economies. Ultimately, what is important is that there is variation between countries in the components which are most important. This should be sufficient as there are also common elements shared between this group of economies.

DATA AND ESTIMATION METHODS

For comparison, we'll first examine in detail the regression without the Economic Freedom Index and then in the following section, the index is included, and those results are used to compute steady states for each period in the sample. To follow the results throughout time, a series of graphs are used to keep the information succinct. The regression tables still apply to every period, although the time trend increases linearly, and appropriate time dummies are included in the calculation of the steady states. The time trend allows for estimation of g while time dummies help control for cross-sectional interdependency such as global macroeconomic shocks.

OECD base results: 1980 – 2010

In these base (without institutions) results, all the OECD countries except for Spain, Turkey, and France remain under their 1980 steady state, indicating that the long run growth rates should be above average for most countries in the following years. The sample begins in 1975 and has full observations in 1980 (since 1975 is needed as the first lag). Table 1 presents the detailed convergence results.

There are a couple of notable distinctions. First, when compared to a worldwide sample, the speed of convergence is much faster in the OECD group, corresponding to 6.8 years and 7.6 years for the restricted and unrestricted half-lives. This is a common result for countries which are similar.

Table 1. Convergence Regressions using an OECD Sample: 1980 - 2010

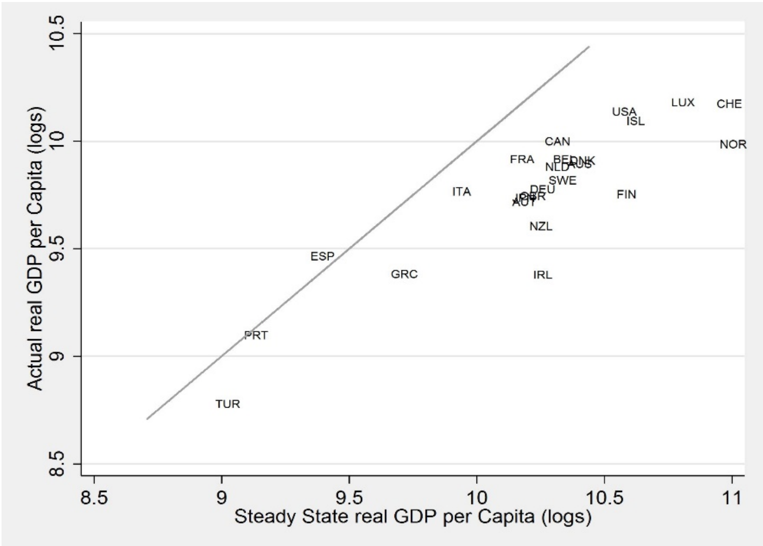
	Pooled y_t	Fixed Effects y_t	GMM Unrestricted y_t	GMM Restricted y_t
y_{t-1}	0.913***	0.601***	0.609***	0.737***
	(0.030)	(0.089)	(0.056)	(0.096)
$(n_t + g + \delta)$	-0.0826	0.0860	-0.0438	–
	(0.077)	(0.118)	(0.227)	–
s_{k_t}	0.115***	0.176***	0.381***	–
	(0.036)	(0.082)	(0.093)	–
s_{h_t}	0.0783*	0.118*	0.407***	–
	(0.043)	(0.063)	(0.093)	–
$s_{k_t} - (n_t + g + \delta)$	–	–	–	
	–	–	–	
$s_{h_t} - (n_t + g + \delta)$	–	–	–	
	–	–	–	
λ	0.018***	0.102***	0.102***	0.091***
	(0.000)	(0.011)	(0.005)	(0.000)
$time\ t$	-0.001	0.0367***	0.0207***	–
	(0.005)	(0.011)	(0.011)	–
$constant$	0.727**	4.191***	3.445***	0.753
	(0.300)	(0.884)	(0.891)	(0.989)
N	168	168	168	168
R^2	0.9655	0.9438	–	–
$Hansen\ J$	–	–	0.254†	0.100†
$Instruments$	–	–	27	22
$AR(1)$	–	–	0.000†	0.001†
$AR(2)$	–	–	0.659†	0.955†

Robust standard error in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
† p-values

Physical capital shares can be recovered and are of a reasonable scale, with 0.32 for the unrestricted and 0.47 for the restricted estimates. These shares are also fairly consistent with what others find in the OECD sample (Canarella and Pollard, 2011). The deterministic growth rate corresponds to a period of five years and is significant in the unrestricted model. In the next section, when institutions are included, the deterministic growth rate becomes significant in the system-GMM estimation. The coefficient on time, t, corresponds to less than 0.5% per year which is lower than might be expected. It would seem that the impacts of the other variables make a strong enough contribution to growth that there isn't much left over for the time trend to pick up.

The focus is on the restricted results in column 5 of Table 2. Steady states are calculated as was described in Section 4 by using Equation (9) and the results are illustrated in Figure 3. The estimated steady states are in the horizontal axis while the actual per capita GDP values are in the vertical axis. Visually, if an economy is to the right of the 45° line, then they must have an actual value which is less than its steady-state level of income. All but one of the countries, Spain, is significantly above its steady state in 1980. This result is consistent with a group of economies which will grow at above-average rates in subsequent periods, catching up to their steady states.

Figure 2: Per capita GDP Relative to the Steady-state GDP, OECD 1980



There are some notable country-specific occurrences in the OECD panel. Ireland, Luxembourg, Sweden, and Norway had the best growth prospects starting in 1980. Interestingly, Greece was in a position to catch up to a much-improved steady state, although it should be noted that the data end in 2010, missing the second half of the debt crisis. That said, the debt crisis often obscures the fact that the Greek economy nearly doubled in size, growing by 89.3% over those decades. Japan is still well below the steady state. However, its economy lost some luster while entering into the 1980-2010 period of development as it came closer to a level of balanced growth and then become overcapitalized by the mid-1990s.

The OECD Panel with institutions: 1980 – 2010

The members of the OECD economies tend to be well-developed democracies with similar political institutions, so a measure of economic institutions, the Economic Freedom Index, is used. This section presents those results in Table 2 and then illustrates the resulting series of steady states.

OLS and fixed effects estimation are again used to make comparisons to the system-GMM estimation. As in the other samples, we find significant convergence as indicated by the positive coefficient on y_{t-1}. In every case, the speed of convergence is much faster for the OECD countries when compared to worldwide speeds of convergence such as those in Mankiw et al. (1992). Ou preferred results are in column 5 of Table 2. These are usin the restricted forms of the augmented Solow model. In column 5, the speed of adjustment parameter, λ, indicates that in only 4.3 years the average OECD country will be half-way to its steady state. As far as long-run growth is concerned, this is an extremely short period of time but makes sense considering that the OECD countries are quick to innovate and take on new technology while quickly adapting the economic activity to the new potential levels of output. The coefficient on $(n_t + g + \delta)$ is insignificant irrespective of the estimation, but the capital investment s_k and human capital investment s_h coefficients take on fairly plausible values for developed economies. Those coefficients imply that $\alpha = 0.27$ and $\beta = 0.20$. The figures are lower than the 1/3 standard for the level of physical capital that the literature has accepted but are very close to the actual accounting estimates of the OECD's Productivity Database (Abu-Qarn and Abu-Bader, 2009).

The Economic Freedom Index is significant and positive in the system-GMM estimation. The index is on a scale from 1–10 so that 0.111 indicates that the level of real GDP would increase by 11.1% for every 1- point increase in the index. For perspective, a 1-point difference in the index is found between the economic institutions of the United States and Mexico, with the US having an index value of 7.73 and Mexico one of 6.64. At the highest end of the scale, Singapore has an index value 1-point higher than the United States. The reasons for the significant relationship to growth may vary. There may be a direct link to productivity or an indirect link through beggar-thy-neighbor policies involving tax shelters and other incentives and trade policy to attract industry rather than grow it. These factors are not examined here but may also explain the positive relationship to growth.

The variable labeled as $time\ t$ is the time trend. Among the OECD sample, it is found to be significant even after time dummies are also included. Time dummies help control for shocks common to each cross-section, such as recessions and expansions affecting most OECD members. The coefficient on t is our estimate of g, and as with the previous example, it is lower than is typically assumed. The 3.37% deterministic growth rate over a period of five years implies that there is an average annual increase of 0.67% in real GDP per year. This can be attributed to growth in TFP. Previous common assumptions and rough estimates have stated that the 2% – 3% average annual growth rates in real GDP among the OECD economies is due entirely to g , the deterministic growth rate. In our sample, the acutal annual rate of real GDP growth is 2.8%. However, using our methods, this is decomposed into factors other than g. The fact that OECD economies move to a position above their steady states in the later observations of the sample implies that much of the growth in real GDP isn't due solely to these improvements in TFP. This technical change component of real GDP growth is only 0.67%. The remainder of the growth in real GDP can only be explained by investments into physical and human capital per worker along with improvements to a country's economic institutions.

As before, the methods of the previous section are employed to derive the values of each steady state. This time institutions are used in the manner shown by Equation (6) from the section. The restricted estimates from the last column of Table 3 will be used, although there isn't very much difference between the two system-GMM estimates. Figure 4 begins the illustration of the country's positions relative to their steady states. Denmark, New Zealand, Sweden, United Kingdom, Spain, Italy, France, Portugal, Turkey, and Iceland are all above their steady state while the remaining 14 countries are below. For example, Spain is $2,237 above its steady state in per capita terms, while France and Turkey are $3,313 and $1,170 above their respective steady states.

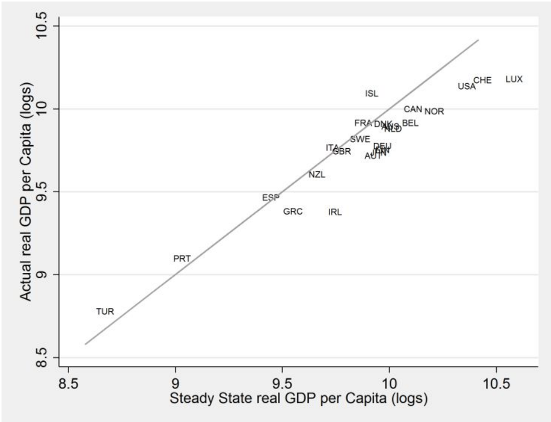
The following graphs illustrate the progression of estimates emerging from the base year. From the last column of Table 2, we can observe that the log of the steady state now increases 0.0337 every five-years due to g and will also increase in response to higher saving and education rates along with changes in economic institutions and any shock common to the countries.

Table 2: Sample of OECD economies with their institutions, 1980 - 2010

	Pooled y_t	Fixed Effects y_t	GMM Unrestricted y_t	GMM Restricted y_t
y_{t-1}	0.894***	0.603***	0.373***	0.450***
	(0.033)	(0.087)	(0.118)	(0.098)
$(n_t + g + \delta)$	-0.0820	0.0857	-0.202	–
	(0.077)	(0.120)	(0.168)	–
s_{k_t}	0.120***	0.176**	0.442**	–
	(0.036)	(0.081)	(0.188)	–
s_{h_t}	0.0523	0.110*	0.394***	–
	(0.044)	0.058)	(0.129)	–
$s_{k_t} - (n_t + g + \delta)$	–	–	–	0.287**
	–	–	–	(0.144)
$s_{h_t} - (n_t + g + \delta)$	–	–	–	0.203*
	–	–	–	(0.144)
$Econ\ Freedom$	0.0194	0.0118	0.0826***	0.111***
	(0.012)	(0.023)	(0.026)	(0.041)
$time\ t$	-0.0014	0.034***	0.045***	0.034***
	(0.004)	(0.012)	(0.013)	(0.016)
$constant$	0.866**	4.354***	4.756***	3.206***
	(0.347)	(0.883)	(0.786)	(0.621)
λ	0.022***	0.101***	0.197***	0.156***
	(0.007)	(0.029)	(0.063)	(0.004)
N	168	168	168	168
R^2	0.9662	0.9441	–	–
$Hansen\ J$	–	–	0.160†	0.105†
$Instruments$	–	–	23	16
$AR(1)$	–	–	0.003†	0.003†
$AR(2)$	–	–	0.916†	0.830†

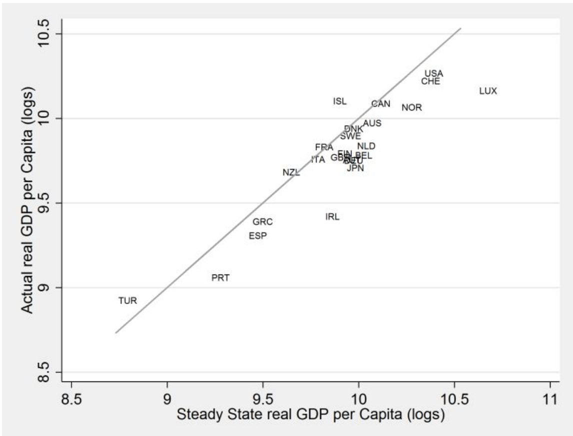
Robust standard error in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
† p-values

Figure 3: 1980 per capita GDP relative to the steady state



By 1985, the majority of the economies are still below their steady states. By 1985, the United States had just experienced a large recovery and expansion following the recessions of 1980 and 1982, but these cyclical impacts seem to be omitted in the restricted version of the results. The Greek, Spanish, and Portuguese economies are now below their steady states. The late 80s saw these economies then growing at much higher than average rates, as would be predicted from these positions. Subsequent slower growth is then predicted as the economies move above their steady states in the following series of illustrations.

Figure 4: 1985 per capita GDP relative to the steady state



The rest of the pattern can be seen from the following graphs of output vs. steady states. The potential level of output has risen above actual levels of output as TFP has had time to evolve and enhance real productivity. The period following the 1980–1985 is also one of moderation, that is until the 2007-2010 recession. Over the late 80s and early 90s, the majority of economies stayed at or well below their potential levels of output, indicating that they would incur higher levels of growth in later periods as capital was accumulated during the convergence to their own steady state. Interestingly, the US stays close to the steady state frontier which is consistent with its role as the source of TFP evolution.

Figure 6: 1990 per capita GDP relative to the steady state

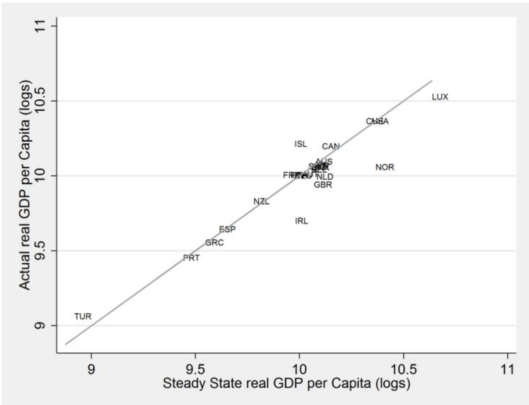
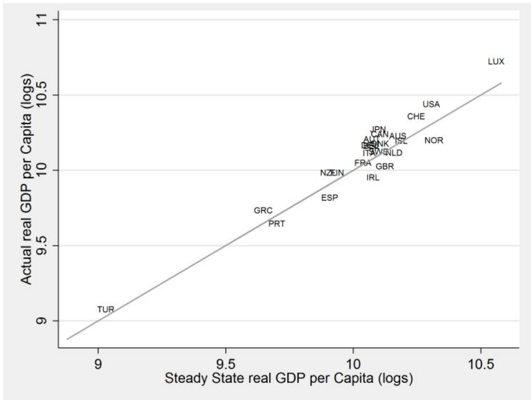


Figure 7: Relative GDP per capita in the stead state in 1995



By 2000, the economies are in great positions to grow, however, beginning in 2005 the OECD economies begin to move above their steady states and by 2010, with the exception of Turkey, Iceland, and France, every OECD economy is well above its potential level of output. The most dramatic change is in the position of Luxemburg. Partly due to the presence of high-income commuting foreign workers, the per capita GDP of Luxemburg is much larger than that of the other economies, however, the analysis here does well in describing the dynamics. The results here would predict such slow growth to occur for some time given the unusually high levels of growth left unexplained by any particular country-specific characteristic that Luxemburg possesses.

Figure 8: 2000 per capita GDP relative to the steady state

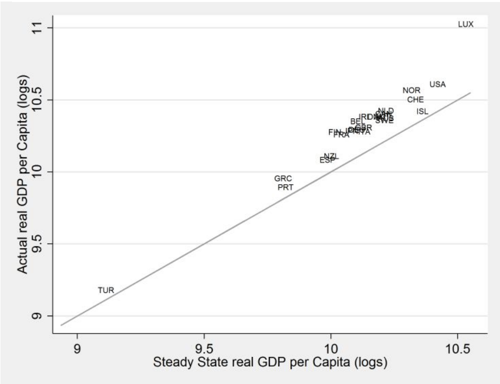


Figure 9: 2005 per capita GDP relative to the steady state.

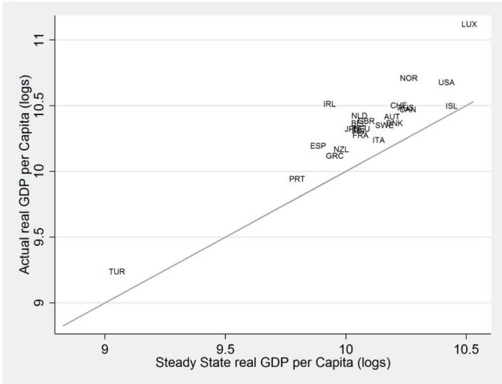
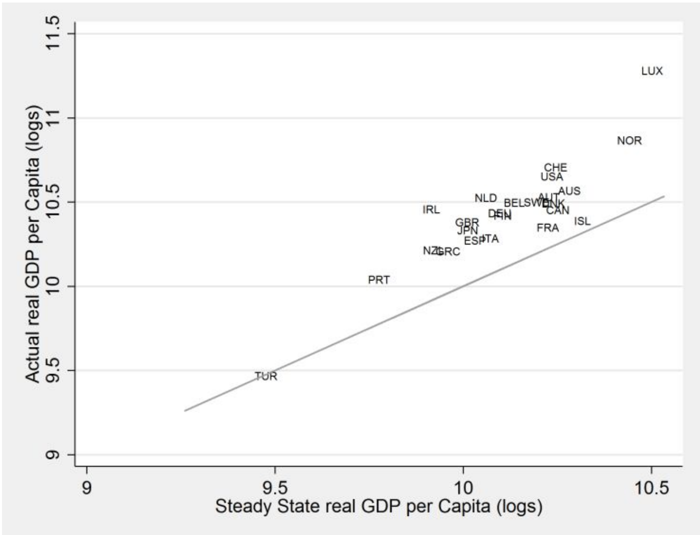


Figure 10: 2010 per capita GDP relative to the steady state.



The out-of-sample predictions thus far seem to be a fair description of reality. There has been no return to recession for the US, despite the strong potential for one to occur (Berge and Jordà, 2010), but growth has been slower than in the average rates of prior decades. This is likely to continue. And, of course, the European debt crisis is only presently subsiding, roughly seven years following the onset of the 2007-2009 recession. The positions of the economies in 2010 are in line with institutional long-term forecasts emerging after the recession (Johansson et al., 2012; OECD, 2012; Energy Information

Administration, 2013). All of these outlooks anticipate slower than average growth in the upcoming decades. In looking at the past periods of slower growth, the present may be comparable to the 1985–1995 period, but with even slower rates of growth and over a more extended period.

CONCLUSIONS

There are several main results which were presented in this paper; some of them are in line with the standard growth forecasts and theories while others may offer a slightly new perspective on things. There is a need to improve parameter estimates, but the overall results using the method of estimating steady states within a convergence analysis seem to be reasonable enough to warrant further innovation of the method. There is strong theoretical backing and these initial empirical results seem to have the potential of being an accurate alternative to traditional methods of steady-state estimation. Stepping the predicted values forward using the estimate of a deterministic trend shows the evolution of the OECD economies, with the US as a likely TFP innovator being close to its steady state and while the other OECD economies grow partly due to the adoption of the innovation. This may be consistent with the US as a source of TFP evolution, that is, until the 2007–2009 recession.

In much of the research on growth, the United States is treated as the main innovator of anything affecting TFP. In fact, a common convention is to have countries' TFP expressed as a fraction of that of the US (Hall and Jones, 1999; Feenstra et al., 2013). We find some support of this practice as the US stays close to its steady state and others move around it, but for the OECD economies, most are below their steady states until 2005. The movements prior to 2005 are in line with the presence of a recession with a strong and quick recovery by 1985, along with the steady growth of the 1990–2000 period. After 2005, there is support for a bearish outlook toward future long-run growth. It's possible this most recent period may mimic that of 1985–1995 but with even slower growth and over a longer time period. The recessions of 1982 and 2001 were not nearly as severe as the 2 largest ones in the sample and were part of a fairly stable period of lackluster growth for the OECD economies. Of course, the period after 1995 was quite different and this is also reflected in the economies remaining below their steady states through the year 2000.

The results support our main hypotheses. The role of economic institutions is strong and positive in relation to growth. Convergence in cross-country incomes is a robust result. There is also a clear pattern of evolution of incomes over time, relative to their steady states. These are somewhat qualitative results in that the interpretations involve predictions of either slower than average or faster than average growth in per capita real GDP. However, with a longer sample of economies, there may be enough time observations so that current positions above and below the steady state can be compared to similar positions in the past. That is, we can use the empirical results to potentially estimate a country's speed of convergence. In this way, the results could be more precise by forecasting similar output falls and a similar length of slow-growth periods in the future. This analysis is an extension as methods would need to be developed to determine the statistical significance of these types of economic growth forecasts. The advantage of doing so would be that we would be able to have a richer theoretical background to long-run growth forecasts, including the ability to incorporate institutional variables. This method shows that importance with the significance of economic institutions in explaining the long-run growth positions of the OECD economies.

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